UNIVERSITY OF NOTTINGHAM

Department of Archaeology

‘Diet and Subsistence in the Anglo-Saxon Trent Valley: A Stable Isotope Investigation of Broughton Lodge Anglo-Saxon Cemetery, Nottinghamshire’

Fiona Moore

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I certify that:

a) The following dissertation is all my own original work
b) The source of all non-original material is clearly indicated
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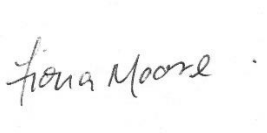

Abstract

Stable isotope analysis was carried out on a small sample population from Broughton Lodge Anglo-Saxon cemetery, Nottinghamshire. The cemetery dates to the late 5th to the early 7th centuries AD, and is located in the Trent valley, which was the centre of the Anglo-Saxon kingdom of Mercia. The broad aim was to investigate diet, subsistence, and breastfeeding and weaning practices.

Rib bone and permanent second molar and premolar dentine collagen was sampled from six individuals from the cemetery population, to investigate the adult and childhood diets of the Broughton Lodge population. Incremental dentine analysis was carried out on the permanent first molars of two of the individuals, to investigate breastfeeding and weaning practices amongst the population.

The results have shown that the diet of the Broughton Lode population was very similar to that at other Anglo-Saxon sites in England, comprised primarily of terrestrial animal protein with some amounts of freshwater fish. There was no significant difference in basic protein sources noted between adult and childhood diet.

The results of the incremental analyses were inconclusive. A definite breastfeeding and weaning signal could not be inferred for either individual, although several observations were made.

The research has highlighted the need for further stable isotope studies in the Trent valley focussing on the Anglo-Saxon period.

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1. Introduction

Stable isotope analysis is a well-established facet of archaeological investigation, and has been in use for almost four decades to inform discussion on the social dynamics of past societies. Prior to the adoption of biochemical techniques, methods of dietary analysis comprised examination of documentary sources, site organisation, artefact assemblages, faunal and plant remains and non-destructive analysis of skeletal remains, all of which restricted interpretation to the level of whole populations (Lightfoot 2009, 304; Schoeninger and Moore 1992, 248-259). Stable isotope analysis allows the archaeologist to investigate past diets at the level of the individual, significantly reducing the need for assumptions and generalisations which can negatively impact upon interpretations.

The end of the Roman rule in 5th century Britain brought about a period of social, political, and economic upheaval accompanied by an influx of Germanic settlers, known as the *adventus Saxonum* (Brettell *et al*. 2012, 118). A wealth of documentary sources exists from this period, but none are particularly informative on the day-to-day activities of the population, focussing largely on the privileged and elite social classes; in any case most are fragmentary and do not necessarily present an accurate impression of Anglo-Saxon life in Britain (Privat and O'Connell 2012, 779). Similarly, archaeological evidence doesn't serve to clarify our understanding of this period, so recent investigation has looked to biomolecular studies of diet for clarification.

The study of diet in archaeological populations can yield a wealth of information on economic and political structure, social roles and human health, and can provide valuable insight into the daily life of a population. The study of Anglo-Saxon diet in particular, provides an attractive opportunity to compare the version of Anglo-Saxon society presented by the early medieval texts, and the information contained within the human body.

The documentary sources tell of 'vigorous agriculture' including livestock and crops, and 'brilliant rivers' from which wild resources could be exploited (Winterbottom 1978, 17). Cattle, pigs, sheep, goats and fowl are mentioned frequently, as are various cereals, legumes, nuts and vegetables, wild boar and deer (Hagen 1992; O'Connell and Hull 2012, 668). The textual evidence presents a picture of a varied diet available to Anglo-Saxon communities. Different foods were assigned different status; pork and dairy products for example may have been reserved for the wealthier members of society, requiring considerable labour for production (O'Connell and Hull 2012, 668; Privat and O'Connell 2002, 785).

The Trent valley remains relatively understudied in terms of Anglo-Saxon archaeology, which is perhaps surprising given its significance throughout the period. At the heart of the kingdom of Mercia, the Trent valley was home to the "most successful of the various early Anglo-Saxon peoples…" (Brooks 1989, 159 – 162). Skeletal assemblages from the Trent valley and the East Midlands appear to have been the subject of only one previous stable isotope dietary investigation, and even then, the region was represented by a small number of samples in a wider assemblage from across the UK (MacPherson 2005). The Broughton Lodge cemetery thus presents an ideal opportunity to carry out the first dedicated isotope study of dietary and subsistence patterns in the former kingdom of Mercia. Four research aims have been identified, to direct the study towards meaningful interpretations, as follows:

1. Undertake a preliminary investigation of the dietary sources exploited by a small sample of the Broughton Lodge Anglo-Saxon cemetery population, taken as representative of the wider Anglo-Saxon Trent valley. Compare the isotope profiles of the Broughton Lodge population with published stable isotope investigations of Anglo-Saxon diet from across England;

2. Investigate any disparity in diet between adults and children within the cemetery population;

3. Investigate any disparity in diet arising from social and biological factors such as age, sex and gender, and status and wealth;

4. Investigate the breastfeeding and weaning patterns of a representative sample from the cemetery population using recently developed, high-precision sampling techniques, and compare with adult and juvenile health. Where possible, identify the weaning age of the representative sample, and assess its conformity with the postulated weaning age for Anglo-Saxon populations of 2-3 years old (Crawford 1999, 73).

A detailed discussion of the theoretical and scientific models underpinning the study of diet through stable isotope analysis is presented in Chapter 2. Chapter 3 explains the methodology adopted throughout the research project, which is followed by a presentation of the results obtained from the analyses in Chapter 4. Chapter 5 comprises a detailed interpretation of the results, placing them within a wider geographical framework, which is followed by a brief conclusion, and recommendations for further research.

2. Background

Introduction

The following chapter will introduce the scientific principles and methods underlying the stable isotope analysis of human dietary patterns. The investigation of human diet through isotope analysis is based on the premise "you are what you eat", i.e. that there is a direct relationship between our diet and the isotope concentrations found in the human body (Pearson *et al*. 2015, 218). As chemical elements are taken up by the body via food and drinking water, their relative abundances measured in human body tissues will reflect those of the diet of that individual. In simple terms, the body tissues of an individual constitute a temporally defined archive of the foods consumed by that individual.

A general definition of isotopes will be presented, followed by a summary of the chemistry of carbon and nitrogen stable isotopes, and their usefulness in investigations of human diet as established by previous research. The methods employed to carry out the investigations will be summarized, along with the materials analysed; finally, a brief summary of previous isotopic investigations of Anglo-Saxon human diet will be presented.

Scientific Theory

Isotopes are different chemical forms of any one element. Isotopes of a single element are atoms which are identical to one another in their number of protons and electrons, but differ in the number of neutrons present within the nucleus (Hoefs 2015, 1; Schoeninger and Moore 1992, 253). This gives rise to differences in mass, and therefore mass number, between isotopes of an element, i.e. the combined number of protons and neutrons within the nucleus of an atom (Schoeninger and Moore 1992, 253).

Most elements exist as composites of two or more isotopes of that element. Only 21 elements are defined as 'pure' elements, i.e. those which contain only one isotope

(Hoefs 2015, 1). The most common isotope of any element is known as the 'parent', 'standard' or 'common' form (Hoefs 2015, 1). Carbon for example, has three naturally occurring isotopes: the standard form, with a mass number of 12, and two isotopes of increased mass, or heavier forms (Faure 1986, 491). The isotopic mass is represented by a superscript number to the left of the element symbol; carbon's three isotopes, for example, are presented as ^{12}C, ^{13}C and ^{14}C indicating that they have 12, 13 and 14 neutrons respectively in their nuclei (Hoefs 2015, 1; Tsutaya and Yoneda 2015, 3).

There are two broad categories of isotope, stable and radiogenic. Stable isotopes are those which are not radioactive, and therefore do not break down independently, whilst radiogenic isotopes will degrade steadily over time (Hoefs 2015, 1). The relative amount of a stable isotope present in an animal tissue will therefore remain constant over time, provided no post-mortem degradation of the tissue itself has taken place (DeNiro and Epstein 1978a, 907). There are around 300 stable isotopes known across all elements, and over 1200 radiogenic forms (Hoefs 2015, 1). There are ten elements of interest for biological studies that have more than one stable isotope, and of these ten, two are of particular interest for this dietary study, carbon and nitrogen (Schoeninger and Moore 1992, 253). As this thesis is concerned with carbon and nitrogen stable isotope analysis, radiogenic isotopes will not be considered further.

The similarity in the atomic number (the number of protons in the nucleus of an atom) across isotopes of an element means that the chemical properties and behaviour of those isotopes will remain broadly similar (Hoefs 1980, 4; Schoeninger and Moore 1992, 253). The difference in mass between isotopes of an element gives rise to subtle differences in physical properties, which causes differences in the reaction rates of each isotope. These differences are known as 'isotope effects' (Hoefs 2015, 4). For example, an additional neutron in the nucleus of an atom will slow the rate of movement, and therefore the rate of reaction, of that atom when compared to its standard, lighter form, giving rise to altered rates of diffusion, chemical reaction and state transition (Hoefs 2015, 6-15; Schoeninger and Moore 1992, 253). The altered reaction rates result in discrimination against one of the

isotopes, usually the heavier, slower isotope, with the lighter isotope being preferentially incorporated into the reaction product during chemical reaction. The process is known as fractionation (Park and Epstein 1960, 110). This differential fractionation forms the basis for stable isotope dietary studies, as fractionation effects are transferred from food source to consumer, and are measurable (Lee-Thorp *et al*. 1989, 585). When a plant undergoes photosynthesis for example, discrimination against the heavier of carbon's two stable isotopes, ^{13}C occurs, resulting in the preferential incorporation of the lighter isotope, ^{12}C into the reaction product. The product, i.e. the plant, will therefore contain a higher concentration of ^{12}C than the source (Bender 1968, 468; Vogel and van der Merwe 1977, 239). The degree of fractionation can be measured using a mass spectrometer, which will provide a ratio of the heavier to the lighter isotope (e.g. $^{13}C/^{12}C$) in the sample being analysed (Craig 1953, 53).

Absolute isotope ratios are difficult to obtain, so the ratios recorded in the sample material are presented relative to established and calibrated standard materials (O'Leary 1981, 553; Schoeninger and Moore 1992, 254). In the case of carbon and nitrogen, the sample to be tested is combusted to convert the compounds to carbon dioxide (CO_2) and nitrogen (N_2) gases respectively (Peterson and Fry 1987, 294). The pure gas is then fed into an isotope ratio mass spectrometer, and its isotopic composition measured relative to the standard (Peterson and Fry 1987, 294; Schoeninger and Moore 1992, 253). The isotope ratio is presented as a δ value of the heavier isotope, (e.g. $\delta^{13}C$) obtained using the following equation:

$$\delta_{element}(‰) = [R_{sample} / R_{standard} - 1] \times 1000$$

where 'R' is the ratio of the heavier to the lighter isotope (Hoefs 2015, 8; O'Leary 1981, 553).

The standard in use for $^{13}C/^{12}C$ ratio measurements is Vienna Pee Dee Belemnite (VPDB). The original standard material in use until relatively recently, was Pee Dee Belemnite, or Chicago Limestone, a marine bicarbonate (HCO_3^-) from the Pee Dee formation in South Carolina (O'Leary 1981, 553; Schoeninger and Moore 1992, 254).

The original PDB standard no longer exists, but exact $\delta^{13}C$ values have been assigned to VPDB relative to PDB (Werner and Brand 2001, 502).

Marine bicarbonates exhibit $\delta^{13}C$ values close to 0‰, and are therefore suitable for use as reference point. Atmospheric carbon is depleted in ^{13}C relative to marine bicarbonate, and therefore PDB, by around 7‰, hence the $\delta^{13}C$ value for atmospheric carbon is -7‰ (Burleigh and Brothwell 1978, 356; Chisholm *et al*. 1982, 1131; Vogel and van der Merwe 1977, 239). Plants are depleted further in ^{13}C by photosynthesis, and this depletion is carried along the food chain (Bender 1968, 468; Vogel and van der Merwe 1977, 239; Lee-Thorp *et al* 1989, 585). $\delta^{13}C$ values for plants and their consumers will therefore be negative (O'Leary 1981, 553).

Atmospheric nitrogen, or AIR (Ambient Inhale Reservoir) is the standard used to measure $\delta^{15}N$ values (Mariotti 1983, 687; Schoeninger and Moore 1992, 254). Atmospheric nitrogen is considered an appropriate standard as it exhibits universal homogeneity, and has very low concentrations of the heavier isotope, ^{15}N, giving $\delta^{15}N$ values close to 0‰ (Mariotti 1983, 685). Most organic materials have higher $^{15}N/^{14}N$ ratios than the atmosphere, meaning their $\delta^{15}N$ values will be positive (Pang and Nriadu 1977, 814; Schoeninger and Moore 1992, 254).

Carbon

Carbon is the most abundant and important element on earth. The majority of the world's carbon is non-biological and is contained in the oceans, at the natural abundance ratio of 98.93% ^{12}C to 0.07% ^{13}C (Hoefs 2015, 64). Oceanic carbon enters the atmosphere via the Carbon Cycle (Figure 2.1), and becomes the major source of carbon for all terrestrial vegetation. As carbon dioxide, it is transferred to terrestrial plants via photosynthesis, and to animals via consumption of plants (Park and Epstein 1960, 110). Carbon enters the biological marine system through photosynthesis of dissolved bicarbonate and carbon dioxide by phytoplankton, and is then passed along the marine and terrestrial food chains (Fontugne and Duplessy 1981, 85). Both processes discriminate, or fractionate, against ^{13}C, resulting in lower $^{13}C/^{12}C$ ratios in living organisms than are present in the ocean (Schoeninger and Moore 1992, 255).

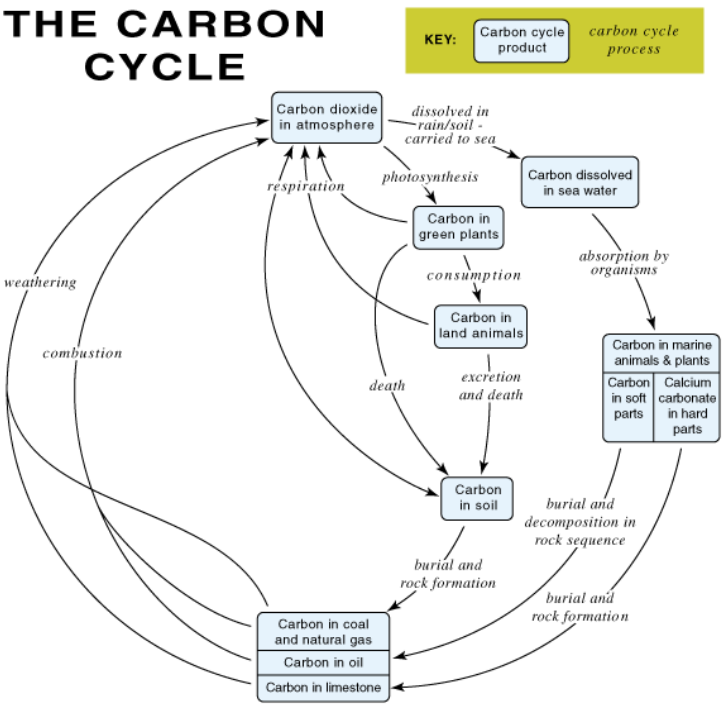

Figure 2.1: The carbon ycle (http://www.rsc.org/Education/Teachers/Resources/jesei/oceans/home.htm)

Following Nier and Gulbransen's 1939 observations that phytoplankton and terrestrial plants are depleted in ^{13}C relative to atmospheric carbon, research has confirmed that $\delta^{13}C$ values in both are a function of photosynthesis (e.g., Craig 1953; Park and Epstein 1960, Deuser *et al*. 1968). The degree of ^{12}C enrichment depends on the photosynthesis pathway that a plant follows, which is determined phytogenically (Burleigh and Brothwell 1978, 355; Vogel 1980, 5-6). There are two main photosynthetic pathways for terrestrial plants, the Calvin cycle, or C3 pathway, and the Hatch-Slack, or C4 pathway (Calvin and Bassham 1962; Hatch-Slack 1966). The C3 pathway synthesizes a 3-carbon molecule (phosphoglyceric acid) during its first stage, whilst the C4 pathway synthesizes a 4-carbon molecule (oxaloacetate) during its first stage (Burleigh and Brothwell 1978, 355; Vogel and Van der Merwe 1977, 238). The C3 pathway is the least efficient, and occurs in temperate regions, whilst the C4 pathway is seen in plants adapted to hot, arid regions with high levels of light (Burleigh and Brothwell 1978, 355; Land *et al*. 1908, 145).

Terrestrial plants are thus grouped according to the pathway they follow. C3 plants make up the majority of terrestrial plant life, and are native to temperate regions,

consisting of trees, shrubs and most temperate grasses such as wheat and barley (Vogel and Van der Merwe 1977, 238-240). C4 plants grow in tropical regions and include grasses such as maize, millet and sugar cane (Lee-Thorpe *et al*. 1989, 585; Tauber 1981, 332). The C4 pathway discriminates against ^{13}C to a lesser degree compared to the C3 pathway, meaning C3 plants will be more enriched in the lighter ^{12}C isotope than C4 plants. C4 plants will therefore have higher $^{13}C/^{12}C$ ratios than C3 plants, and more positive $\delta^{13}C$ values (Vogel and Van der Merwe 1977, 238). As a result, each of the two plant groups displays a distinct range of $\delta^{13}C$ values, which do not overlap (Burleigh and Brothwell 1978, 355).

The C3 pathway depletes ^{13}C by an average of 19‰. Considering the atmospheric carbon $\delta^{13}C$ value of -7‰, this gives C3 plants $\delta^{13}C$ values of around -26‰ on average relative to PDB, although they generally fall with a range of -20 to -34‰ (Bender 1971, 1239; Bender *et* al. 1981, 346; Schoeninger and Moore 1992, 255; Smith and Epstein 1971, 380; Vogel and van der Merwe 1977, 239).

C4 pathways deplete ^{13}C by an average of around 6‰, which gives mean $\delta^{13}C$ values for C4 plants of around -13‰ relative to PDB (Bender 1971, 1239; Bender *et al.* 1981, 346; Land *et al*. 1980, 145; Tauber 1981, 332; Vogel and van der Merwe 1977, 239; Burleigh and Brothwell 1978, 256). Again though, C4 $\delta^{13}C$ values fall within a range, currently reported as -9 to -16‰ (Schoeninger and Moore 1992, 356). The respective ranges for C3 and C4 $\delta^{13}C$ values are displayed graphically in Figure 2.2.

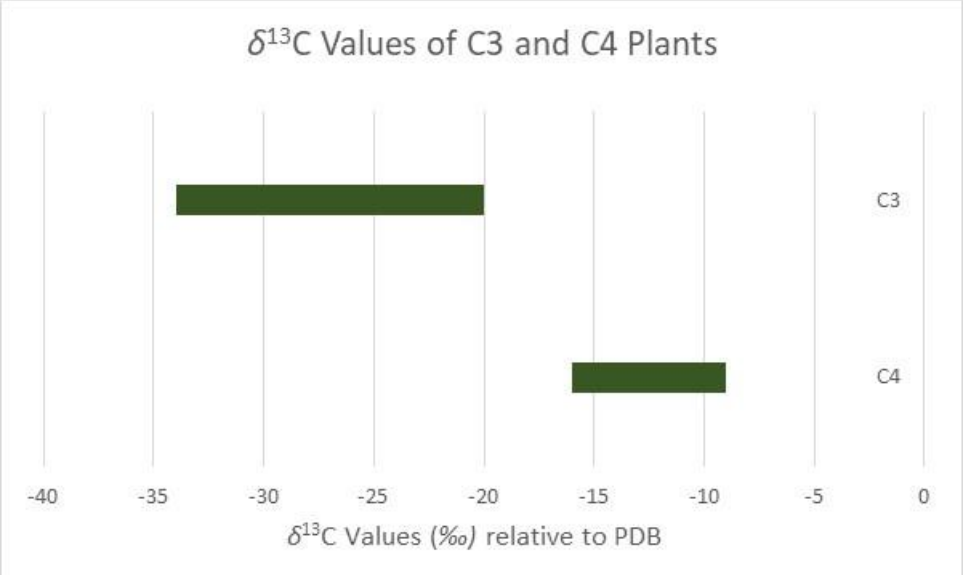

Figure 2.2: Relative ranges of $\delta^{13}C$ values recorded for C3 and C4 plants

As there is no overlap between the C3 and C4 two ranges, $\delta^{13}C$ values have become invaluable in differentiating C3 and C4 plant groups in human and animal food chains (DeNiro and Epstein 1978a, 506; Smith and Epstein 1971, 380; Vogel and van der Merwe 1977, 238). Notably, some of the earliest work on $\delta^{13}C$ values in bone collagen has dealt with tracing the introduction and relative importance of maize (a C4 plant) to prehistoric diets in North and South America (e.g. Bender *et al*. 1981; Boutton *et al*. 1984; Burleigh and Brothwell 1978; Lynott *et al.* 1986; Vogel and Van der Merwe 1977; Van der Merwe and Vogel 1978, 815). Results indicated that the introduction of maize took place earlier in some areas earlier than realised, and that maize was introduced to southern regions ahead of northern (Schoeninger and Moore 1992, 267).

A third photosynthetic pathway, the Crassulucean Acid Metabolism (CAM), is utilised by succulents adapted to xerophytic environments, and mimics either the C3 or C4 pathway (O'Leary 1981, 554; Vogel and Van der Merwe 1977, 239)**.** CAM pathways produce values that are dependent on light versus dark CO_2 fixation, and are generally intermediate between those of C3 and C4 plants (Farquhar *et al*. 1982, 121; O'Leary 1981, 554). The CAM pathway is not relevant to this particular study, and will not be considered further.

$\delta^{13}C$ values are also effective in identifying the consumption of marine foods, but only in areas where C3 plants are the predominant terrestrial plant food source, such as north-west Europe (O'Connell and Hull 2011, 671). As noted above, the absorption of CO_2 and marine bicarbonate leads to $\delta^{13}C$ values of close to 0‰ (Tauber 1981, 332). During photosynthesis of marine plants, ^{13}C is depleted by around 10 to 18‰, which gives rise to $\delta^{13}C$ values of -10 to 18‰, similar to those of C4 plants ($\delta^{13}C$ -9 to -16‰) (Figure 2.3) (Chisholm *et al*. 1982, 1131-1132; Schoeninger and DeNiro 1984, 635; Tauber 1981, 332; Vogel and van der Merwe 1977, 241).

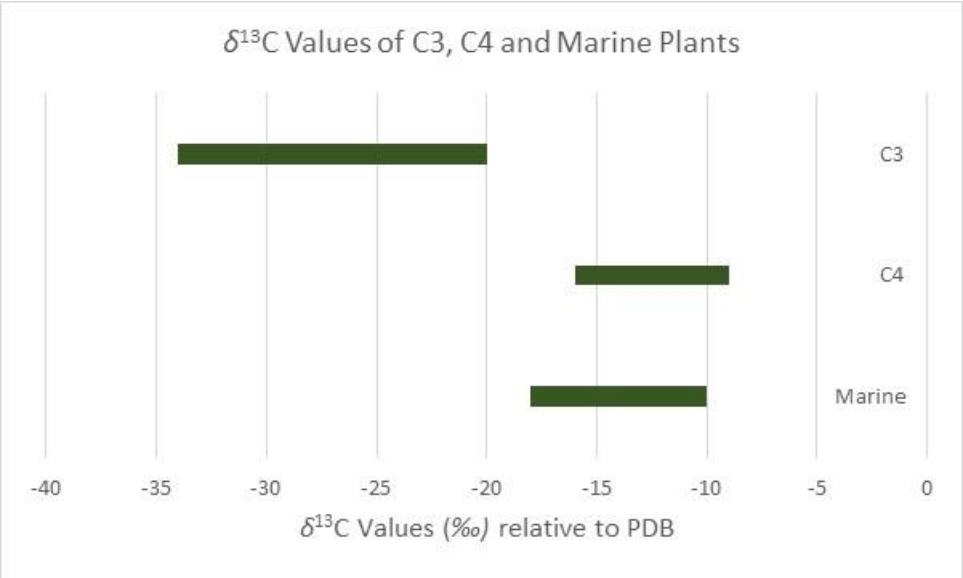

Figure 2.3: Relative ranges of $\delta^{13}C$ values recorded for C3, C4 and Marine plants

The overlap between marine and C4 $\delta^{13}C$ values confuses the identification of marine food sources in C4 areas; however, as there is no overlap between C3 plants and marine sources, $\delta^{13}C$ values are a useful tracer of marine food consumption in temperate areas, if it is known that the terrestrial plant diet consisted only of C3 plants (Chisholm *et al*. 1982, 1132; Hobson and Collier 1984, 238; Schoeninger *et* al. 1983, 1382; Schoeninger and DeNiro 1984, 625; Tauber 1981, 332). Combined analysis of carbon, nitrogen and where available, sulphur isotopes can however remove the confusion between C4 plant and marine values, and enable a tentative determination of the relative proportions of C3 and marine foods in human diets (e.g. Hedges and Reynard 2007; MacPherson 2005, 41; Mays and Beavan 2012;

Schoeninger *et* al. 1983, 1382). Analysis of $\delta^{13}C$ values in human bone collagen has been successfully applied to various coastal communities in North America and Europe, and remains an effective means of identifying marine food consumption in temperate regions (e.g. Chisholm *et al*. 1982; Chisholm *et* al. 1983a; Schoeninger *et al*. 1983, Tauber 1981).

The identification of freshwater food sources presents more of a challenge. Due to the considerable variation in carbon sources of fresh waters, $\delta^{13}C$ values of freshwater organisms vary significantly, reflecting, the relative contributions of all available carbon sources (Peterson and Fry 1987, 301; Rau 1978, 901; Schoeninger and Moore 1992, 256). As such it is not yet possible to confidently identify freshwater food source consumers amongst human samples using $\delta^{13}C$ values alone.

Nitrogen

Most of the earth's nitrogen (over 99%) exists as N_2 in the atmosphere and dissolved in oceans (Hoefs 2015, 70). Nitrogen consists of two stable isotopes, ^{15}N and ^{14}N; the former comprises 99.63% of atmospheric nitrogen, and the latter 0.37% (Hoefs 2015, 70). Atmospheric N_2 is the most abundant form of nitrogen, and can be 'fixed' by blue-green algae and some terrestrial plants, for example, legumes (Hoefs 2015, 71). Fixation of nitrogen from the atmosphere usually produces organic materials with ^{15}N abundances very similar to atmospheric nitrogen, i.e. 0‰ (Hoefs 2015, 71 & 72; Virginia and Delwiche 1982, 317). Plants which are unable to fix atmospheric nitrogen synthesize nitrates, which have higher levels of ^{15}N than atmospheric nitrogen, which results in higher (more positive) $\delta^{15}N$ values (Schoeninger and Moore 1992, 255; Virginia and Delwiche 1982, 317). In theory, $\delta^{15}N$ values could be used to distinguish consumption of N_2-fixing plants from non-N_2fixing plants; however, this has not yet been investigated empirically (Schoeninger and Moore 1992, 260). Terrestrial plants exhibit a broad range of $\delta^{15}N$ values, although the majority are close to 0‰ (Schoeninger and Moore 1992, 255).

Until the early 1980s, all animal and human dietary isotope analyses had been based on $\delta^{13}C$ values. In 1981 DeNiro and Epstein were the first to test the usefulness of

$\delta^{15}N$ in dietary analysis, with work on animals grown and fed in a laboratory environment (DeNiro and Epstein 1981). They concluded that animals preferentially incorporate dietary ^{15}N over ^{14}N, which is excreted, meaning that in most cases an animal's ^{15}N concentration is enriched relative to its diet (DeNiro and Epstein 1981, 341-344). This effect can be observed in the whole animal, or in individual tissues (DeNiro and Epstein 1981, 343-344). This assimilation of ^{15}N occurs at each level of a food chain, meaning that an organism's $\delta^{15}N$ values will increase steadily from primary producer to apex consumer. This is known as the 'trophic level effect', and will be discussed further below (Ambrose and DeNiro 1986, 321). The systematic enrichment of ^{15}N forms the basis of dietary studies using $\delta^{15}N$ values, enabling researchers to trace relative concentrations of ^{15}N from food source to consumer, identify the consumption of marine foods, and under certain conditions identify the trophic level at which a consumer feeds (Minagawa and Wada 1984, 1140).

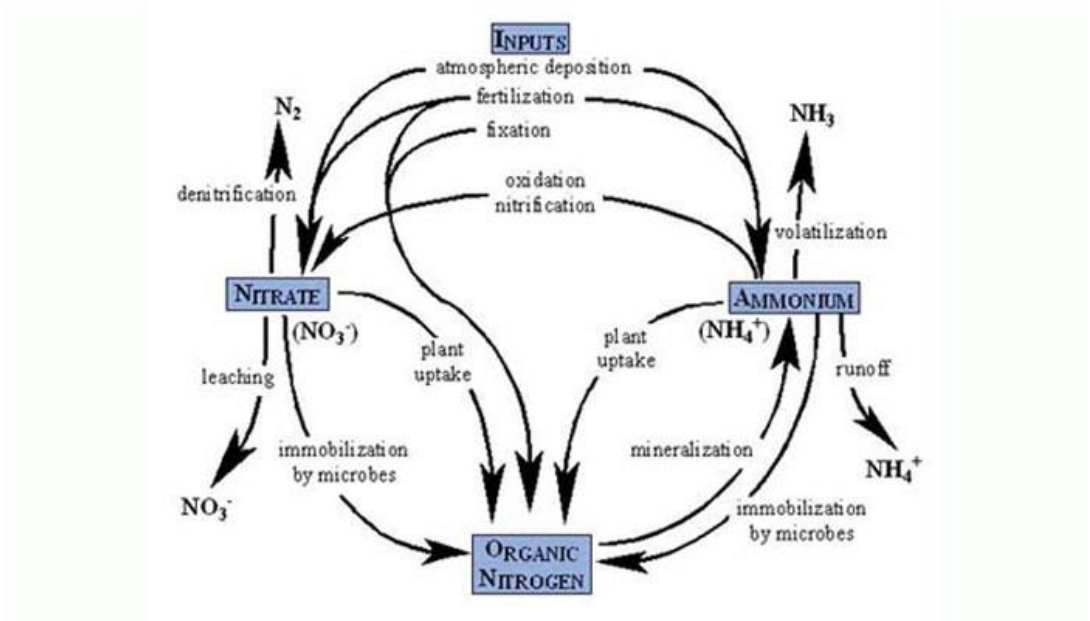

Figure 2.4: A simplified version of the Terrestrial Nitrogen Cycle
(https://www.learner.org/courses/envsci/visual/visual.php?shortname=nitrogen_cycle)

In general, organisms at the base of marine food chains exhibit more positive $\delta^{15}N$ values than terrestrial plants, due to the biochemical processes taking place within the marine Nitrogen Cycle, the varying degrees of nitrogen isotope fractionation inherent in each, the source of inorganic nitrogen used for synthesis, and the complexity of marine food webs when compared to terrestrial (Miyake and Wada

1967, 42-44; Wada and Hattori 1976, 249; Wada 1980, 376). It follows therefore that animals and humans feeding on marine food sources should have elevated δ^{15}N values when compared to those feeding exclusively on terrestrial sources (Schoeninger *et al.* 1983, 1381). In 1984, Schoeninger and DeNiro analysed a sample of over 100 species of birds, fish and mammals from multiple food webs and concluded that bone collagen δ^{15}N values of animals that fed exclusively in the marine environment are on average 9‰ more positive than those of animals that fed exclusively in the terrestrial environment (Schoeninger and DeNiro 1984, 625). It is not yet possible to identify the human consumption of freshwater resources in archaeological populations using δ^{15}N values alone (Hedges and Reynard 2007, 1242). Elevated δ^{15}N values can also be an indicator of nutritional and psychological stress resulting from famine or anorexia (Beaumont *et al*., 2013, 91).

Trophic level effects

Trophic level effects, i.e. the unidirectional enrichment of heavier isotopes along food chains, has been proposed for ^{13}C, and established for ^{15}N. Early work on oceanic species seemed to suggest a small increase in δ^{13}C values with increasing trophic level of around 1‰, but no consistent trend has been empirically proven for coastal or terrestrial species (DeNiro and Epstein 1978b, 495; Rau *et al*. 1983, 1317; Schoeninger and DeNiro 1984, 625; Schoeninger 1985, 516). This has led Schoeninger to conclude that the effect is only observable within single, controlled food webs, as the effect will be masked by other factors, for example C3 or C4 fractionation effects (Schoeninger 1985, 516-525). Analysed in isolation, δ^{13}C values will yield little information on a consumer's trophic level; used in conjunction with δ^{15}N values however, a reliable assessment of trophic level can be made, as discussed below.

The differential value between δ^{13}C in bone collagen and in the mineral portion of bone, apatite, appears to differ depending on the trophic level at which an animal feeds. In humans, bone collagen reflects the meat portion of the diet, whilst the plant portion dictates the isotopic composition of apatite (Krueger and Sullivan 1984, 217-220). This led Schoeninger and Moore to suggest that theoretically, a comparison between collagen and apatite δ^{13}C values may highlight a trophic level effect (Lee-

Thorpe *et* al. 1989, 593; Schoeninger and Moore 1992, 262). The spacing between apatite and collagen $\delta^{13}C$ values across trophic levels (around 8‰ for herbivores and 4‰ for herbivores) has proven somewhat useful for identifying trophic levels in areas where C4 plants form the major dietary component; more work is needed however to conclusively demonstrate this (Schoeninger and Moore 1992, 262).

Nitrogen's trophic level effect was first reported by Miyake and Wada in 1967, who noted that zooplankton were enriched in ^{15}N compared to phytoplankton, and fish displayed the highest ^{15}N concentrations in marine environments (Miyake and Wada 1967, 43 & 44). From this initial observation, they and others asserted the existence of a regular enrichment of ^{15}N in nitrogenous compounds along successive trophic levels of the marine food web, suggestive of nitrogen transfer through the food chain, in the following order:

Inorganic nitrogen ➡ phytoplankton ➡ algae ➡ zooplankton ➡ fish

(Miyake and Wada 1967, 45; Wada and Hattori 1975, 251; Wada *et al.* 1975, 139; Wada 1980, 376).

Such an effect has been suggested for freshwater food webs as well (Pang and Nriadu 1977, 811). Later work on marine organisms, and terrestrial carnivores and herbivores has confirmed the assertion that $\delta^{15}N$ values become more positive with higher trophic levels, and it has been shown that $\delta^{15}N$ values of humans and animals that feed at successive trophic levels in marine and terrestrial environments are separated from their food source by an enrichment factor of around 2-5‰; the exact enrichment value for humans remains uncertain (DeNiro and Epstein 1981, 343-344; Fogel *et al*. 1989, 111; Hedges and Reynard 2007, 1241; Macko *et al.* 1982, 145; Schoeninger *et al*. 1983, 1382; Vogel *et al*. 1990, 150). It has been suggested that the effect is only apparent within single trophic systems, as the primary nitrogen sources, and therefore the magnitude of fractionation effects, differ within each system (e.g. marine versus terrestrial) (Minagawa and Wada 1984, 1137; Schoeninger and Moore 1992, 258). In recent years attempts have been made to investigate the proportion of animal products consumed by human populations, by comparison of human $\delta^{15}N$ values with the local fauna (Hedges and Reynard 2007, 1244). Data from sites in

England has suggested that between 60 and 80% of prehistoric nutrition was comprised of animal protein, perhaps indicating high levels of pastoral subsistence (Hedges and Reynard 2007, 1244-1249).

The trophic level effect has aided the investigation of weaning patterns and nutritional stress in human populations, using bone and dentine collagen as sample materials. A breastfeeding child is essentially a consumer of its mother's body tissue, and should display δ^{15}N values consistent with a higher trophic level when compared with adults from the same population (Fuller *et al* 2006, 280; Hemer *et al*. 2016, 9; Beaumont *et al*. 2015, 442). There have been numerous archaeological investigations into weaning patterns since the 1990s, across various time periods and geographies (e.g. Eerkens *et al*. 2011; Katzenberg *et al*. 1993; MacPherson 2005; Mays *et al*. 2002; Tsutaya and Yoneda 2015). These, in conjunction with research on modern hair and fingernail keratin and archaeological bone collagen samples have established that there is a 2 – 4‰ increase in δ^{15}N values in breastfeeding infants in comparison with mothers (Beaumont *et al*. 2015, 442; Fogel 1989, 116; Fuller *et al*. 2006, 279). A 1‰ increase in δ^{13}C values has also been observed and Fuller *et al*. have suggested that δ^{13}C values could be useful in identifying the introduction of solid foods to a child's diet (Fuller *et al*. 2006, 279). Once weaning has commenced, the disparity in values between child and adult should steadily reduce until the child's values are consistent with the mother's, indicating the end of the weaning period (Fogel *et al*. 1989, 113-114).

Materials

All carbon and nitrogen-containing tissue in an organism's body will reflect their dietary intake via isotope ratios, but not all are suitable for archaeological investigations. Soft tissues rarely survive, meaning most dietary studies using isotope analysis have been carried out on calcified tissues, such as bones and teeth (Lee-Thorpe *et al.* 1989, 589).

The isotopic values of different tissues vary depending on their composition, their turnover rates, secondary fractionation effects and synthesis from various dietary

constituents (Lee-Thorpe *et al*. 1989, 586). The information gleaned from isotope ratio values will therefore depend on the choice of tissue analysed. DeNiro and Epstein concluded from controlled experiments on various vertebrates that to obtain accurate results from carbon and nitrogen isotope analysis, multiple tissues should be analysed (DeNiro and Epstein 1978b, 504; DeNiro and Epstein 1981; 344). Subsequent investigations concluded that provided the fractionation and turnover rates of the tissues used are known, meaningful conclusions can still be drawn from a limited number of tissue types (Tieszen *et al* 1983, 26).

Bone collagen

Animal and human body tissues exist in a state of dynamic equilibrium, with new components synthesized and older components degraded continuously (Tieszen *et al*. 1983, 32). It has been shown that metabolically active tissues, such as liver and fat tissues, will have faster turnover rates than less metabolically active tissues (Tieszen *et al*. 1983, 32-34). Collagenous tissues have been shown to turn over much more slowly than their non-collagenous counterparts, and collagen is relatively straightforward to extract and prepare for analysis (Lee-Thorpe *et al.* 1989, 586; Libby *et al*. 1964, 1171; Thompson and Ballou 1956, 795-807). As a result, collagenous proteins have received significantly more attention in isotope studies than their non-collagenous counterparts (Schoeninger and Moore 1992, 261-262).

To obtain a long-term dietary profile and identify any changes in an individual's diet, ideally a combination of soft tissues and collagen should be analysed, or in the majority of archaeological cases, when bone is the only material available, a combination of collagen, cholesterol and apatite (Jim *et al*. 2004, 61; Tieszen 1983, 36). When only hard tissues are available, a useful comparison can be made from analysis of bone and tooth collagen. The earliest stable isotope dietary analyses of bone collagen were reported in 1977 by Van der Merwe and Vogel, who applied the technique on prehistoric skeletons from New York (Vogel and Van der Merwe 1977).

Bone is a living tissue that continuously remodels itself in response to external and internal factors (e.g. skeletal growth and repair), which results in the release of

previously incorporated elements such as carbon and nitrogen, and the reincorporation of old and incorporation of new isotope concentrations. The rate at which bone remodels varies depending on the type of bone, the age of the individual, environmental factors and health status (Beaumont *et al*. 2014, 213; Tieszen *et al*. 1983, 36). Cortical bone such as the femur for example, is dense and has a relatively slow turnover rate, of around 10 years, and varies with an individual's age (Hedges *et al*. 2007, 810-815). Trabecular bone, such as the ribs, has a higher turnover rate due to its increased surface-to-volume ratio, and is thought to regenerate every 2 – 5 years, although the precise turnover rate is not yet known (Lamb *et al*. 2014, 560). A rib will therefore provide an averaged dietary profile of approximately the last 2-5 years of a person's life.

In archaeological isotope studies, the importance of bone collagen comes with its relative abundance in archaeological materials, compared to other collagenous body materials, such as hair and nails (Ambrose 1990, 431). Bone collagen is also known to preserve its isotopic composition (Chisholm *et* al. 1982, 1131; Chisholm *et al*. 1983a, 355; DeNiro and Epstein 1978a, 907). Furthermore, there appear to be no appreciable variations in $\delta^{15}N$ and $\delta^{13}C$ values from collagen extracted from different bones of an individual (less than 1‰), and any differences in $\delta^{15}N$ and $\delta^{13}C$ values from a single bone and from multiple bones from an individual, will be within around 1‰ (DeNiro and Schoeninger 1983, 202). This ensures the validity of any results obtained from small assemblages or even one bone per individual, often a necessity when dealing with archaeological humans (DeNiro and Schoeninger 183, 202). Several recent studies have utilised the isotope offsets between different bones from the same individual, and the varying turnover rates between types of bone to demonstrate dietary changes over individual lifetimes, for example Sealy *et al*. (1995), Pollard *et al*. (2012), and Lamb *et al*. (2014).

The use of bone as a sample material is not without its issues. Fractionation occurs in the formation of bone collagen, which can result in enrichment of ^{13}C to a factor of around 5 - 6‰, additional to that observed during incorporation of dietary protein (Hare *et* al. 1991, 290; Vogel and van der Merwe 1977, 240; Van der Merwe and Vogel 1978, 815). Bone and the collagen within is subject to diagenesis, i.e. physical,

chemical and biological processes affecting bone post-mortem (DeNiro 1985, 808; Hare *et al.* 1991, 278). Provided these effects are accounted for, the isotope profile of bone collagen samples can still inform dietary assessments. DeNiro's 1985 assessment of the effects of diagenesis on human bone concluded that not all bone is subject to diagenesis, and that it is possible to identify that which has been by examining the C/N ratio present in the material (DeNiro 1985). DeNiro tested a sample of prehistoric bone collagen from terrestrial herbivores and marine and terrestrial carnivores from archaeological sites in Peru, California and Florida, and concluded that material displaying a C/N ratio within the range of 2.9-3.6 is unlikely to have undergone significant diagenesis. Such samples can be expected to produce accurate $\delta^{13}C$ and $\delta^{15}N$ values reflective of an animal's *in vivo* $\delta^{13}C$ and $\delta^{15}N$ values, and therefore reflective of their diet (DeNiro 1985, 808). It is now standard practice to omit any samples which show C/N ratios outside of this range, as the $\delta^{13}C$ and $\delta^{15}N$ values of those samples may have been altered post-mortem. This is not to say that samples displaying ratios within this range will not have undergone diagenesis, only that they are less likely to have done so (DeNiro 1985, 808). Diagenesis of bone material does remain a concern in isotope in isotope analysis, which has led to the increased use of tooth dentine as a sample material.

Dentine Collagen

An averaged isotope profile obtained from bone can be useful in assessing diet from the last ten years or so of an individual's life, but if the objective is to target a particular stage of a life course, collagen extracted from human tooth dentine has become the sample material of choice. Each tooth forms within a known stage of an individual's life and the primary dentine within is not remodelled in that time, preserving the isotopic signal from the formation time of the tooth (Beaumont *et al*. 2013, 277). Deciduous teeth begin forming in a developing foetus within 14-19 weeks of fertilisation, and are complete within 2.5 years of birth. Permanent dentition begins to form at around 4.5 months of age with first molars (M1) and is complete from around 12 years of age, depending on whether third molars (M3), commonly known as wisdom teeth, are present (AlQuatani 2009; Budd *et al.* 2007, 198-199;

Montgomery 2002, 41-44). Each tooth therefore provides the opportunity to examine a temporally-defined, short-term archive of isotope composition, which allows investigation of childhood diet from adult skeletons and dietary changes experienced by an individual. M1 primary dentine for example, can provide an isotope signal from roughly the first 7.5 years of a child's life, allowing examinations of breast-feeding and weaning behaviour, as discussed below. A summary of the development of each permanent tooth is presented below in Table 1. Deciduous teeth are not considered here, as they have not been utilised for this study.

Permanent Tooth (notation in brackets)	Human age at development (months or years)	
	Beginning of Formation	Completion and full eruption
First molar (upper and lower; (M^1 and M_1 respectively)	4.5 months	7.5 years
First upper incisor (I^1)	4.5 months	7.5 years
First lower incisor (I_1)	7.5 months	7.5 years
Second lower incisor (I_2)	7.5 months	7.5 years
Upper canine (C^1)	7.5 months	12.5 years
Second upper incisor (I^2)	10.5 months	9.5 years
Lower canine (C^1)	10.5 months	10.5 years
First premolar (upper and lower) (P^1 and P_1 respectively)	2.5 years	11.5 years
Second lower premolar (P_2)	2.5 years	12.5 years
Second molar (upper and lower; M^2 and M_2 respectively)	2.5 years	13.5 years
Second upper premolar (P^2)	3.5 years	12.5 years
Third molar if present (upper and lower; M^3 and M_3 respectively)	8.5 years	Variable (if present, will remain partially complete and unerupted until at least 15.5 years)

Table 2.1: Developmental time periods of whole permanent teeth. A detailed pictorial representation of the formation of all teeth can be found in AlQuatani's *Atlas of Tooth Development and Eruption*, available at: https://atlas.dentistry.qmul.ac.uk/

The analysis of teeth can also negate issues of diagenesis presented by bone material. The dense structure of tooth enamel makes it impermeable, and therefore largely resistant to degradation, preserving the collagen within. It has been shown that the overall diagenetic effects on archaeological teeth and their isotopic signal are

minimal (Budd *et al.* 2007, 198-199; MacPherson 2005, 39; Schoeninger *et al.* 2003, 12).

Recent developments in sampling techniques and instrumentation have enabled even narrower, sub-annual timeframes to be examined using increments of primary dentine. Primary dentine is secreted and mineralised in a two-phase process, whereby an initial dentine matrix, predentine, is secreted and then mineralised at a constant, known rate (Beaumont *et al.* 2013, 297) (Figure 2.5).

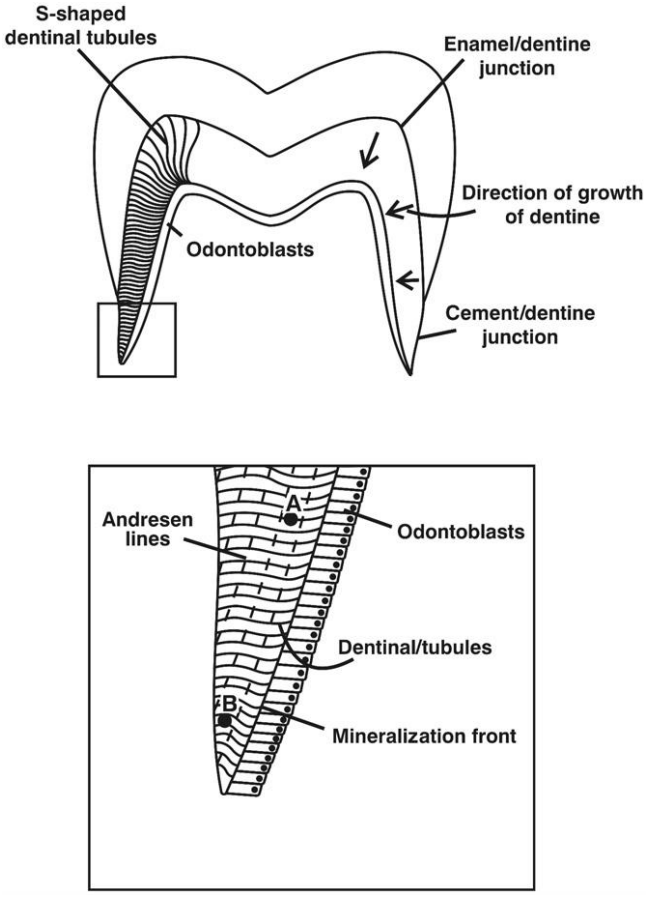

Figure 2.5: Section through a molar showing direction of dentine development (Beaumont *et al*. 2013, 279)

These high-resolution sampling procedures mean that very small yet sufficient amounts of collagen can be extracted from increments of dentine and related to the age at which that dentine was formed (e.g. Figure 2.6) (Beaumont *et al*. 2015, 213; Beaumont & Montgomery 2016, 2). This has facilitated the identification of

previously invisible, short-term dietary changes in individuals, enabling new and reinforcing previous investigations into weaning patterns, seasonal variations, migrations and periods of nutritional stress (e.g. Beaumont *et al*. 2013; Beaumont & Montgomery 2016).

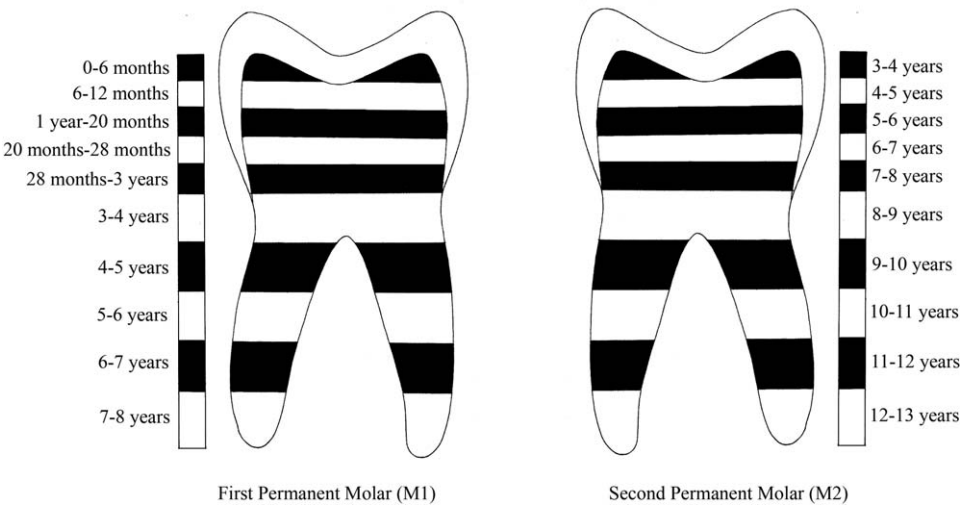

Figure 2.6: Diagram showing increments of dentine and their relative ages of formation (Henderson *et al* 2014, 588)

Previous Isotope Work on Anglo-Saxon Diet

A significant corpus of carbon and nitrogen isotope data now exists for Anglo-Saxon England (e.g. Hemer *et al*. 2016, Mays and Beavan 2012; Müldner and Richards 2007, Privat and O'Connell 2002). A full list of the archaeological sites which have been investigated to date is given in Appendix 3, and will form part of the discussion in later chapters. In general, the data highlighted a reliance on terrestrial foods across all sites, with a reasonably high proportion of animal protein from cattle, sheep, pig, chickens and geese (Mays and Beavan 2012, 871; O'Connell and Hull 2011, 673). Freshwater fish consumption has been suggested for a number of sites from elevated δ^{15}N values, but remains equivocal (O'Connell and Hull 2011, 673). A detailed discussion of the available data will follow in Chapter 5, alongside the data obtained from the present analyses.

3. Methodology

Introduction

The sample derived from Broughton Lodge Anglo-Saxon cemetery, situated in the Trent valley in South Nottinghamshire, approximately 11km south-east of Nottingham. This chapter discusses the Broughton Lodge site as a whole in brief, followed by a more detailed description of the Anglo-Saxon cemetery, and presents a discussion of the burials selected for sampling and the rationale for selection. A description of the materials analysed follows, as well as the methods employed for the preparation of the samples, and the methods and equipment used for the mass spectrometer analysis of $^{13}C/^{12}C$ and $^{15}N/^{14}N$ ratios.

The Site

Broughton Lodge Anglo-Saxon cemetery site is located 700m east of Willoughby-on-the-Wolds, in the historic parish of Bingham (NGR SK648250) (Figure 3.1) (University of Nottingham Manuscripts and Special Collections 2017). The River Trent lies around 14km to the north-east. Situated on the north side of the Willoughby Brook valley within a gently undulating landscape, the site is part of the Leicestershire and Nottinghamshire Wolds National Character Area, as designated by Natural England (Kinsley 1993, 1; Natural England 2012, 3). The A46 extends north-south along the site's eastern extent; a secondary, feeder road now extends through the site, the construction of which required extensive landscaping of the site itself (Figure 3.2).

Several programmes of excavation were carried out in advance of road building from 1951 to 1968. The first two uncovered an extensive Romano-British settlement adjacent to the Fosse Way Roman road (Kinsley 1993, 1-9). Further works called for a third programme of excavation, which was carried out by M.J. Dean between 1964 and 1986, and uncovered the extensive Anglo-Saxon cemetery (Kinsley 1993, 1-9).

The excavation report pertaining to the Anglo-Saxon cemetery was published quite some time after the excavation itself, in 1993, by A.G. Kinsley.

Broughton Lodge Anglo-Saxon Cemetery
Nottinghamshire

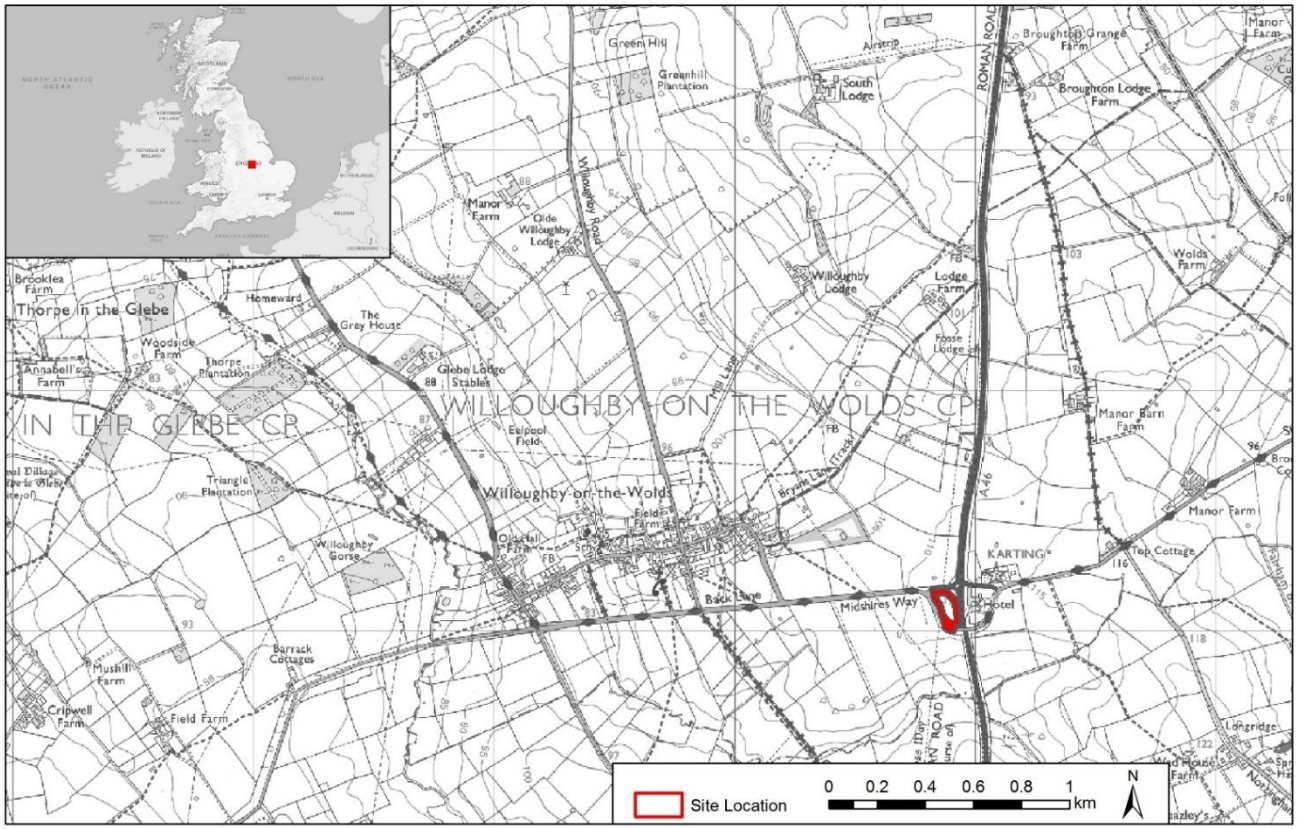

Figure 3.1: Location of the Broughton Lodge site within the UK and Nottinghamshire

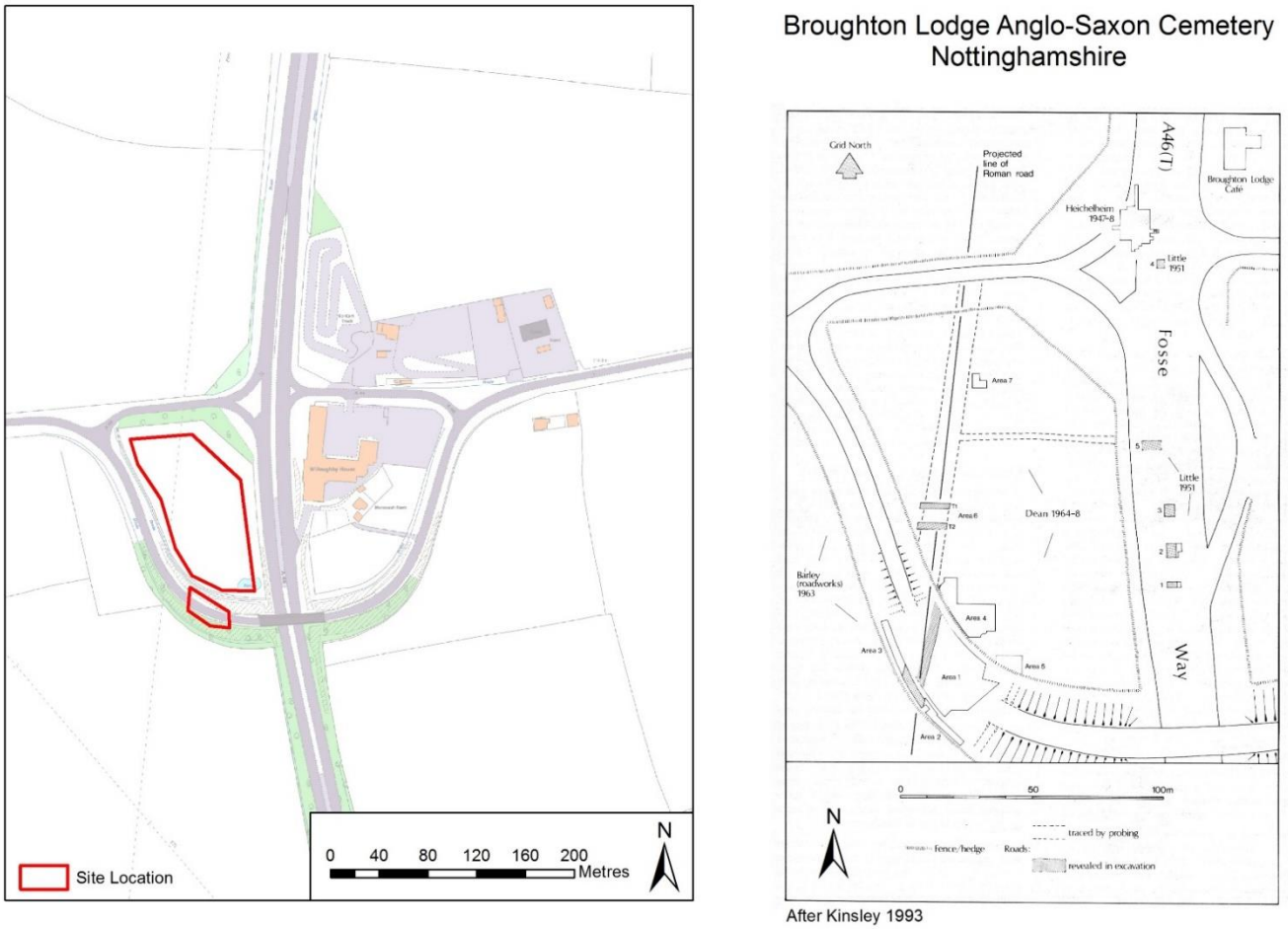

Figure 3.2: Plan of the Broughton Lodge site, showing areas excavated by M.J. Dean in 1964-68

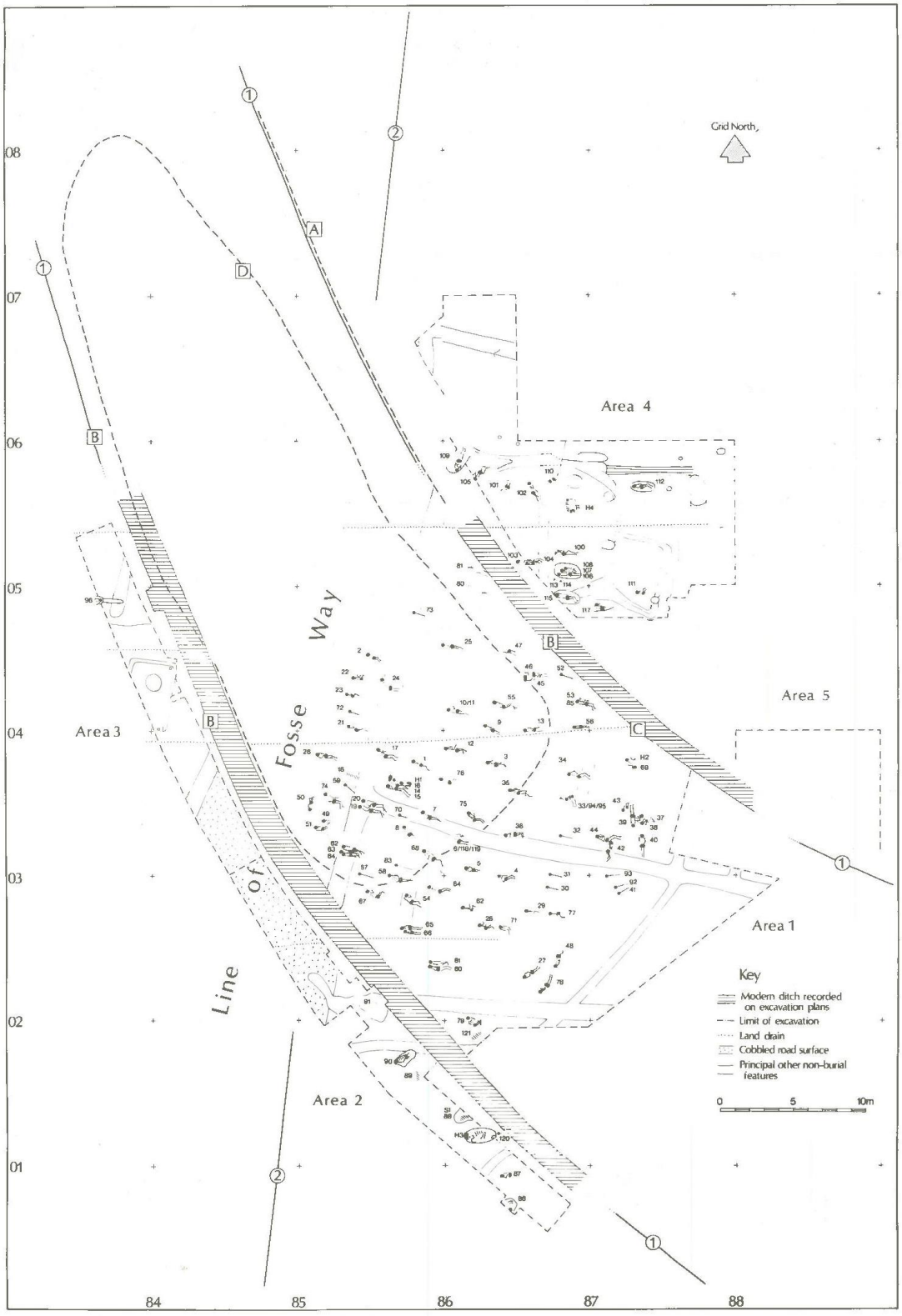

Figure 3.3: Cemetery plan showing distribution and orientation of burials, and projected line of Roman road (Kinsley 1993, Figure 103)

The Anglo-Saxon Cemetery

One hundred and twenty-one human inhumations were recorded at Broughton Lodge between 1964 and 1968 (Figure 3.3). A relative chronology for the cemetery has been suggested based on established Anglo-Saxon grave good typologies, and should be regarded as tentative (Kinsley 1993, 61). Based on this, the main period of use for the cemetery appears to have been during the late 5th to early 7th centuries AD, although earlier or later burials may lie beyond the excavated area. A gilded copper alloy square-headed brooch recovered from Burial 16 for example (Figure 3.4) is described as broadly similar to a group dating to 510-550AD, and a pair of disc brooches from Burial 35 (Figure 3.5) are of a type thought to have had a main period of use from 450-550AD (Kinsley 1993, 58).

Figure 3.4: Great square-headed brooch recovered from Burial 16, broadly similar to a group dating to 510-550AD (Kinsley 1993, Plate XI)

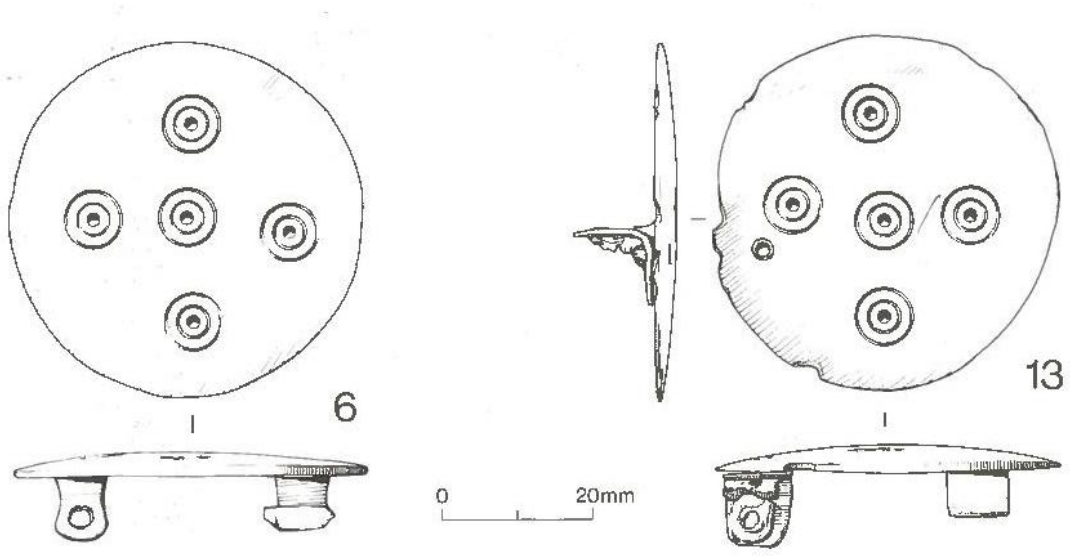

Figure 3.5: Pair of disc brooches recovered from Burial 35, similar to a group whose main period of use was 450-550AD (Kinsley 1993, 126)

A scutiform pendant from Burial 65/66 may date to the 7th century AD (Figure 3.6); similar types have been recorded from 'classic' 7th and 8th century cemeteries at Chamberlain's Barn, Bedfordshire, and Burwell and Shudy Camps, Cambridgeshire (Kinsley 1993, 62-64).

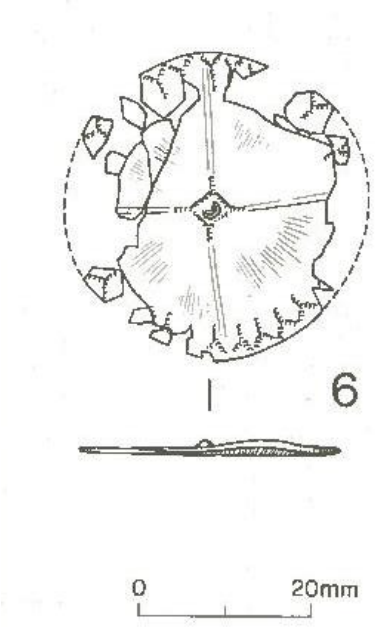

Figure 3.6: White metal scutiform pendant recovered from Burial 56/66, similar to a type dating to the 7th century AD (Kinsley 1993, 147)

A purse mount and several pairs of iron latch lifters from Broughton Lodge may also indicate that burials were taking place during the 7th century (Kinsley 1993, 61-64). Chronologies arising from typological assessments are uncertain however, and none of the Broughton Lodge burials have been subject to radiocarbon dating. As such, a tentative late 5th to 7th century date for the cemetery will be accepted here for broad reference purposes only. No attempts will be made to assign dates to the burials selected for sampling, despite the presence of broadly diagnostic grave goods. It is not within the scope of this thesis to carry out a full reassessment of Kinsley's typological chronology, although this could be included in a programme of further research, as could radiocarbon dating of a selection of burials.

The initial recording of the burials appears to have been rudimentary; original grave plans, sketches and photographs exist only for some burials (e.g. Figure 3.7). The skeletons were aged according to broad categories (child, juvenile, young adult, adult) and no attempts were made to assign biological sex. The entire skeletal assemblage was boxed unwashed, labelled in a somewhat haphazard manner, and curation was split between the University of Nottingham Museum, University Park; and the Museum of Nottingham Life at Brewhouse Yard, Nottingham.

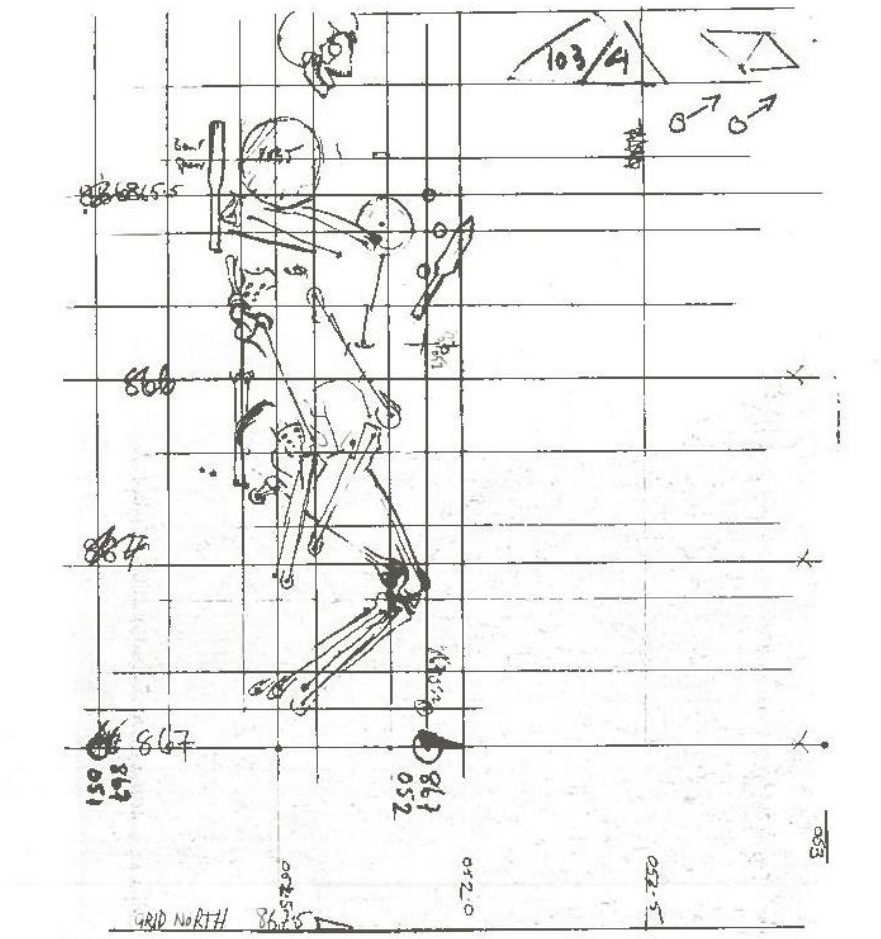

Figure 3.7: M.J. Dean's original field drawing of Burial 103/104 (Kinsley 1993, Plate IV)

Burial position and orientation varied significantly. Skeletons were recorded as extended, flexed, supine or buried on the left and right sides of the body; one prone burial was recorded, tentatively suggested by Kinsley as possibly that of an executed woman (Kinsley 1993, 67-70). Most, but not all, of the burials appear to have been oriented approximately east-west (Figure 3.3). Several double and triple burials were recorded, including one triple burial with horse remains. One single human burial with horse remains, a single burial with sheep remains and two isolated horse burials were also recorded (Kinsley 1993, 25-54). Grave good types included jewellery, domestic fittings and weaponry, and the degree to which the burials were furnished varied dramatically, from the elaborately furnished to those completely lacking grave

goods. Kinsley notes particularly 'poor' burials towards the south-eastern edge of the excavated area, some of which had no accompanying grave goods (Kinsley 1993, 71).

A thorough skeletal assessment of one hundred and five of the burials was made by M. Harman and C. Roberts to inform the excavation report. The condition of the assemblage by this time varied; many bones were still well-preserved whilst some were very fragile and fragmentary (Harman in Kinsley 1993, 56). Where possible, each burial was assigned an accurate age and sex, and any pathologies described. A full catalogue can be found with the excavation report (Kinsley 1993). Those that could be sexed and aged confidently represented a reasonably equal number of males and females (38 and 42 respectively), and ages ranged from neonates to those described as over forty, although Harman notes that several of the latter could have been up to sixty or seventy years old at death (Harman in Kinsley 1993, 57). Adults comprised the larger part of the cemetery population.

The Sample

Six individuals were sampled from Broughton Lodge. To enable meaningful conclusions to be drawn with relation to diet and various social and biological factors (age, sex, status, etc), it was necessary for each individual to have been assigned, as accurately as possible, an age and sex, and their graves goods recorded. The teeth selected for analysis were required to have been formed during childhood and needed to exhibit a good degree of preservation, minimal wear and no significant dental pathologies.

It was intended to obtain samples from a wide cross-section of the burial population, i.e. elaborately furnished and non-furnished burials (as very tentatively representative of status), an equal number of both biological sexes and a wide range of ages; in addition, it was hoped to target several of the double and triple burials recorded. Unfortunately, the sample was necessarily limited due to the poor condition of a large portion of the remains, the absence of several skeletons originally recorded, and the ambiguity of age, sex and provenance of many; the latter arising from questionable labelling.

Ultimately, the samples obtained are biased towards male adults, representing three adult males, one adult female, one adult possible female and one unsexed juvenile. It was possible to target two double burials, one of which comprised two adult males of similar age, and the second, an unsexed juvenile and adult female. Details of the burials sampled, as presented in the excavation report, are presented below in Table 2.1. The museum acquisition numbers for each burial (prefixed by 'BLE') have been adopted here. For the double burials, M.J. Dean's assignation of particular grave goods to particular bodies has been followed. The location and positioning of each of the six skeletons as originally recorded is shown below in Figures 3.8 -3.11.

Burial number	Burial type (single / double)	Age (years) / Sex	Grave goods	Orientation	Position	Pathologies
BLE26	Single	15-20 / possible Female	Iron knife with possible leather sheath	WNW-ESE	Turned to left, skull apparently in upright position, spine curved into S-shape, left arm straight, right forearm bent across stomach, legs slightly bent	None recorded
BLE48	Single	>40 / Male	Knife, animal bone (both missing)	SSW-NNE	On right side, legs bent at hip and knee, left shoulder and left pelvis collapsed forward, left hand on chest	Caries on right upper first and second molars and left upper third molar

BLE65	Double (with BLE66)	30-35 / Female	Iron knife, iron buckle, pair of copper annular brooches, 76 beads, copper alloy wrist clasp, copper alloy fittings, metal scutiform pendant, iron rod, two iron strips, iron bar	W-E	Supine, head left, left forearm bent over pelvis, right arm below 66, legs extended	Slight evidence of osteoarthritis, on the lower cervical vertebrae. Abscess on upper right second and third molars, and lower right second premolar
BLE66	Double (with BLE65)	c. 13 / unsexed	None recorded / assigned	WNW-ESE	On left side, right arm bent, hand on right pelvis of 65, legs extended	None recorded

BLE103	Double (with BLE104)	25 – 30 / Male	Iron spearhead Undifferentiated between the two bodies: Copper alloy fitting, bronze 'hanger'	E-W	Turned to left, right forearm across lower spine, left arm bent away from body. Nine packing stones were placed over the body, and over the lower body of BLE104 (Figure 3.11)	None recorded
BLE104	Double (with BLE103)	25 – 30 / Male	Iron spearhead, iron shield boss, six iron studs Undifferentiated between the two bodies: Copper alloy fitting, bronze 'hanger'	E-W	Turned to left, arms by sides, right forearm below pelvis, legs bent. Nine packing stones were placed over the lower body, and over the entire body of BLE103 (Figure 3.11)	None recorded

Table 3.1**:** Broughton Lodge burials selected for sampling

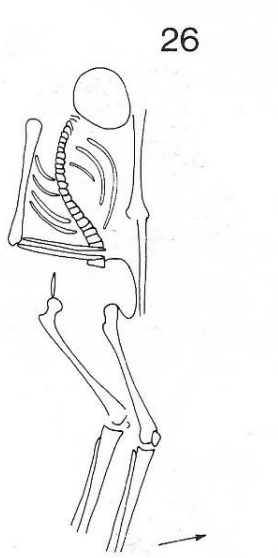

Figure 3.8: Plan of BLE26 (Kinsley 1993, 89)

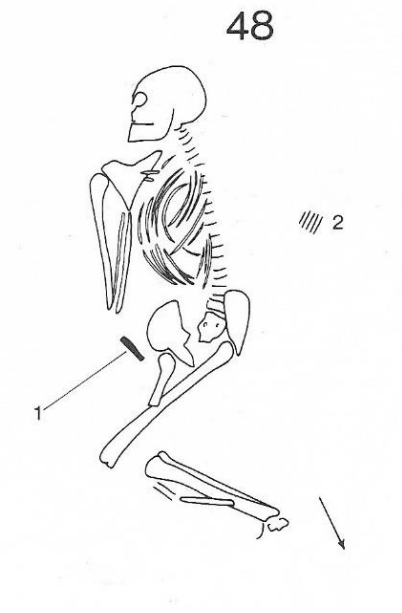

Figure 3.9: Plan of BLE48 (Kinsley 1993, 92)

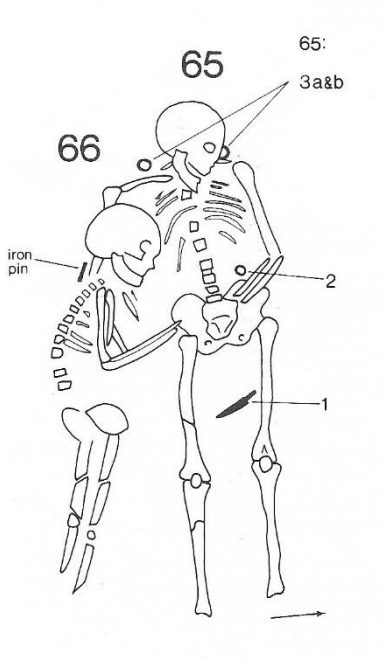

Figure 3.10: Plan of BLE65 and BLE66 (Kinsley 1993, 93)

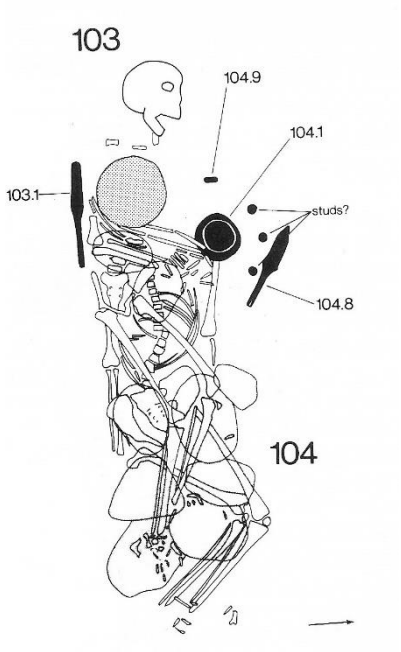

Figure 3.11: Plan of BLE103 and BLE104 (Kinsley 1993, 97)

Materials Sampled

Dentine Collagen

Permanent teeth were extracted from all six individuals, with the aim of investigating their childhood diets. The teeth selected for analysis are discussed below, and presented in Table 3.2. The relative time periods presented for the development of each tooth are based on Hillson (1996) and AlQuatani (2009). Dentition is described using the Zsigmondy-Palmer System (Hillson 1996).

Burial no.	Material sampled	Tissue / tooth sampled	Part of tooth from which dentine extracted	Age of development of crown dentine (months and years of age)	Age of development of root dentine (years of age)	Age range of individual analysed (month and years of age)
BLE26	Dentine	RM^1	Root and crown	4.5 months – 3.5 years	3.5 years to 7.5 years	4.5 months to 7.5 years
		RM^2	Crown	2.5 – 8.5 years	8.5 – 12.5 years	2.5 – to 8.5 years
BLE48	Dentine	RP_2	Crown	2.5 – 5.5 years	5.5 – 11.5 years	2.5 – 5.5 years
BLE65	Dentine	LP^2	Crown	3.5 – 6.5 years	6.5 – 11.5 years	3.5 – 6.5 years
BLE66	Dentine	LM^1	Root and crown	4.5 months – 3.5 years	3.5 years to 7.5 years	4.5 months to 7.5 years
	Dentine	LP^2	Crown	3.5 – 6.5	6.5 – 11.5 years	3.5 – 6.5 years
	Bone	Rib	-	-	-	Final 2 -5 years of life
BLE103	Dentine	LP_2	Crown	2.5 – 5.5 years	5.5 – 11.5 years	2.5 – 5.5 years
	Bone	Rib	-	-	-	Final 2 -5 years of life
BLE104	Dentine	LP_2	Crown	2.5 – 5.5 years	5.5 – 11.5 years	2.5 – 5.5 years
	Bone	Rib	-	-	-	Final 2 -5 years of life

Table 3.2: Materials selected for analysis and their relative development ages

Incremental analysis

Two individuals, BLE26 and BLE66 were targeted for a sequential dietary profile of their early childhoods, thus an upper first molar (M1) was extracted from each. Analysis of the entire M1 allows an assessment of diet from the age of 4.5 months to 7.5 years. Recent studies have demonstrated that sequential sampling of dentine increments can provide a time-series model of childhood diet (e.g. Beaumont *et al*. 2013, Eerkens *et al*. 2011, Lamb *et al*. 2014). Incremental dentine analysis was carried out for both teeth with the aim of identifying any short-term dietary changes during this period of childhood, relating to breast-feeding, weaning and / or nutritional stress. Dentine forms in lines of growth, which can be identified with magnification and related to an individual's age (Chapter 2: Background, Figures 2.5 and 2.6; Lamb *et al*. 2014, 560), however the present research methodology allowed only ten increments from each tooth to be analysed. As such the increments were between 1 and 2mm in length, and will represent around 1 – 2 years of life. Individual measurements and weights are presented in Appendix 1: Tables 1 and 2. An approximate age profile for each tooth was calculated using the lengths of the increments, based on that presented by Henderson *et al.*, which was itself based on a development chart presented by Massler *et al.* in 1941 (Henderson *et al*. 2014, 588). The approximate age profile is presented below in Table 3.3.

Increments (descending from crown to root)	Length (mm) (range of values for BLE 26 and BLE66 first molars)	Approximate age of development (months or years of age)
1	1.00 – 2.00	0 – 6 months
2	1.00 – 2.00	6 – 12 months
3	1.00 – 2.00	1 year – 20 months
4	1.00 - 1.50	20 months – 28 months
5	1.00	28 months – 3 years
6	1.00 - 1.50	3 – 4 years
7	1.00 - 1.50	4 – 5 years
8	1.00 - 1.50	5 – 6 years
9	1.50 – 2.00	6 – 7 years
10	2.00	7 – 8 years

Table 3.3: Approximate age profile of sampled dentine increments for BLE26 and BLE66

Bulk dentine samples

Dentine was extracted from the crowns of a further six teeth, and bulk dentine analysis carried out to obtain an averaged dietary profile for the stage of life relating to the crown development of that tooth (Table 3.2). The averaged isotope profile obtained from bulk dentine analysis for BLE26 and BLE66 served as a useful comparison to the higher resolution profiles obtained from the incremental analyses.

An upper right second molar (RM^2) was extracted from BLE26. The crown dentine of each upper second molar forms at around 2.5 years of age, and is completed by around 8.5 years of age.

Upper left second premolars (LP^2) were extracted from BLE65 and BLE66. The crown dentine of the upper second premolar begins forming at 3.5 years of age, and is complete by around 6.5 years of age.

Lower left second premolars (LP_2) were extracted from BLE103 and BLE104 and a lower right second premolar (RP_2) from BLE48. The crown dentine of the lower premolars begins forming from around 2.5 years of age and is complete by around 5.5 years of age.

Bone Collagen

A fragment of rib was obtained from BLE103, BLE104 and BLE66 (Table 3.2). Only rib fragments displaying a good degree of preservation were selected. Collagen was extracted from each and analysed to obtain an overall dietary profile from the later stage of their lives, and leading up to their deaths. This also provided a useful comparison of the childhood diets of each of the three individuals.

Age profiles were constructed for all the individuals using data from Tables 3.2 and 3.3, and presented alongside the results of the analysis in Chapter 4.

Sample Preparation

The samples were prepared for analysis in June and July 2017 at the NERC Stable Isotope Facility, Keyworth, Nottinghamshire, under the guidance of Dr Angela Lamb.

Incremental Analyses: Each tooth was sectioned using a diamond saw attached to a dental drill, to obtain one compete root and partial crown (Figure 3.12).

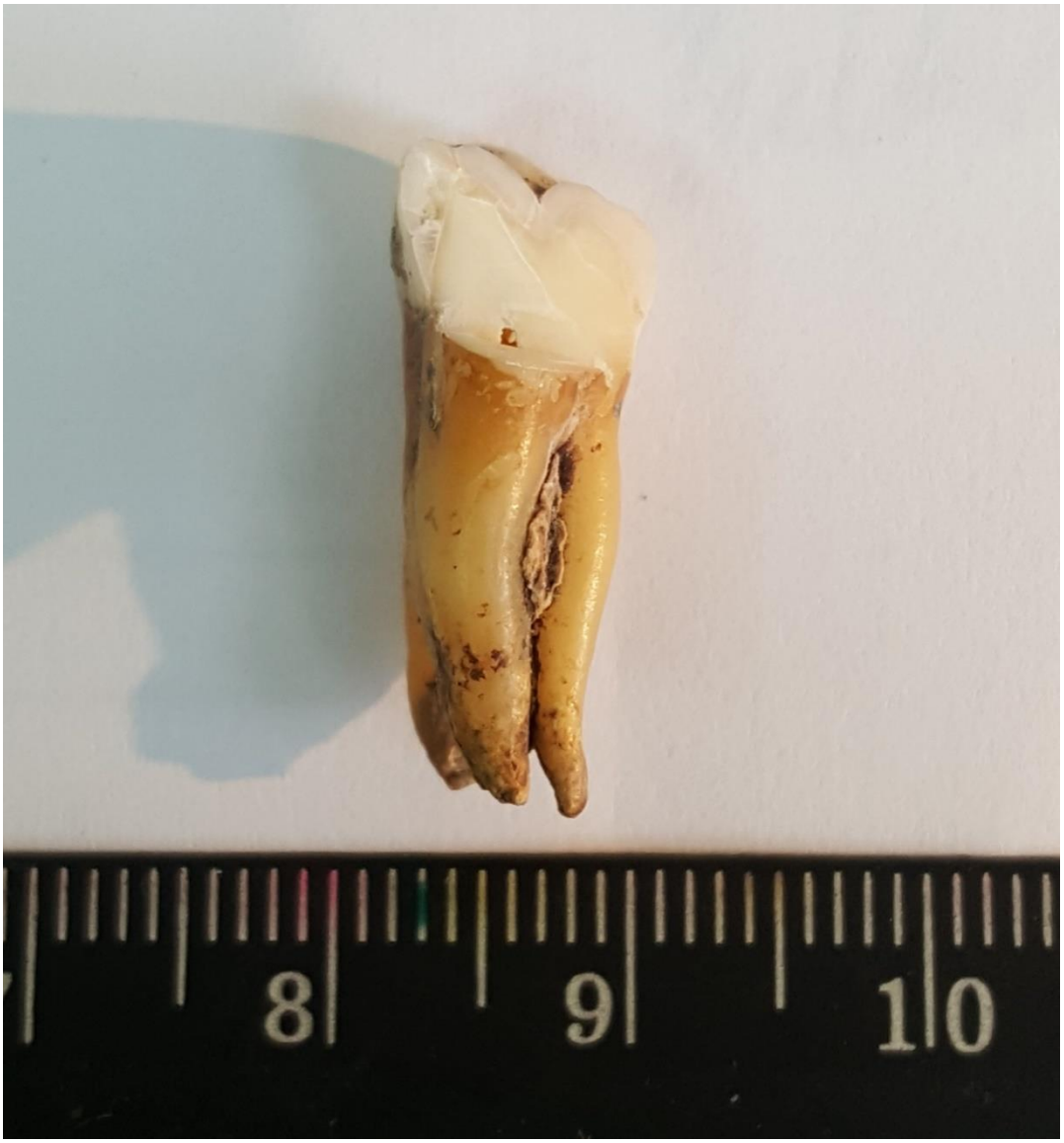

Figure 3.12: Molar sectioned for incremental dentine analysis (photo: author's own)

The sections were cleaned with a burr and any cementum removed from the root. The enamel was removed from the crown using a diamond-tipped saw, and 10 slices of dentine were cut from each tooth, to the lengths presented in Appendix 1: Tables 1 and 2. The increments were placed in separate, labelled test tubes.

Bulk dentine collagen analyses: A section of the crown of each tooth was removed using a diamond-tipped saw, cleaned and the dentine drilled from the enamel using a burr (Figure 3.13). The enamel was retained for later strontium (Sr), oxygen (O) and lead (Pb) isotope analyses, and calculus was retained from selected teeth for further

dietary investigations. The powdered dentine from each tooth was placed in separate, labelled test tubes. The amounts of bulk dentine by weight obtained from each tooth are presented in Appendix 1: Table 3.

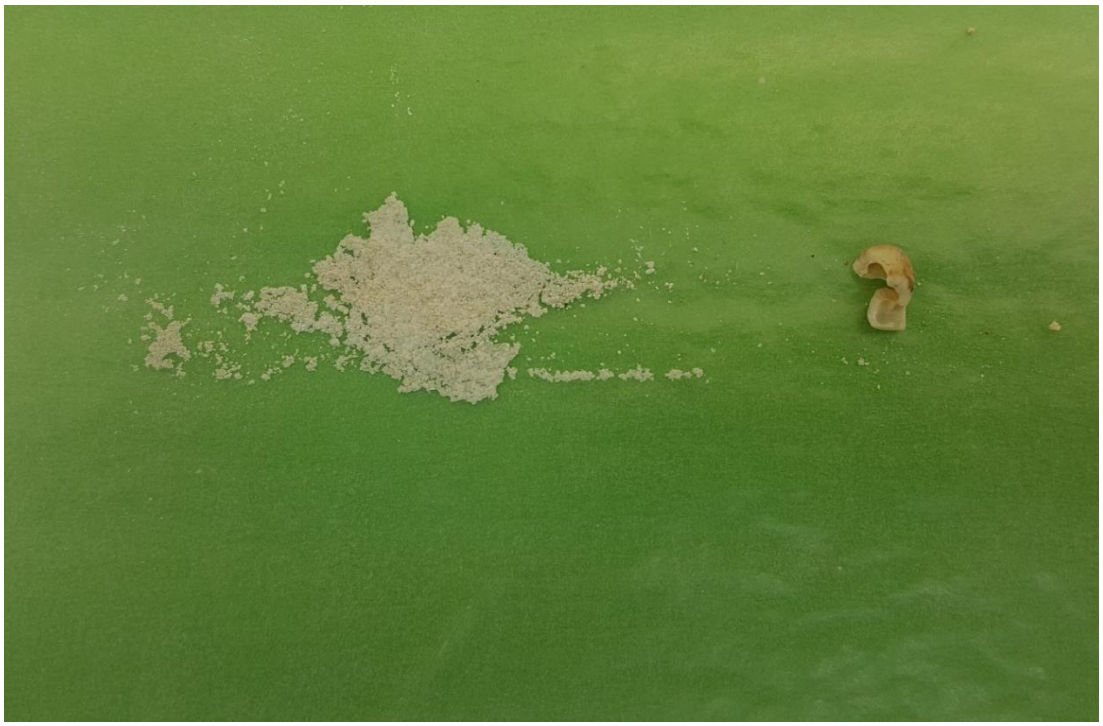

Figure 3.13: Drilled powder dentine and enamel fragments (photo: author's own)

Bulk bone collagen analyses: Sediment and dirt was removed from the surface of each rib fragment using a burr and a small section of rib (approximately 1cm in length and 300-400mg in weight) was cut from each fragment using a diamond-tipped saw (Figure 3.14). Each section was washed with Milli-Q water (an ultra-pure water) before being placed in a labelled test tube.

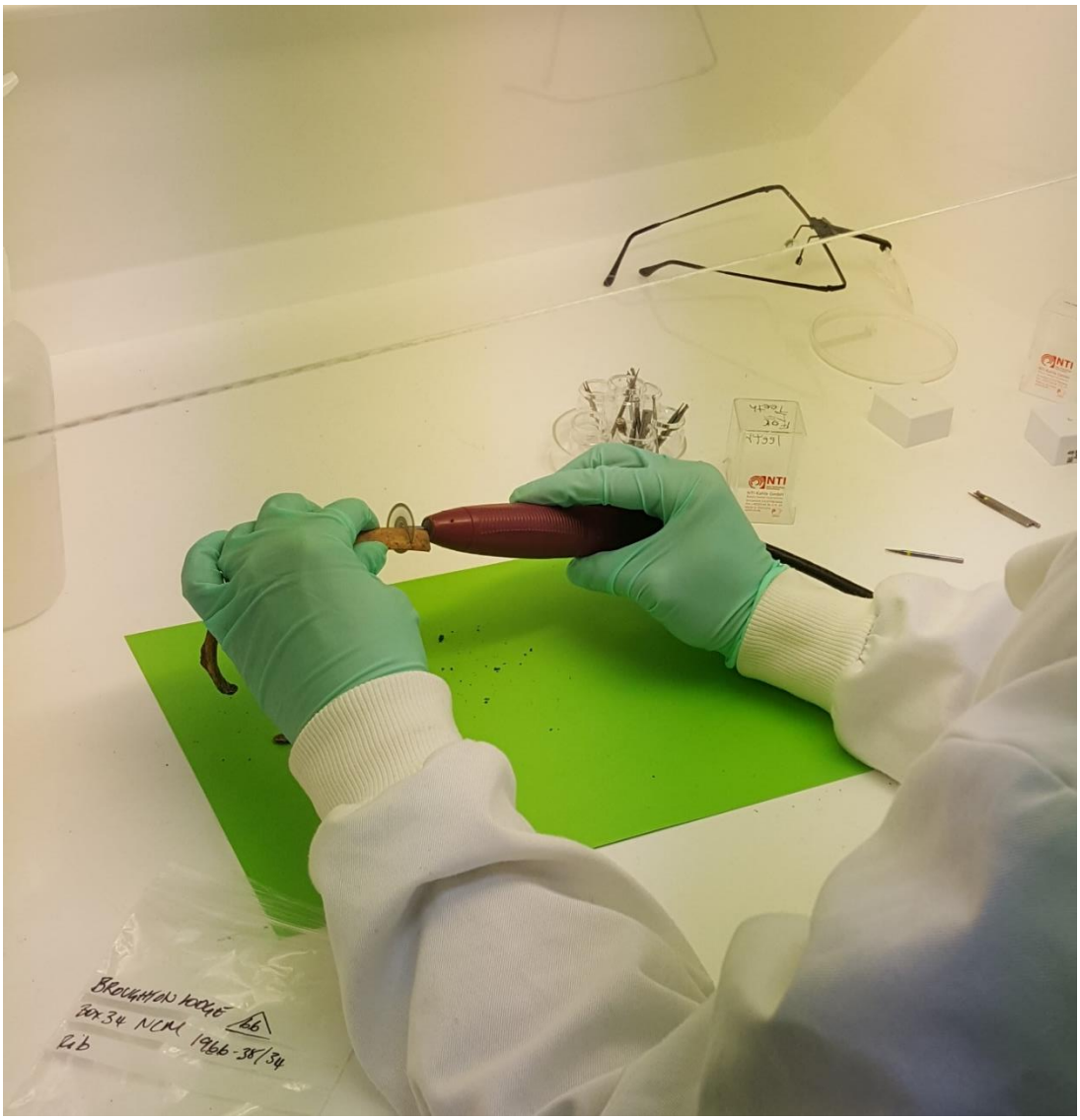

Figure 3.14: Preparation of rib material (photo: author's own)

Collagen was extracted using a modified Longin method (Brown *et al*. 1988) whereby the dentine and rib fragments were left in a solution of 0.5M HCL and refrigerated to demineralise, after being weighed. The amounts of rib material by weight sampled for each individual are presented in Appendix 1: Table 4. Demineralisation of the bone samples took around one week, whilst the dentine samples took between two days and one week. The demineralised bone and collagen slices were washed with Milli-Q water (Figure 3.15), placed in test tubes with pH3 Milli-Q water, sealed with foil and placed in a hot block at 70°C to gelatinise. All instruments were washed with Milli-Q water between samples.

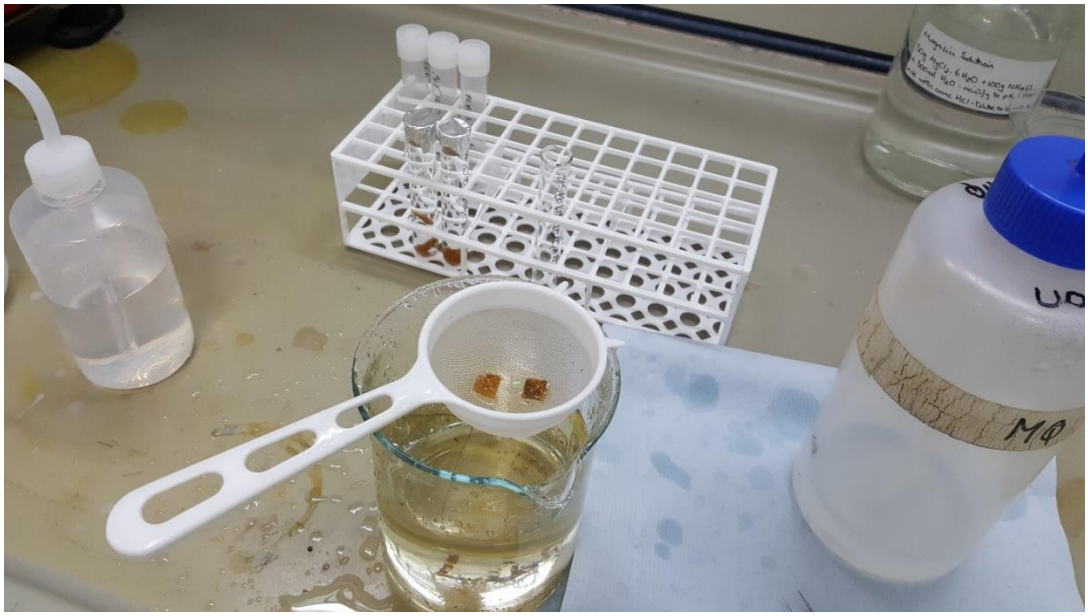

Figure 3.15: Washing of demineralised bone collagen (photo: author's own)

The collagen took around 48 hours to dissolve. The samples were filtered to remove any remaining contaminants, then frozen in Milli-Q water and freeze dried.

The freeze-dried sample materials were weighed according to the required range, i.e. 0.580 – 0.625mg) and placed into tin capsules in duplicate. Around 0.600mg of the lab standards, SADCOW and M1360P were also placed into tin caps. Several empty tin caps were included as 'blanks' to monitor the accuracy of the mass spectrometer run. Each tin-wrapped sample or blank was randomly assigned a sample tray number (A1-H12), corresponding to one of the 96 carousel spaces of the autosampler which feeds the samples through the mass spectrometer (Figures 3.16 and 3.17). This ensures objectivity when the raw data is produced by the mass spectrometer, as each sample is known only by its autosampler number. A list of each duplicate sample, its relative autosampler number and the amount by weight run through the mass spectrometer is presented in Appendix 1: Table 5. The instruments used for weighing were sterilised with ethanol (C_2H_6O) between each sample.

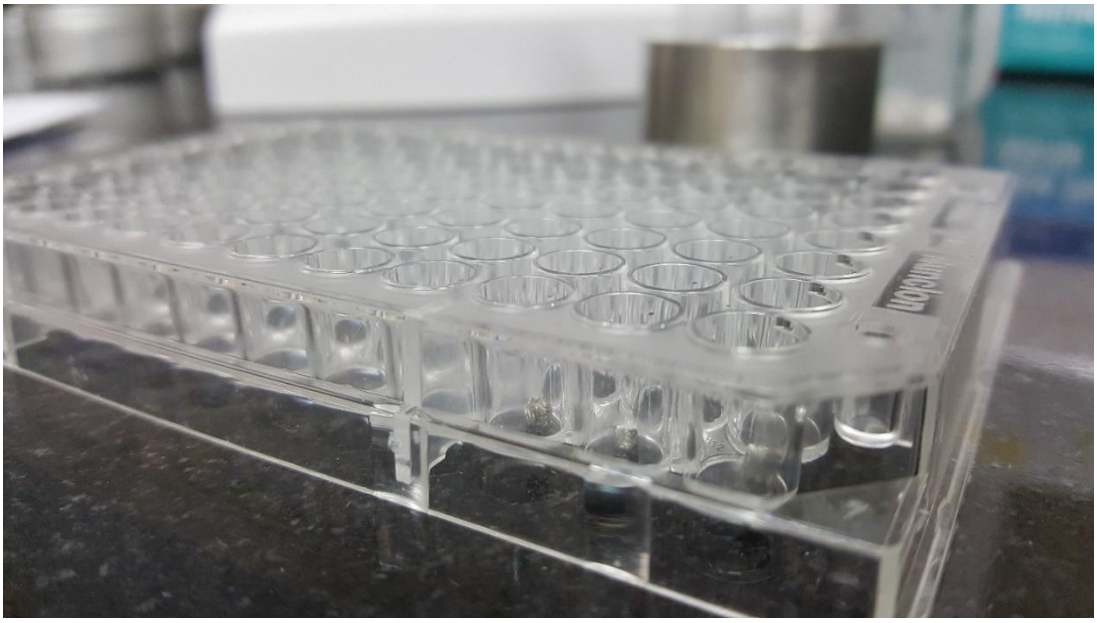

Figure 3.16: Weighed samples in tin capsules, placed into sample tray (photo: author's own)

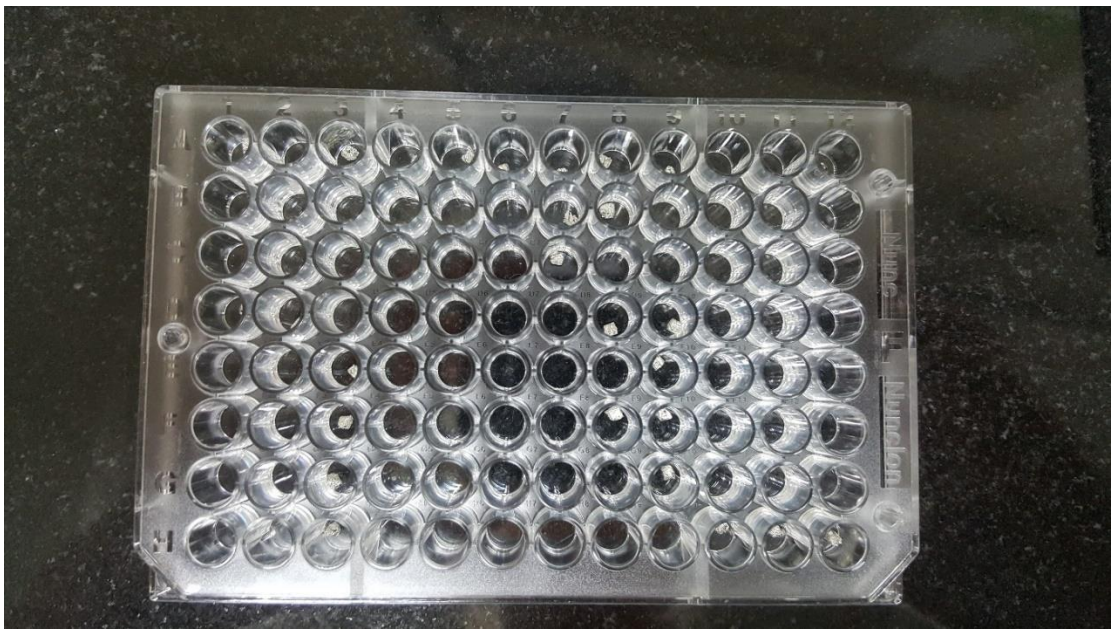

Figure 3.17: View from above of some of the weighed samples in tin capsules, showing their positions in the sample tray (photo: author's own)

Mass Spectrometry

The mass spectrometry was carried out in July 2017 at the NERC Stable Isotope Facility, Keyworth. The prepared collagen samples were analysed using Continuous Flow-Elemental Analysis-Isotope Ratio Mass Spectrometry (CF-EA-IRMS) comprised of an Elemental analyser (Flash/EA) coupled to a Thermo Finnigan Delta^{Plus} XL isotope ratio mass spectrometer via a ConFlo III interface (Figure 3.18).

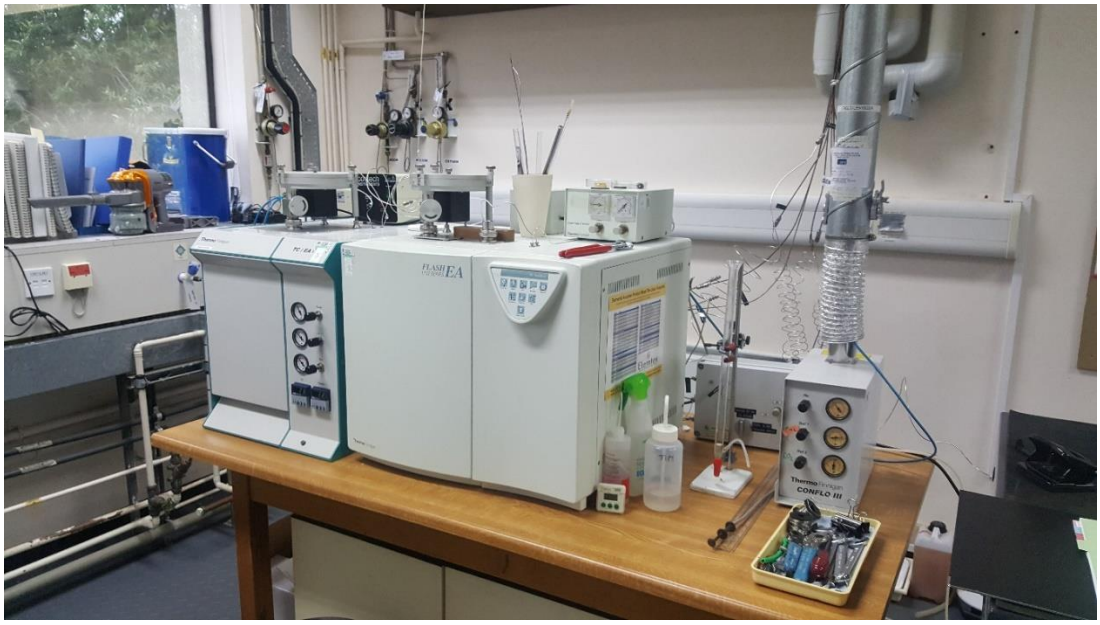

Figure 3.18: Elemental analyser (Flash/EA) coupled to a Thermo Finnigan Delta^{Plus} XL isotope ratio mass spectrometer used to carry out the analysis (photo: author's own)

The samples were placed into a 'Zero Blank' autosampler carousel mounted on a quartz combustion column (Figure 3.19).

Figure 3.19: View of the autosampler carousel from above (photo: author's own)

The autosampler also contained eleven empty tin capsules for comparison purposes, twenty-six capsules containing weighed amounts of M1360P, and three capsules containing SADCOW (Appendix 1: Table 5).

The temperature of this column is maintained at 900^{o}C and 'flash-combustion' is achieved by injecting a pulse of oxygen when the sample enters the tube. The gaseous products of combustion are swept in a helium stream over a silvered cobaltous oxide combustion catalyst, CuO wires to oxidize hydrocarbons and silvered cobaltous oxide to remove sulfur and halides. The resultant gases (N_2, NO_x, H_2O, O_2, and CO_2) are then swept through a reduction stage of pure copper wires held at 680°C. This removes any remaining oxygen and converts NO_x gases to N_2 Water is removed by a magnesium perchlorate trap. Nitrogen and carbon dioxide are separated by a packed column gas chromatograph held at an isothermal temperature. The gas stream then passes through a Conflo-III interface before entering the ion source of the mass spectrometer where the gases are ionised and accelerated. Gas species of different mass are separated in a magnetic field and

simultaneously measured. For N_2, masses 28, 29 and 30 are monitored and for CO_2, masses 44, 45 and 46.

The samples were run through the mass spectrometer on 27th to 28th June 2017. All reported isotope ratios were expressed using the delta (δ) notation in parts per thousand (‰) relative to a standard:

$$\delta(‰) = ((R_{sample}/R_{standard}) - 1) \times 1000$$

The $\delta^{13}C$ and $\delta^{15}N$ results were reported in per mil (‰) relative to VPDB and AIR standards, respectively. Internal lab standards were used throughout the run to correct for instrument drift and to normalize the data to internationally accepted standards. Collagen carbon and nitrogen isotopes ratios were calibrated using the in-house reference material M1360p (powdered gelatine from British Drug Houses) with expected δ values of -20.32‰ and +8.12‰ (calibrated against USGS40 and USGS41, IAEA) for carbon and nitrogen respectively. A modern cattle bone sample, SADCOW, was used as a lab standard. The long-term lab values for SADCOW are -22±-0.2 for $\delta^{13}C$, and 4.6±-0.2 for $\delta^{15}N$ (A. Lamb, pers comm.). The analytical error was calculated based on the reproducibility of M1360P in each run and was ±0.2 or less (A. Lamb, pers comm.). The results are presented in the following section.

4. Results

Introduction

The following section presents the $\delta^{13}C$ and $\delta^{15}N$ values obtained from the isotope ratio mass spectrometer run carried out on 27-28th June 2017. A full list of the results is presented in Appendix 2: Table 1. Collagen preservation and integrity of the results will be discussed first, followed by a brief explanation of the $\delta^{13}C$ and $\delta^{15}N$ values for each group of samples, i.e. bulk dentine collagen, bulk rib collagen and incremental dentine collagen. All $\delta^{13}C$ and $\delta^{15}N$ values are expressed relative to the standard materials, in the following notations:

$\delta^{13}C$ relative to VPDB = $\boldsymbol{\delta^{13}C_{VPDB}}$

$\delta^{15}N$ relative to AIR = $\boldsymbol{\delta^{15}N_{AIR}}$

To ensure the measure of precision of reported results to 95%, the mean and two standard deviations (2σ) have been calculated for each pair of duplicates, or in those instances where repeat samples were analysed, the mean and 2σ of all usable duplicate results. The mean and 2σ is expressed in the following notation:

Mean ± 2σ ‰

Preservation of the Material

Twenty-nine samples were processed in total. Traditional methods for assessing the preservation of collagen extracted from human bone and teeth have relied largely on measuring the carbon:nitrogen atomic ratio (C:N) of each sample, and rejecting any material that falls outside of the range 2.9-3.6 (DeNiro 1985). The C:N atomic ratio accounts for different atomic masses of carbon and nitrogen. It has since been suggested that the C:N ratio values alone are an insufficient measure of collagen preservation, and should be used in conjunction with collagen yield values and the carbon and nitrogen composition of the resulting collagen (Schoeninger *et al*. 1989, 290-291; Ambrose 1990, 448-447). All three criteria were therefore applied to the

processed samples to assess the preservation of the material, and hence the biogenic integrity of each: the collagen yield, the carbon:nitrogen ratio (C:N) and the carbon and nitrogen composition of each sample (Ambrose 1990; Schoeninger *et al*. 1989).

C:N Ratio

As an initial measure of collagen preservation, any C:N values that fell outside of the numerical range suggested by DeNiro as indicative of minimal diagenesis, i.e. 2.9-3.6, were discounted, and where possible additional material for each sample was analysed during a second mass spectrometer run (DeNiro 1985, 897).

The second duplicate for BLE26-04, i.e. the fourth increment sliced from the BLE26 first molar, produced a C:N ratio of 3.7. An insufficient amount of material remained for a duplicate reanalysis, and a single reanalysis produced the same C:N ratio, i.e. 3.7 (Appendix 2: Table 1). As such, this sample has been excluded from the overall isotope profile for BLE26 RM[1].

Duplicates from three of the bulk dentine samples produced C/N ratios of 3.7; BLE65 LP[2], BLE103 LP_2 and BLE104 LP_2. Insufficient material remained from BLE103 LP_2 for a repeat mass spectrometer run, leaving only one potentially usable result which could not be duplicated; as such this sample has been excluded from the overall analyses (Appendix 2: Table 3). BLE65 LP[2] and BLE104 LP_2 were reanalysed in duplicate, and produced C:N ratios of 3.4 for each duplicate. The $\delta^{13}C$ and $\delta^{15}N$ values from the repeat mass spectrometer run have therefore been included in the overall analyses, and the initial values discounted (Appendix 2: Table 3). The mean C:N ratios for each group of samples are presented below in Table 3.1. Only the samples showing ratios within the 2.9 – 3.6 range have been included in the mean calculations.

Sample material	Average C:N ratios
Bulk dentine (x4)	3.5
Dentine increments (x19)	3.3
Bulk bone (rib) (x3)	3.4

Table 4.1: Average C:N ratios from sampled material

All of the samples analysed displayed C:N ratios lying towards the upper limit of DeNiro's preservation index of 2.9-3.6, and it was judged that further measures were required to assess and confirm the collagen preservation of the remaining samples.

Collagen Yield

Fresh bone yields around 22% collagen, which declines following burial (van Klinken 1999, 689). The rate of degradation is dependent on geographical location, as are the thresholds in place for well-preserved or non-contaminated versus poorly-preserved or contaminated collagen. In Europe, a lower limit of 1% is applied to collagen yields, i.e. any collagen yields of 1% or lower are considered to be either too diagenetically altered or too contaminated to have preserved a useful biogenic signal (Ambrose 1990, 440; Haydock *et al*. 2013, 606; van Klinken 1999, 689).

Twenty-eight of the Broughton Lodge samples yielded sufficient collagen for duplicates to be analysed (Appendix 1: Tables 1-4). The bulk dentine extracted from the BLE26 RM^2 did not yield any collagen, which is likely due to errors during the processing phase. This sample will not be considered further. It is interesting to note here that the collagen yield from BLE103 LP_2 was less than 1%; as noted above this sample has already been excluded due to its C:N ratio falling outside of the acceptable range of 2.9-3.6.

Collagen yields by weight from bone and dentine are expected to be around 10% of the original sample weight (A. Lamb, pers. comm.). For the most part, the dentine increments obtained from the BLE26 and BLE66 M1 teeth adhered to this, with one or two exceptions (Appendix 1: Tables 1 and 2). The collagen yields from the bulk dentine were significantly lower, not exceeding 5%, whilst the collagen yields from the rib material varied from around 3-12%. Mean yields for each material are presented in Table 3.2 below, and individual yields are displayed in Appendix 1: Tables 1-4. The bulk dentine yields from BLE26 RM^2 and BLE103 LP_2 have not been included in the mean calculations, for the reasons explained above.

Sample material	Mean collagen yield (%)
Dentine increments (x20)	15.7
Bulk dentine (x5)	2.6
Bulk bone (rib) (x3)	6.5

Table 4.2: Average collagen yields (%) from twenty-seven samples

Carbon and Nitrogen Composition by Weight (%)

Mean carbon and nitrogen concentrations for each group of samples are displayed below, and individual values are presented in Appendix 2: Tables 1-4. Ambrose (1990: 442-444) observed that well-preserved prehistoric tooth collagen can be expected to have carbon and nitrogen concentrations of 5.2% and 1.8%, respectively, whilst well-preserved prehistoric bone collagen should display carbon and nitrogen concentrations of 4.8% and 13%, respectively. Modern animals have been shown to contain 15.3-47% carbon and 5.5-17.3% nitrogen by weight (Ambrose 1990, 442-443). All of the Broughton Lodge samples (excluding those already discounted) displayed carbon and nitrogen values lying towards the upper limits of each of the ranges for modern animals reported by Ambrose (1990). Mean carbon and nitrogen composition values for the Broughton Lodge samples are shown below in Table 3.3.

BLE103 LP_2, which has been excluded from the study based on its low collagen yield and high C:N ratio, did not display carbon and nitrogen composition values indicative of poor collagen preservation. This appears to disagree with suggestions from Ambrose (1990) and Schoeninger *et al*. (1989) that carbon and nitrogen composition values should be the least ambiguous indicator of collagen preservation (Ambrose 1990, 447).

Sample material	Mean carbon concentration (%)	Mean nitrogen concentration (%)
Bulk dentine (x4)	42.0	14.2
Dentine increments (x19)	41.3	14.7
Bulk bone (rib) (x3)	40.8	14.2

Table 4.3: Mean carbon and nitrogen composition values for the three groups of Broughton Lodge samples

Based on the above assessments, it is considered that all processed samples other than from the BLE103 LP_2, the fourth increment sliced from the BLE26 RM^1, and the bulk dentine samples from the BLE103 LP_2 and BLE26 RM^2 have retained their biogenic integrity and are suitable for dietary analysis.

Summary of Results

The isotope ratio values for all individuals are presented below in Tables 4.4-4.7, and represented graphically in Figures 4.1 – 4.10**.** A full discussion and interpretation of the results will follow in Chapter 5. The age ranges presented for the rib collagen samples are approximate only, based on the premise that rib collagen will reflect the last 2-5 years of an adult's life (Lamb *et al*. 2014, 560). The age range for the unsexed sub-adult rib, BLE66, is even less certain, as collagen growth and turnover is more rapid during adolescence compared to adulthood and varies between males and females (Hedges *et al*. 2007, 808).

Bulk Dentine Collagen

The $\delta^{13}C$ and $\delta^{15}N$ values for the bulk dentine collagen analysis are presented below in Table 4.4 and Figure 4.1.

Burial no.	Material Sampled	Sex / age at death	Age represented by values (years)	$\delta^{13}C_{VPDB}$ (mean and 2σ) ‰	$\delta^{15}N_{AIR}$ (mean and 2σ) ‰
BLE48	RP_2 crown dentine	Male / >40	2.5 – 5.5	-21.0±0.19	10.4±0.07
BLE65	LP^2 crown dentine	Female / 30 – 35	3.5 – 6.5	-20.3±0.78	11.3±0.05
BLE66	LP^2 crown dentine	Unsexed / c. 13	3.5 – 6.5	-21.1±0.95	10.8±0.02
BLE104	LP_2 crown dentine	Male / 25 – 30	2.5 – 5.5	-20.9±0.23	10.7±0.12

Table 4.4: $\delta^{13}C$ and $\delta^{15}N$ values obtained from bulk crown dentine analysis

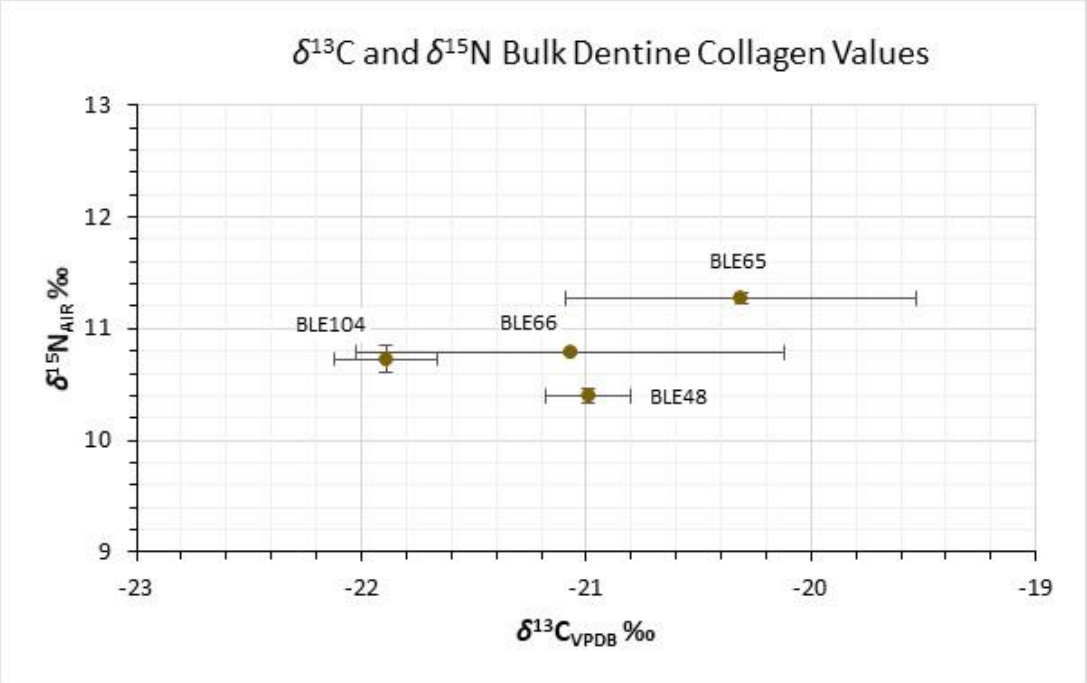

Figure 4.1: $\delta^{13}C$ and $\delta^{15}N$ values obtained from bulk dentine collagen analyses. 2σ shown as vertical and horizontal error bars

The data from the bulk dentine analysis of teeth formed during later childhood show a range of -21.1±0.95 to -20.3±0.78 for $\delta^{13}C$, and 10.4±0.07 to 11.3±0.05 for $\delta^{15}N$. Mean values are $\delta^{13}C$ 20.8‰ and $\delta^{15}N$ 10.8‰.

If we assume that no C4 dietary sources were available to the Broughton Lodge population, then the $\delta^{13}C$ values seem to reflect a diet of terrestrial C3 protein, from either plant or animal sources (Mays and Beavan 2012, 870; Richards *et al*. 2006, 123). The $\delta^{15}N$ values suggest a diet predominantly composed of terrestrial animals, with perhaps some input from omnivore protein (Mays and Beavan 2012, 870; Müldner and Richards 2005, 44). Elevated $\delta^{15}N$ values in the range displayed by the Broughton Lodge bulk dentine may indicate consumption of freshwater resources, however the $\delta^{13}C$ signal of all individuals appears to be entirely terrestrial.

Whilst the two males and the unsexed individual display broadly similar values, the female (BLE65) displays slightly elevated values for both $\delta^{13}C$ and $\delta^{15}N$ which are higher relative to the remaining three individuals by around 0.7‰ and 0.5‰ respectively. The possible reasons for this will be discussed in Chapter 5. In general, the ranges exhibited for the $\delta^{13}C$ and $\delta^{15}N$ values are narrow enough to suggest very little significant dietary variation between individuals.

The $\delta^{13}C$ values for BLE65 and BLE66 LP_2 dentine collagen display a much higher standard deviation (2σ) than BLE48 and BLE104. This could be due to reduced sample integrity, however, although the first of two duplicate samples for BLE66 had to be excluded as the C:N ratio was 3.7, the second of the two duplicates from the first mass spectrometer run gave a C:N ratio of 3.6, and both duplicates from the repeat mass spectrometer run gave C:N ratios of 3.4. Although lying towards the upper limit of DeNiro's preservation range, these are no higher than the majority of the ratios reported for any of the three sample groups. The C:N ratios for BLE65 were also within the range, albeit lying towards the upper extreme. The collagen yields for both teeth were the highest within their group, and their carbon and nitrogen compositions do not vary significantly from the mean for that group. Sample preservation or contamination was therefore not an obvious issue, and alternative explanations may need to be sought.

Bulk Bone Collagen

The $\delta^{13}C$ and $\delta^{15}N$ values for the bulk rib collagen analysis are presented below in Table 4.5 and Figure 4.2.

Burial no.	Material Sampled	Sex / age at death	Age represented by values (years)	δ^{13}C VPDB (mean and 2SD) ‰	δ^{15}N AIR (mean and 2SD) ‰
BLE66	Rib collagen	Unsexed / c. 13	c. 8 – 13	-20.2±0.14	9.8±0.01
BLE103	Rib collagen	Male / 25 – 30	c. 20 – 25	-20.6±0.10	11.0±0.11
BLE104	Rib collagen	Male / 25 – 30	c. 20 – 25	-20.3±0.05	11.01±0.12

Table 4.5: δ^{13}C and δ^{15}N values obtained from bulk rib collagen analysis

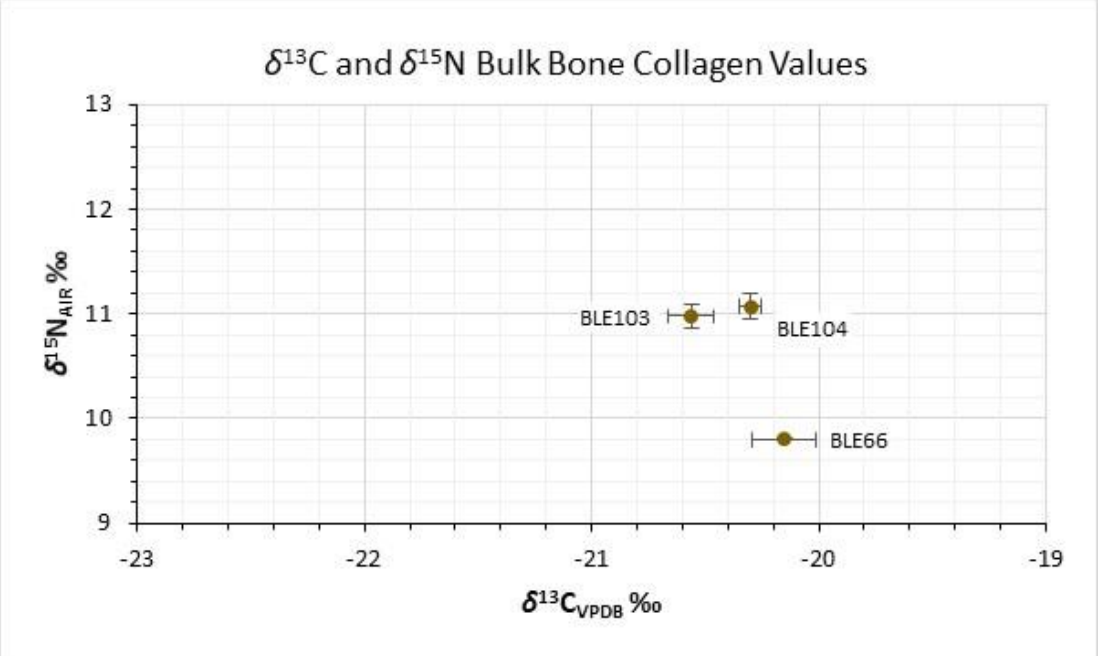

Figure 4.2: δ^{13}C and δ^{15}N values obtained from bulk bone collagen analyses. 2σ shown as vertical and horizontal error bars

The data from the bulk bone collagen analyses show a range of δ^{13}C values from -20.6±0.10 to -20.2±0.14‰ with a mean of -20.3‰, and δ^{15}N values ranging from 9.80±0.01 to 11.1±0.12‰, with a mean of 10.6‰. Again, these values are indicative of a diet primarily based on terrestrial animals (Mays and Beavan 2012, 870).

Both adult males show similar $\delta^{13}C$ and $\delta^{15}N$ values for adulthood, whilst the clear outlier in this group is the unsexed juvenile (BLE66), displaying a slightly elevated $\delta^{13}C$ value and a $\delta^{15}N$ value around 1-1.5‰ lower than the two adult males. It must be remembered however that the values for BLE66 reflect their bone collagen isotope ratios in childhood; this individual did not survive to adulthood, thus the rib collagen analysed is likely to have been formed between the ages of 8 and 13 years old. The slight difference in $\delta^{13}C$ values is not of particular note, but the anomalous $\delta^{15}N$ value for this individual is most probably reflective of the differences in ages between the two males and the juvenile, potentially reflecting dietary differences between adults and juveniles. This is supported by the fact that BLE66 doesn't display any significant differences in $\delta^{13}C$ or $\delta^{15}N$ values within the dentine collagen sample group, as all samples within that group represent similar ages (Chapter 3: Table 3.2).

There are therefore only two individuals for which adult $\delta^{13}C$ or $\delta^{15}N$ values have been obtained, BLE103 and BLE104. $\delta^{13}C$ and $\delta^{15}N$ values are very similar for both, suggesting a similar diet in adulthood. BLE103 and BLE104 also represent the only double burial which provided sufficient material for comparison of adult diet between two individuals, and their $\delta^{13}C$ and $\delta^{15}N$ values are very similar; furthermore, both have elevated $\delta^{15}N$ values which may be indicative of omnivore or freshwater resource consumption. This will be discussed further in Chapter 5.

BLE66 is one of two individuals sampled that has provided both dentine and bone values. The bone collagen extracted from BLE66 potentially reflects an age range of between around 3 and 13 years old, whilst the bulk dentine analysis for the same individual reflects an age range of 2.2 to 5.5 years old. A tentative comparison of the two sets of values suggests an increase in $\delta^{13}C$ and a decrease in $\delta^{15}N$ values between the ages of around 5.5 and 13 years.

BLE104 has also provided sufficient sample material to attempt a tentative comparison between dentine and bone collagen values. This individual shows an increase in both $\delta^{13}C$ and $\delta^{15}N$ values between childhood and possible adulthood (2.5-5.5 years old to around 15-26 years old), of 0.5‰ and 0.3‰ respectively. Both are very minor differences, and are within the usual error of 0.2‰; therefore it is unlikely that these are reflective of any significant dietary variation.

Incremental Analyses of BLE26 and BLE66

The results of the incremental dentine analysis of the BLE26 and BLE66 M1 teeth are presented below, in tabular and graphical format. The $\delta^{13}C$ and $\delta^{15}N$ values for each individual are plotted separately, and then compared. When attempting to construct archaeological breastfeeding and weaning profiles, the convention is to compare M1 values with adult female values from the same archaeological assemblage obtained from later-forming teeth, based on the assumption that these values will represent the 'normal' $\delta^{13}C$ and $\delta^{15}N$ ratios of the female sector of a population, and hence the breastfeeding mothers of the group. Unfortunately, the nature of the Broughton Lodge sample population has not allowed any analysis of adult female isotope ratios, thus no such comparison is possible here. The only female collagen analysed presents an averaged isotope composition from the ages of 2.5 to 5.5 years, which is encompassed by the incremental analyses from BLE26 and BLE66. Any conclusions drawn as to potential weaning signals from BLE26 and BLE66 will be based on documentary sources and published weaning studies to date, and will be tentative at best. A comparison of the Broughton Lodge incremental values with adult values from the same cemetery could form part of a programme of further research.

The increments have been numbered below to correspond with the ascending age of the individual, i.e. Increment 1= the earliest forming part of the tooth (the crown) and Increment 10 = the latest forming part of the tooth (the root). The mean and 2σ of each pair of values is presented, alongside the corresponding approximate age of the individual analysed, as per Table 3.3 above in Chapter 3. For ease of graphical representation, the upper limit of each approximate age range has been taken as the age of the individual corresponding with each increment. The sample which was excluded due to issues of collagen preservation, BLE26 Increment 7, is not displayed graphically, rather a dashed line has been drawn to artificially connect the values on either side.

Burial number	Increment no.	Approximate age of individual	$\delta^{13}C_{VPDB}$ (mean and 2σ) ‰	$\delta^{15}N_{AIR}$ (mean and 2σ) ‰
BLE26	1	0 – 6 months	-20.80±0.19	11.8±0.24
	2	6 – 12 months	-20.80±0.03	11.2±0.12
	3	1 year – 20 months	-20.34±0.03	11.5±0.15
	4	20 months – 28 months	-20.29±0.02	11.6±0.18
	5	28 months – 3 years	-20.26±0.04	11.6±0.10
	6	3 – 4 years	-20.35±0.01	11.6±0.08
	7	4 – 5 years	N/A – sample excluded	
	8	5 – 6 years	-20.11±0.08	11.2±0.22
	9	6 – 7 years	-20.14±0.04	11.4±0.03
	10	7 – 8 years	-20.31±0.02	11.5±0.12

Table 4.6: $\delta^{13}C$ and $\delta^{15}N$ values for incremental analysis of BLE26 RM^1

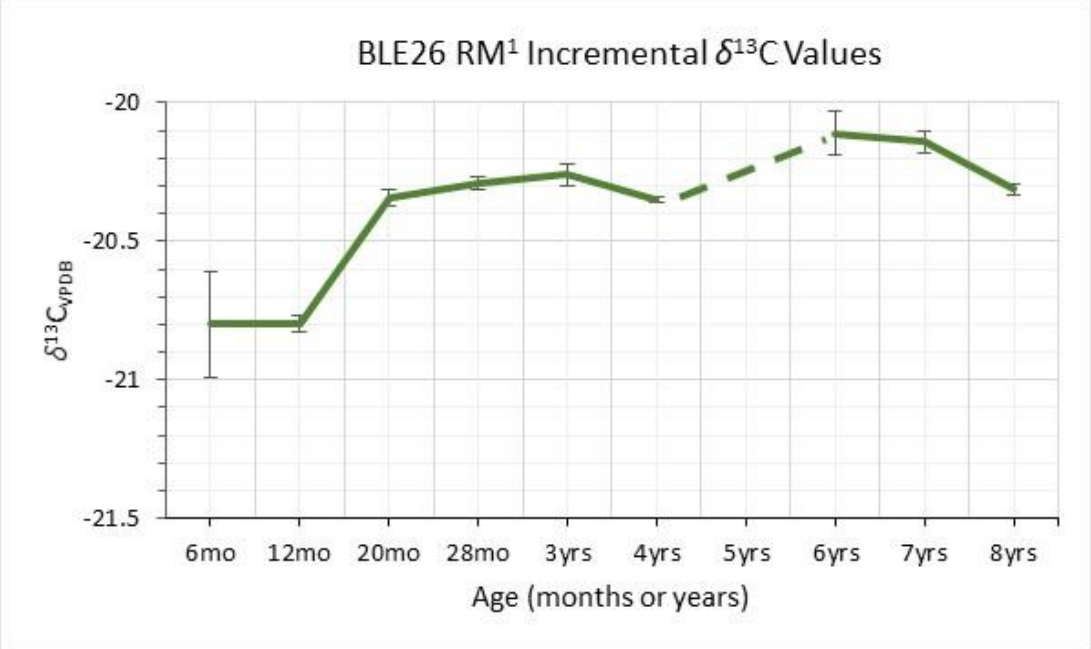

Figure 4.3: $\delta^{13}C$ values for incremental analysis of BLE26. 2σ shown as error bars

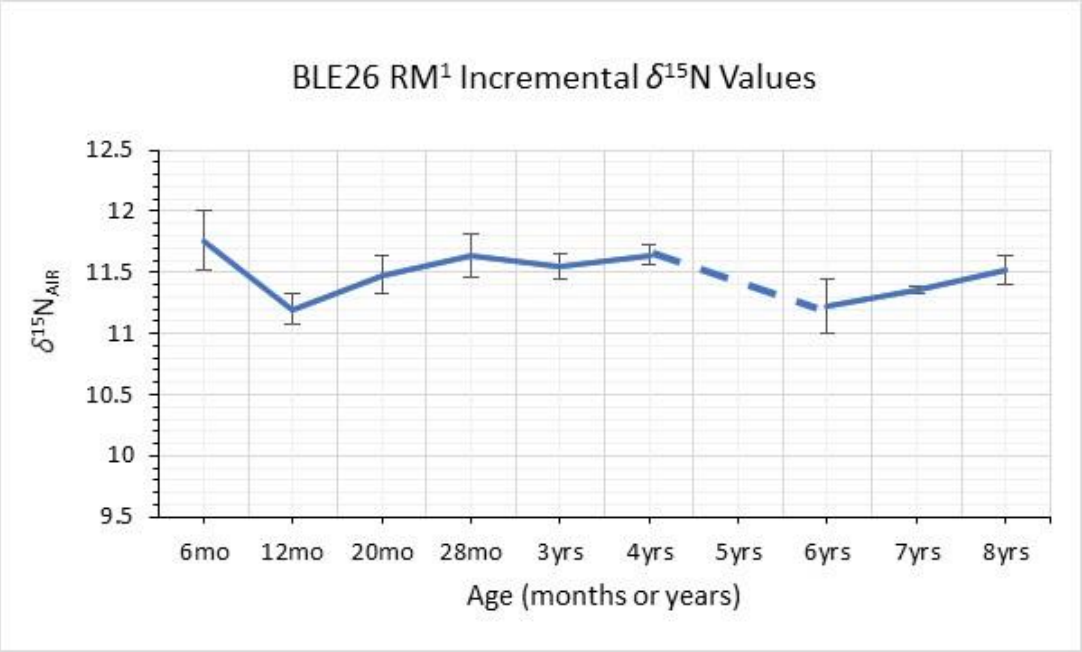

Figure 4.4: δ^{15}N values for incremental analysis of BLE26. 2σ shown as error bars

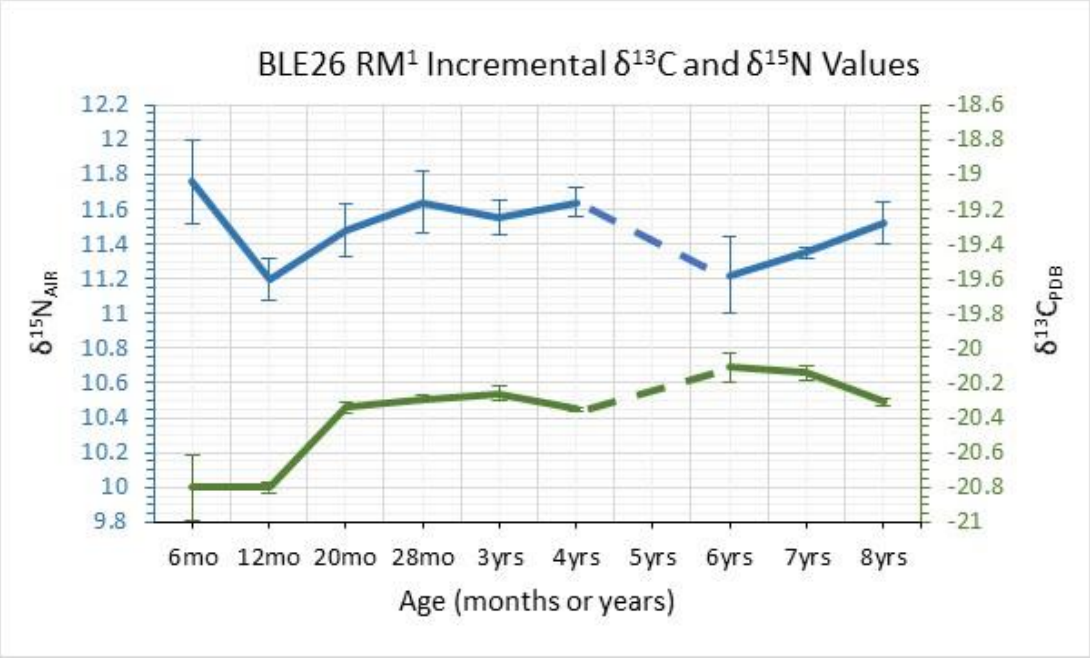

Figure 4.5**:** δ^{13}C and δ^{15}N values for incremental analysis of BLE26. 2σ shown as error bars

Burial number	Increment no.	Approximate age of individual	$\delta^{13}C_{VPDB}$ (mean and 2σ) ‰	$\delta^{15}N_{AIR}$ (mean and 2σ) ‰
BLE66	1	0 – 6 months	-20.71±0.08	11.3±0.13
	2	6 – 12 months	-20.79±0.17	11.5±0.10
	3	1 year – 20 months	-20.65±0.19	11.01±0.18
	4	20 months – 28 months	-20.63±0.04	10.5±0.01
	5	28 months – 3 years	-20.51±0.12	10.3±0.00
	6	3 – 4 years	-20.54±0.01	10.2±0.17
	7	4 – 5 years	-20.65±0.03	10.0±0.07
	8	5 – 6 years	-20.59±0.03	10.3±0.08
	9	6 – 7 years	-20.16±0.01	10.9±0.01
	10	7 – 8 years	-20.24±0.07	1.2±0.10

Table 4.7**:** $\delta^{13}C$ and $\delta^{15}N$ values for incremental analysis of BLE66 LM[1]

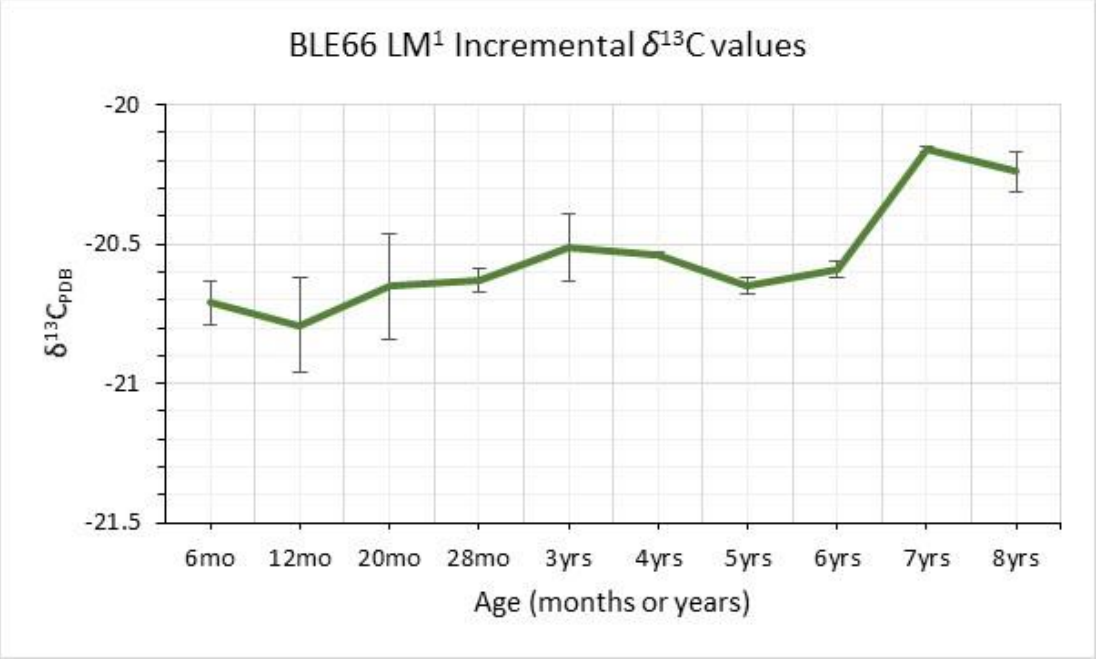

Figure 4.6: $\delta^{13}C$ values for incremental analysis of BLE66. 2σ shown as error bars

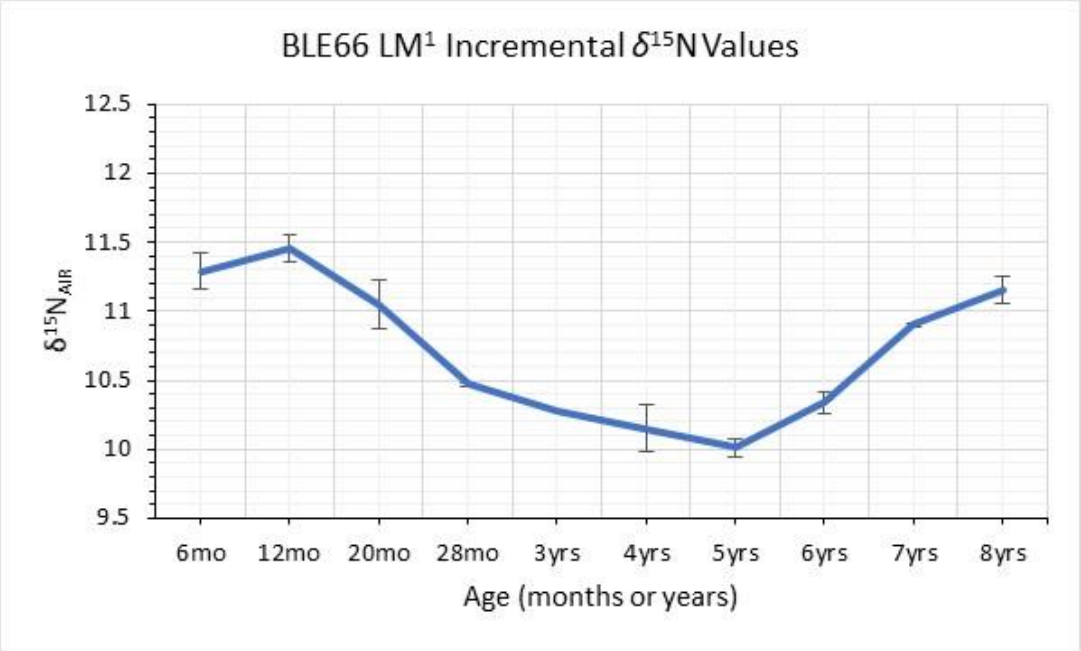

Figure 4.7: δ^{15}N values for incremental analysis of BLE66. 2σ shown as error bars

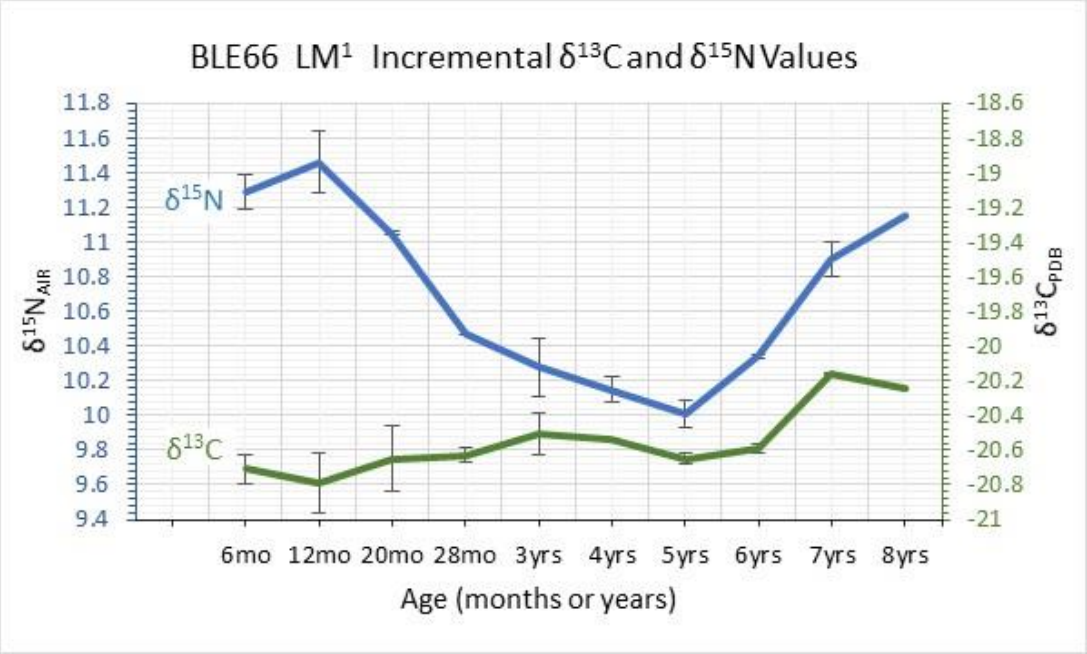

Figure 4.8: δ^{13}C and δ^{15}N values for incremental analysis of BLE66. 2σ shown as error bars

The δ^{15}N values from both individuals follow broadly similar patterns, in that a higher δ^{15}N value can be observed at the youngest age of tooth growth, which then decreases (Figures 4.4, 4.7 and 4.9). Indications of breastfeeding and weaning are

generally accepted as a 'trophic level' decline in of around 2-3‰ in δ^{15}N values from the period of breastfeeding through to the cessation of weaning (Beaumont *et al*. 2015, 442; Fogel 1989 *et al*., 116; Fuller *et al*. 2006, 279; Schurr 1997, 919). A secondary indicator has been suggested as a decline in δ^{13}C values of around 1‰ over the same period of time (Fuller *et al*. 2006, 279).

The δ^{15}N values from BLE66 exhibit a broad pattern which may indicate a weaning signal, however the decrease in δ^{15}N values takes place from around 0-6 months, until 5-6 years (Figures 4.7 and 4.9). This may indicate a longer weaning period than should be expected for Anglo-Saxon infants, thought to have been fully weaned by age 2-3 years (Crawford 1999, 73). However, the decrease in δ^{15}N values during this age period is around 1.3‰, which is significantly less than the expected trophic level decrease of 2-3‰. BLE26 shows a more erratic pattern, with no real decline in δ^{15}N values overall (Figures 4.4 and 4.9). A slight decrease of around 0.5‰ is observed from between 0-6 months and 6-12 months, followed by minor fluctuations in values, with an end value at 7-8 years which is only 0.2‰ lower than the highest value shown at 0-6 months (Figure 4.4).

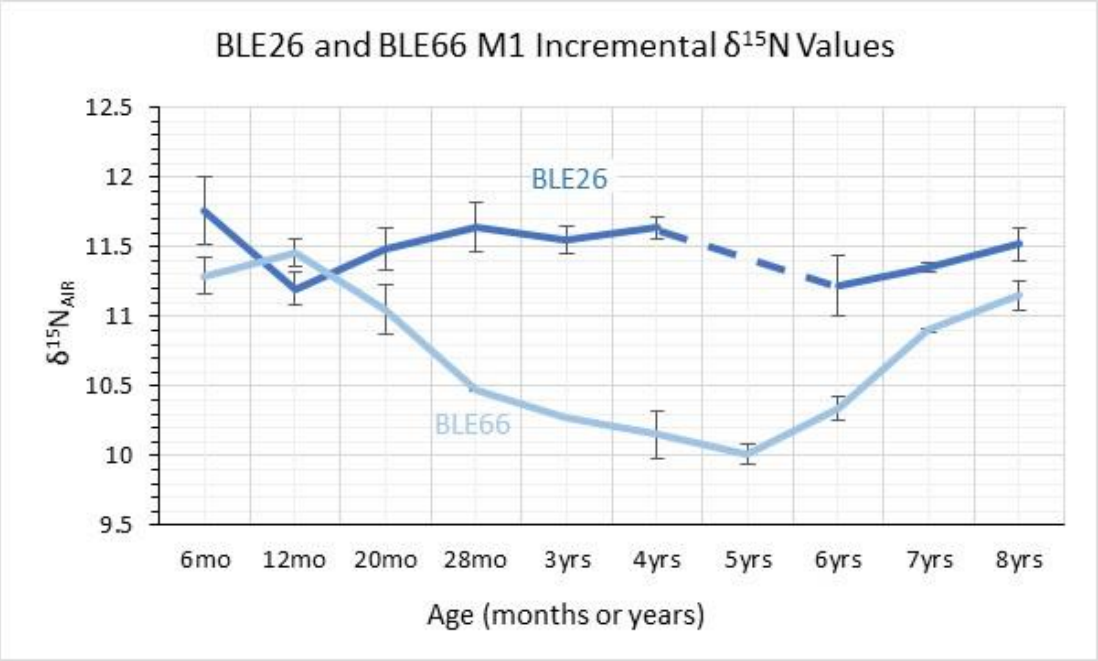

Figure 4.9: δ^{15}N values for incremental analysis of BLE26 and BLE66. 2σ shown as error bars

In the absence of female adult data to compare the M1 values to, all that can be inferred from both sets of δ^{15}N data is that they reflect considerable variation between one another in infant dietary profiles. It is impossible to unequivocally infer a weaning signal for BLE26 due to the lack of an appreciable decrease in δ^{15}N values, whilst BLE66 gives the impression of a weaning signal but does not show a large enough decrease in δ^{15}N values to suggest a trophic level effect.

The δ^{13}C values from BLE66 are much more regular compared to the δ^{15}N values, and suggest dietary intake deriving ultimately from terrestrial food sources (Figures 4.6 and 4.8). The δ^{13}C values for BLE26, although showing slightly more variation than those of BLE66, reflect similar food sources (Figures 4.3, 4.5 and 4.10). No significant decrease in δ^{13}C values is evidence from either set of values which could represent a trophic level decline as suggested by Fuller *et al*. (2006, 279); indeed, both sets of δ^{13}C values become less negative overall over time (Figure 4.10).

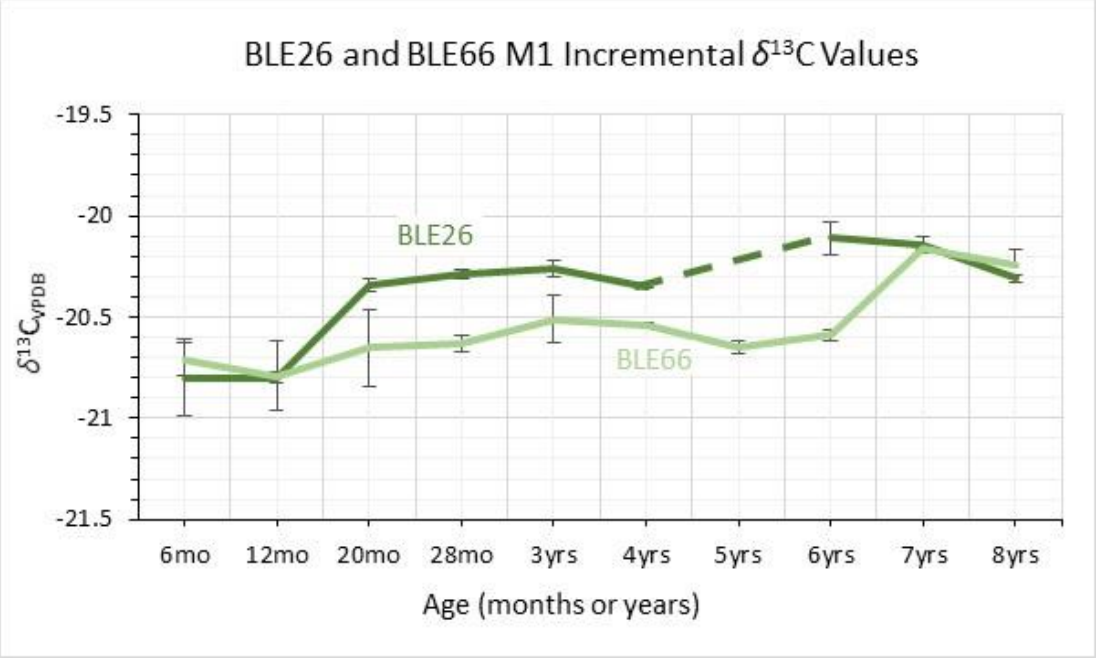

Figure 4.10: δ^{13}C values for incremental analysis of BLE26 and BLE66. 2σ shown as error bars

To check the integrity of the results, a comparison was made between the $\delta^{13}C$ and $\delta^{15}N$ values obtained from the dentine increments and the bulk crown dentine of BLE66, displayed below in Figures 4.11 and 4.12.

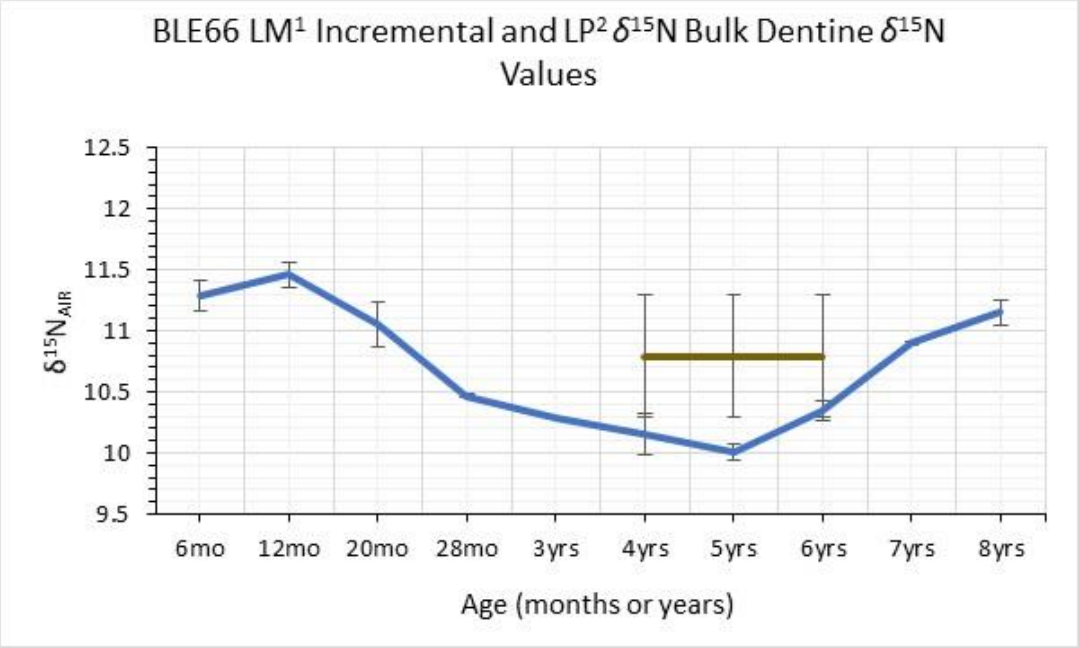

Figure 4.11: BLE66 LM[1] Incremental and bulk dentine $\delta^{15}N$ values. 2σ shown as error bars

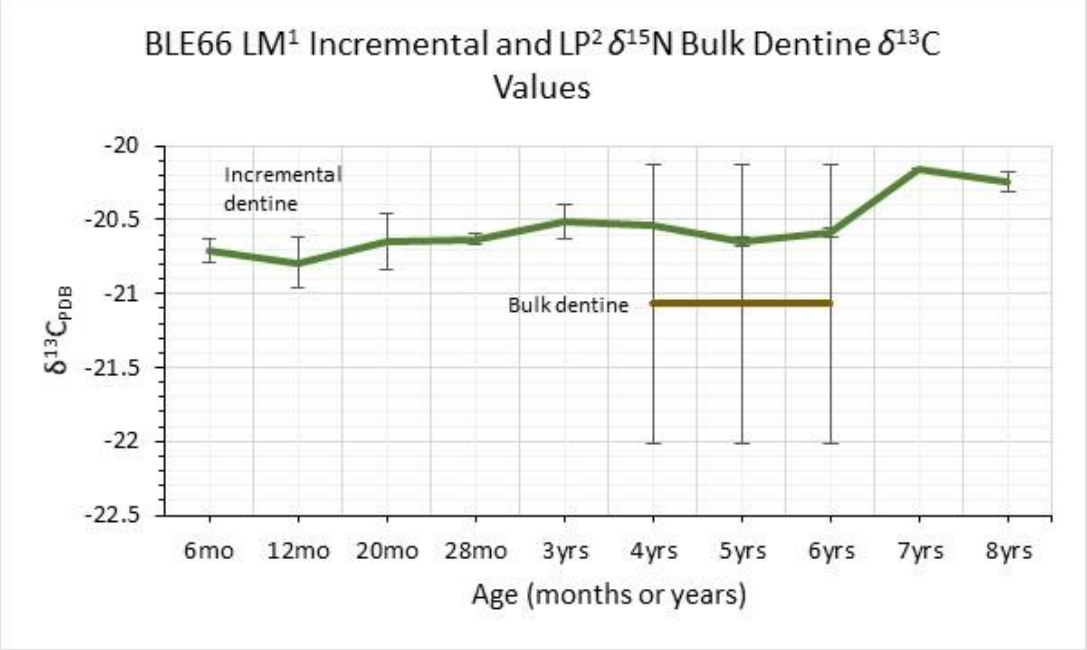

Figure 4.12: BLE66 LM[1] Incremental and bulk dentine $\delta^{13}C$ values. 2σ shown as error bars

The mean bulk dentine δ^{15}N is elevated by around 0.65‰ compared to the incremental values from the same tooth formation period (Figure 4.11), whilst the δ^{13}C value is lower by around 0.5‰ Figure 4.12). Ideally the bulk dentine values should be similar to the mean of the incremental values from the same time period. This may suggest that the bulk dentine results are less accurate than the incremental results, which is reinforced by the relatively high 2σ values for both the δ^{15}N and δ^{13}C bulk dentine values. The δ^{13}C bulk dentine 2σ value overlaps with the corresponding incremental values, therefore the incremental values are still within the margin of error for the bulk δ^{13}C values. The 2σ of the bulk δ^{13}N values overlaps very slightly with the incremental δ^{15}N value obtained for the 5 – 6 years increment. Concerns with the accuracy of the bulk dentine results have been raised previously, and it may be that poor preservation of collagen or contamination of the sample have led to inaccuracies. The difference in values between the incremental and the bulk dentine samples is however very slight, and should not impact upon conclusions regarding dietary sources. Nevertheless, any conclusions drawn from the bulk dentine results should be regarded as tentative.

A detailed interpretation and discussion of the results follows in Chapter 5.

5. Discussion

A detailed interpretation of the results is presented below. The Broughton Lodge bulk collagen analyses are considered separately to the incremental dentine analyses, in terms of the distinct research aims outlined in Chapter 1.

The bulk collagen data is first of all discussed in terms of the potential dietary sources it reflects, based on previous dietary research, and is then considered in a wider geographical context alongside published research pertaining to Anglo-Saxon period dietary investigations. Where possible, preliminary interpretations are made of the social implications of the dataset, with respect to case studies drawn from Anglo-Saxon sites in England. A discussion of the results from the two incremental dentine analyses will follow. It should be noted that due to the small sample size obtained from the Broughton Lodge cemetery population, all observations are preliminary at this stage, and further research is needed for confirmation.

The General Diet of the Broughton Lodge Population

The dentine and bone collagen samples produced mean $\delta^{13}C$ values of -21.1±1.3‰ and -20.3±0.4‰ respectively, and narrow ranges of -21.9±0.95 to -20.3±0.78‰ from dentine and -20.6±0.1 to -20.2±0.14‰ from bone collagen. A cursory examination of these results in Chapter 4 has shown that the $\delta^{13}C$ values reflect a mainly terrestrial diet, derived ultimately from C3 plants and their consumers. Diets composed exclusively terrestrial animal protein sources generally display mean $\delta^{13}C$ values of around -21.5 to -20‰, depending on the type and amount of protein consumed, whilst a fully marine diet could be expected to fall within a range of -14 to -10‰, with a mean value of around -12‰ (Bender 1971, 1239; Bevan and Mays 2013, 116-128; Hemer *et al*. 2016, 434; Richards *et al*. 2006, 123; Schoeninger and DeNiro 1984, 635). A combination of foods derived from both environments would therefore place the mean $\delta^{13}C$ values at some point between -21.5‰ and -12‰, the isotope ratio determined by the relative proportions of protein from each environment (Beavan

and Mays 2013, 116). The lower limits of both Broughton Lodge $\delta^{13}C$ ranges extend beyond the -21.5‰ suggested as the end value for purely terrestrial diets, which may reflect consumption of freshwater resources, discussed below (Müldner and Richards 2005, 45). It should be noted that the relationship between marine and terrestrial protein $\delta^{13}C$ values in human collagen is not yet completely understood, and debate is ongoing over the appropriate endpoints for a terrestrial to marine range (Chisholm *et al*. 1983, 396; Beavan and Mays 2013, 116; Richards and Hedges 1999, 719).

The $\delta^{15}N$ values obtained from the Broughton Lodge bulk collagen also appear to reflect a predominantly terrestrial diet, with no marine component evident. The samples produced $\delta^{15}N$ ranges of 10.4±0.07 to 11.3±0.05‰ from dentine collagen and 9.8±0.01 to 11.1±0.12‰ from bone, with means of 10.8±0.7‰ and 10.6±0.8‰ respectively. Human diets with a marine component should result in $\delta^{15}N$ values of between around 12‰ and 22‰, depending on the trophic level of the dietary protein consumed (Ambrose and DeNiro 1986, 321; DeNiro and Epstein 1981, 347-350; Minagawa and Wada 1984, 1140). The narrow range of $\delta^{13}C$ and $\delta^{15}N$ values obtained from both sets of samples suggests little variation in basic protein sources between individuals, although differences in the amounts of each protein source consumed may be reflected in the slight fluctuations between values. Furthermore, no meaningful difference in broad protein sources (e.g. animal vs plant protein) in childhood and adult diets could be discerned.

Trophic level enrichment of ^{13}C and ^{15}N from dietary source to consumer means that to achieve an accurate dietary interpretation for a sample human population, human stable isotope ratios should be examined relative to those of a food source 'baseline'. $\delta^{13}C$ and $\delta^{15}N$ values analysed from plant and faunal remains, as representative of potential food sources, are utilised to this end. Ideally, the faunal data should be obtained from the same archaeological contexts from which the human samples derive, as plant and animal isotope ratios can vary considerably across time periods, geographical location, and environment (Müldner and Richards 2007, 684). Fish and sheep values from the multiperiod site at Newark Bay in Orkney, for example, are noticeably elevated compared to the rest of the UK (Richards *et al*. 2006, 124-125).

The anomalies were attributed to the 'sea spray effect', whereby marine nitrogen is absorbed by terrestrial plants growing near the coast, and passed on to consumers (Richards *et al* 2006, 125). δ^{15}N values of Bronze Age sheep, goat and cattle bone collagen from salt marsh areas, for example the Severn Estuary, have also been shown to differ significantly compared to other faunal datasets in the UK (Britton *et al* 2008, 2117). Human agency can also give rise to variations in plant and animal isotope ratios. Fertilizing crops with manure, for example, can result in elevated δ^{15}N values in cereal grains and chaff, and differing techniques in animal husbandry have been put forward as an explanation for elevated δ^{15}N values in Roman period cattle and pigs (Bogaard *et al*. 2007, 335; Lightfoot *et al*. 2009, 320; Müldner and Richards 2007, 684).

Faunal remains from Broughton Lodge were not analysed here; it was not within the scope of the project and in any case, very few are available for study. The archived assemblage consists only of the fragmentary remains of four horses and one sheep, excavated from five burials. It was instead deemed sufficient to use published faunal data from archaeological sites in England, as per previous research (e.g. Beavan-Athfield and Mays 2009; O'Connell and Wilson 2011).

Baseline faunal data should include values for all types of protein source available to the human population under study. Given the temporal and geographical variation in plant and animal isotope signals, only published values from Anglo-Saxon contexts in England have been used here. The data included are limited in volume, and derive from locations some distance from the Broughton Lodge site. As such they may not provide a wholly accurate food source baseline for Broughton Lodge, and any observations made should remain preliminary until suitable faunal data from the East Midlands is forthcoming. The locations of each site which provided faunal data are shown in Figure 5.1, and range and mean values for each analysed species are presented below in Table 5.1**.** A detailed summary of the faunal data is presented in Appendix 3: Table 1.

Figure 5.1: Location map of archaeological sites from which faunal data included in this analysis has been published. Broughton Lodge shown for reference

Species	No. of Samples	Range $\delta^{13}C_{VPDB}$ (‰)		Mean $\delta^{13}C_{VPDB}$ (‰)	Range $\delta^{15}N_{AIR}$ (‰)		Mean $\delta^{15}N_{AIR}$ (‰)
		Lower	Upper		Lower	Upper	
Cow	16	-23.0	-21.3	-21.9	1.4	9.1	5.7
Sheep / goat	14	-23.1	-21.1	-21.8	4.4	9.5	6.5
Horse	3	-22.4	-22.3	-22.4	5.0	5.5	5.2
Pig	14	-22.0	-20.9	-21.5	5.9	12.7	7.3
Domestic fowl	3	-21.1	-19.7	-20.4	9.9	12.4	10.8
Carp	1	-23.6	-23.6	-23.6	11.0	11.0	11.0
Eel	2	-25.0	-24.5	-24.8	8.8	9.0	8.5
Herring	1	-15.2	-15.2	-15.2	11.0	11.0	11.0
Pike	1	-22.7	-22.7	-22.7	12.5	12.5	12.5
Dog	2	-20.6	-20.0	-20.7	8.1	11.4	9.8
Fox	3	-21.6	-21.1	-21.4	9.0	10.0	9.4

Table 5.1: Baseline faunal data from Anglo-Saxon archaeological sites in England

Based on a model developed by Beavan-Athfield and Mays (2009), the faunal data have been used to construct a basic illustrative box chart showing the potential $\delta^{13}C$ and $\delta^{15}N$ values expected in human collagen according to protein source. Each box represents the range of $\delta^{13}C$ and $\delta^{15}N$ values expected in humans consuming primarily terrestrial vegetation, terrestrial animal, freshwater and marine protein (Figure 5.2). Published values from cattle, sheep and goats, pigs and domestic fowl represent terrestrial animal protein; herring is taken as marine protein, carp and pike as freshwater protein, and eel comprises its own category. Enrichment factors of 1‰ for $\delta^{13}C$ and 4‰ for $\delta^{15}N$ have been applied to all but the terrestrial vegetation ranges to account for the trophic level effect observed between food source and consumer, as per Beavan-Athfield and Mays (2009), and Beavan and Mays (2011 and 2013) (DeNiro and Epstein 1978b, 495; Hedges and Reynard 2007, 1241; Jay and Richards 2006, 655; Richards *et al*. 2002, 205).

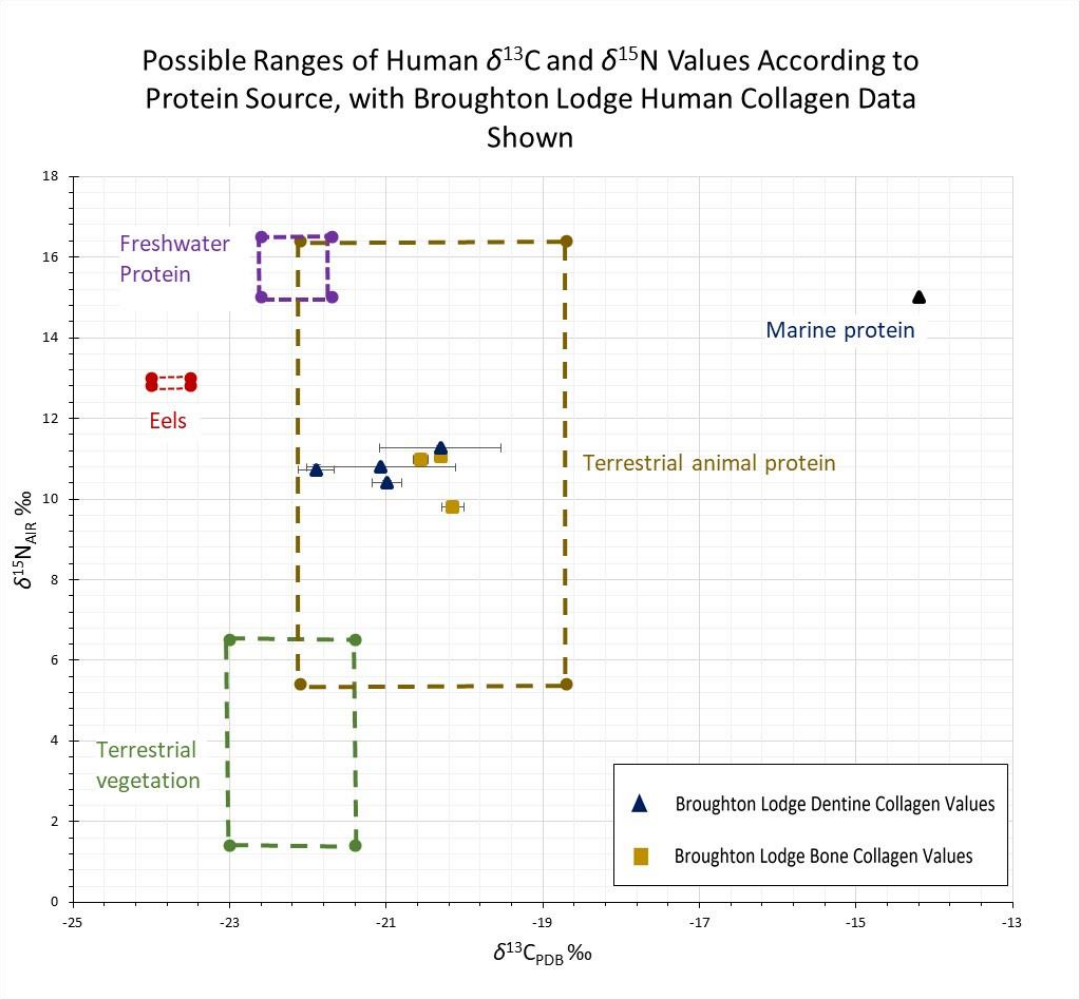

Figure 5.2: Box chart showing possible indicative ranges of $\delta^{13}C$ and $\delta^{15}N$ for human bone collagen based on protein source with Broughton Lodge data shown. 2σ shown as error bars for Broughton Lodge samples. Faunal data from MacPherson (2005), Müldner and Richards (2007), O'Connell and Lawler (2009) and Privat *et al*. (2002)

Data from cattle are used as a proxy measure for vegetarian humans, as per previous research (Beavan-Athfield and Mays 2009; Beavan and Mays 2011 & 2013). Cattle data obtained from West Halton, North Lincolnshire have been excluded, as they produced unusually high $\delta^{15}N$ values for herbivore species (up to 9.1‰). This was explained in terms of West Halton's proximity to the Humber Estuary, where cattle may have fed on seaweed or other marine plants (MacPherson 2005, 146). The elevated values may also result from the sea spray effect, noted at Newark Bay (Richards *et al*. 2006, 123). In any case, the West Halton data are not reflective of the isotope profile usually displayed by cattle.

The chart should be taken as a very tentative indicator of potential isotope ratios for human bone collagen, for the reasons noted above. Freshwater protein and eel were rare within the faunal datasets used, and as such provide only a very small potential range for corresponding human bone collagen values. A single sample represents marine protein, and can only be depicted as a point on the chart; this is likely to be less of an issue regarding the Broughton Lodge dietary interpretations, given the lack of any marine signal from the material analysed. In addition, the use of cattle as a proxy for human vegetarian consumers is problematic, as it has not been conclusively shown that the plant protein sources available to humans would have had the same isotopic signal as those available to herbivorous animals. There is some evidence, for example, that wheat is enriched in ^{15}N over forage by 1 to 1.5‰, which could be systematic or due to human intervention such as fertilisation of crops with manure (Hedges and Reynard 2007, 1245).

Figure 5.2 indicates that the $\delta^{13}C$ and $\delta^{15}N$ values for dentine and bone collagen are significantly enriched above the terrestrial vegetation range, and are well within the range for terrestrial animal protein. This suggests the diet of the Broughton Lodge sample population was composed primarily of animal protein, consumed on a regular basis (Privat and O'Connell 2002, 785). The $\delta^{13}C$ signals suggest some complexity in diet, specifically different types of animal protein derived from various trophic levels (Beavan and Mays 2011, 765). Whilst protein types from a single animal species cannot be distinguished from one another, it is possible to tentatively identify protein sources to species level.

Omnivore Protein

The Broughton Lodge $\delta^{15}N$ values may reflect the consumption of omnivore protein and freshwater fish. Mean $\delta^{15}N$ values for dentine and bone collagen are significantly enriched over the mean herbivore food source values in Table 5.1 (cattle and sheep/goat), of up to around 5‰, which exceeds the trophic level enrichment factor, suggesting that herbivores are not the only regularly consumed animal protein source (Privat and O'Connell 2002, 785). The consumption of omnivore protein is suggested as a possibility. Four omnivore species are represented in Table 5.1, marked by their trophic enrichment over the herbivore samples (West Halton cattle

samples notwithstanding): fox, dog, pig and domestic fowl, of which pig and fowl are likely to have been consumed by Anglo-Saxon populations (O'Connell and Wilson 2011, 118-121). Pigs would have been the most readily available omnivore protein source; bacon is given frequent mention in documentary sources, as are spit-roasting methods for pork (Hagen 1992, 41-60). Chicken features in various Anglo-Saxon recipes, and appears to have been a common food source for its meat and eggs (Hagen 1992, 59-60; 120-122).

The values for pigs in Table 5.1 display a considerable range, as some produced δ^{15}N values characteristic of herbivores, such as at Berinsfield and Bloodmoor Hill (O'Connell and Lawler 2011, 319; Privat and O'Connell 2002, 784). δ^{15}N values for pigs can therefore vary significantly, depending on the food sources available to them. To simplify a comparison regarding the Broughton Lodge samples, the fox, dog and domestic fowl values in Table 5.1 are taken as broadly characteristic of omnivorous animals, and their mean δ^{15}N values (between 9‰ and 11‰) indicate that a human consumer of omnivore protein may be expected to produce δ^{15}N values of between 12‰ and 14‰, given a 3‰ trophic level enrichment (O'Connell and Wilson 2011, 123). The highest δ^{15}N value from the Broughton Lodge samples was 11.3‰ (BLE104 dentine) reflecting an enrichment of around 2‰ over the lowest omnivore value, and around 1.4‰ over the lowest value recorded for domestic fowl, which suggests that omnivore protein may have featured in the diet, but was not necessarily a regular addition. Regarding δ^{13}C trophic level enrichment, two of the Broughton Lodge dentine samples (BLE66 and BLE104) are enriched relative to the pig sample from Berinsfield by up to 1.5‰, whilst three of the dentine samples (BLE48, BLE66 and BLE104) are enriched by 1-2‰ over domestic fowl sampled from Fishergate and Bloodmoor Hill. Pigs and domestic fowl may therefore have featured in the Broughton Lodge diet to some extent.

Freshwater Protein

A terrestrial δ^{15}C signal combined with high δ^{15}N values can indicate consumption of freshwater resources (Hemer *et al*. 2016, 343; Müldner and Richards 2005, 44). The δ^{15}N values from the Broughton Lodge samples are significantly lower than those of the freshwater fish and eels from the faunal baseline data used here (Figure 5.1), but as noted, very few freshwater resource data were available for inclusion. More samples are needed from Anglo-Saxon England, particularly from the East Midlands and Trent valley, to allow any meaningful assessment as to freshwater resource consumption at Broughton Lodge. O'Connell and Wilson (2011, 122) have suggested a δ^{15}N range for human collagen of 9-17‰ as reflective of the regular consumption of freshwater resources. If this can be taken as broadly indicative, then the Broughton Lodge samples may reflect a diet with some element of freshwater protein.

The fishbone assemblage from early Anglo-Saxon sites in England is dominated by freshwater and estuarine species, particularly at high-status sites (Beavan and Mays 2013, 130). Fish traps have been recovered from various Anglo-Saxon contexts in England, including an example dated to the 8th – 9th centuries from the River Trent at Colwick (Losco-Bradley and Salisbury 1998, 329-340). Given the overlap of δ^{15}N values in some freshwater resources with terrestrial animal protein however, defining the amounts of freshwater fish consumed, if any, are very difficult, and as noted, elevated δ^{15}N can result from a multitude of factors (Müldner and Richards 2005, 44; Schoeninger and DeNiro 1985, 632). All that can be observed from the Broughton Lodge data at this point is that there may have been some freshwater fish, eel and possibly wildfowl included in the diet, and given the site's location in the Trent valley, these would have been a readily available resource.

<u>The Wider Geographical Context</u>

The Broughton Lodge data were examined with respect to previous Anglo-Saxon dietary research from England. Published data are presented below alongside the Broughton Lodge data. Twenty-six datasets representing Anglo-Saxon period burials

from across England are considered below. A summary of the published data is presented in Appendix 3: Table 2**.** Most previous analyses have been carried out on bone collagen, with a small number carried out on dentine collagen as part of a wider investigation into weaning and childhood diet in Anglo-Saxon England (MacPherson 2005). The data for adult bone collagen and dentine collagen are presented separately, as they represent different ages for each individual. Only the adult rib collagen results from Broughton Lodge are discussed in this context, i.e. those from BLE103 and BLE104. BLE66 died at the age of 13, so the rib collagen has provided data from this individual's childhood, and as such is not directly comparable with adult data due to potential dietary differences dependant on age. Juvenile bone collagen data was not considered here as weaning signals could be confused with later childhood dietary values, within the averaged dietary profile provided by bone. Data obtained from the Broughton Lodge dentine collagen samples has instead been compared with MacPherson's data from M2 teeth, to allow defined age-based comparisons.

The data have been categorised by topographical location and by region, the former adopting the model used by Beavan and Mays (2013) and Mays and Beavan (2012), consisting of coastal, inland and riverine categories. Coastal sites are those which lie within 10km of a coastline, inland sites are located over 10km from a coastline, and riverine sites are those which are located within reasonable proximity of a major river (Mays and Beavan 2012, 869). Data additional to that assessed previously been included, to attempt a wider comparison of the datasets.

The locations of each site included are displayed in Figure 5.3, and mean $\delta^{13}C$ and $\delta^{15}N$ values from each dataset are displayed on Figures 5.4 and 5.7, with the Broughton Lodge data shown to aid categorisation. Range and mean values (Figures 5.5, 5.6, 5.8 and 5.9) are then presented separately for $\delta^{13}C$ and $\delta^{15}N$, to highlight the differences between each site, and to clarify any relationships which may be reflected in individual $\delta^{13}C$ and $\delta^{15}N$ datasets. In several cases it was not possible to obtain standard deviation values, therefore none have been reported for sites other than Broughton Lodge, and then only on the Figure 5.4 and 5.9. Sites represented by

a single red line on the $\delta^{13}C$ and $\delta^{15}N$ range charts are those from which only one sample was analysed.

Figure 5.3: Location map of archaeological sites from which human data has been derived for this study. Broughton Lodge shown for reference

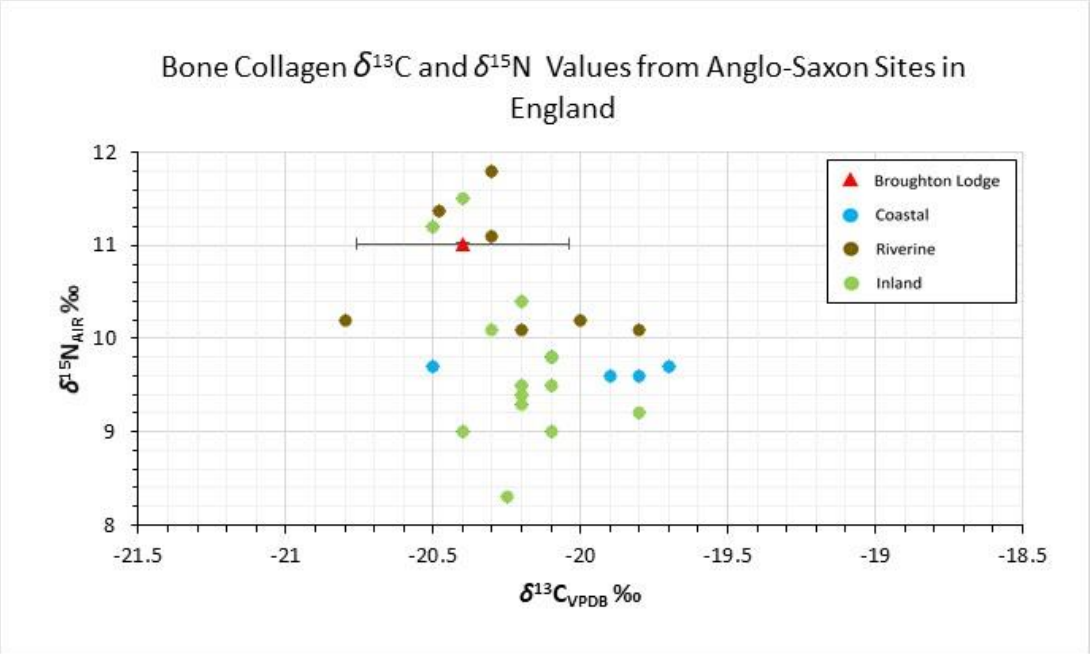

Figure 5.4: Mean $\delta^{13}C$ and $\delta^{15}N$ values obtained from bulk bone collagen analyses at Anglo-Saxon sites across England, organised by topographical location. 2σ shown for Broughton Lodge as vertical and horizontal error bars

The Broughton Lodge data lies within the broad area of the riverine sites plotted (Figure 5.4), which could be expected given its proximity to the River Trent, a major waterway (around 14km from the site). It should be kept in mind that the Broughton Lodge data is comprised of only two samples, both adult males from a double weapon burial, which may allude to a differential dietary status over the wider cemetery population, discussed below. However limited, the Broughton Lodge data reflects isotope values similar to the other riverine sites, which strengthens the argument for at least some consumption of freshwater resources. The site is henceforth classified as riverine, and will be discussed in this capacity below.

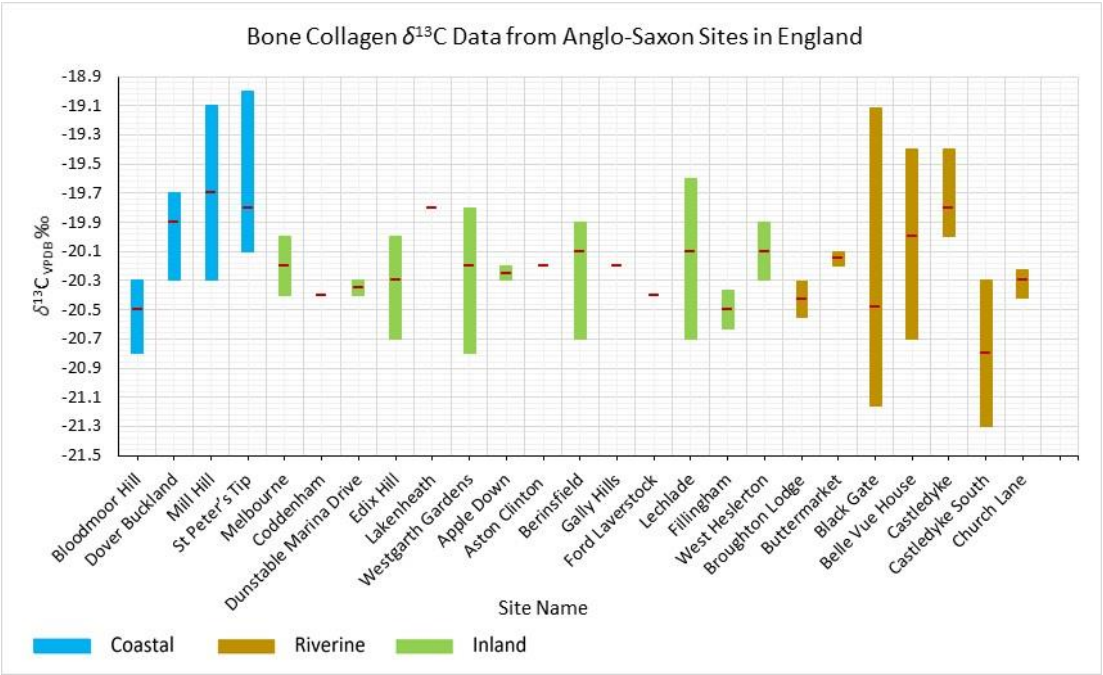

Figure 5.5: Ranges of $\delta^{13}C$ values from Anglo-Saxon sites in England, organised according to topographical group

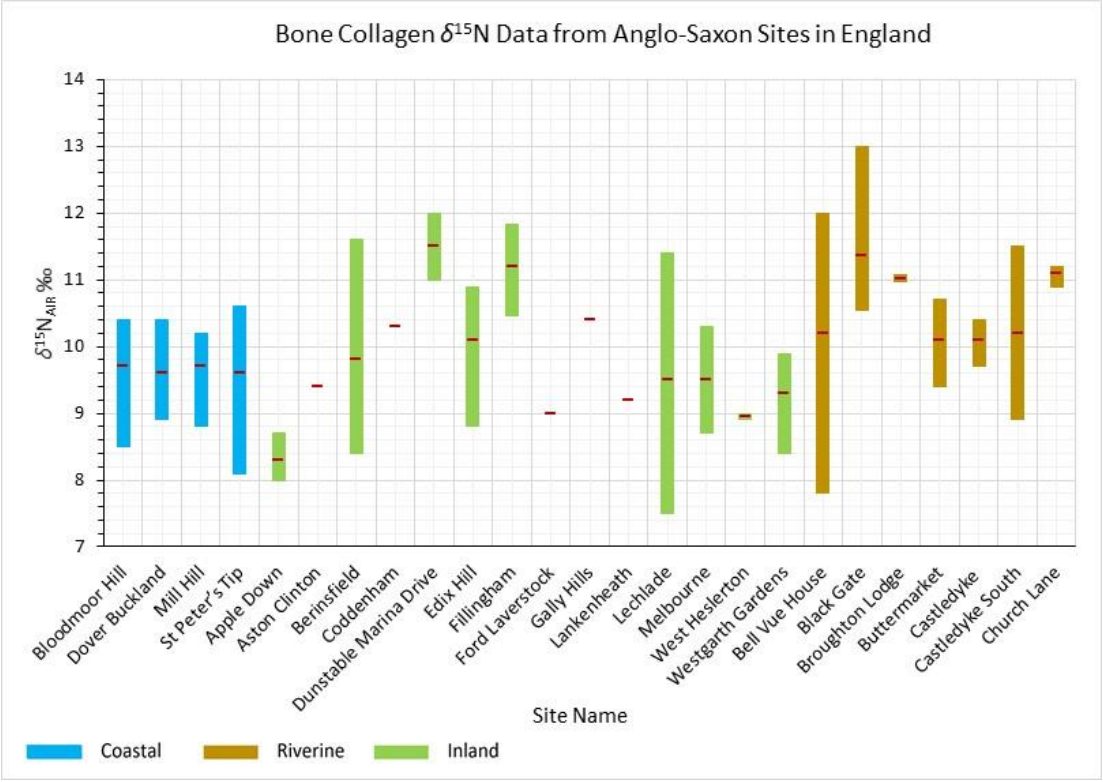

Figure 5.6: Ranges of δ^{15}N values from Anglo-Saxon sites in England, organised according to topographical group

The data display a relatively wide variation in δ^{13}C values (Figure 5.5) which suggests variation in the dietary resources available to each population. They all exhibit a strong terrestrial signal, which is interesting given the inclusion of four coastal sites. The coastal sites do show less negative δ^{13}C values than the inland and riverine sites, suggesting perhaps some degree of marine consumption, but overall the data indicate that during the Anglo-Saxon period marine resources were not being exploited to a large degree even along the coastlines. Elevated δ^{13}C values from marine protein consumption should be accompanied by elevated δ^{15}N values (Figure 5.2), which is not the case here.

The consumption of marine resources in Anglo-Saxon England is largely invisible archaeologically; high-status sites such as Hartlepool have produced evidence of cod fishing during the late 7th to 8th centuries, but for the most part, fishbone assemblages are dominated by freshwater and estuarine species such as carp, eel, and less frequently, dolphin (at Flixborough, for example) (Jacques *et al* 2007, 49). Barrett *et al*. (2004, 2419-2420) have suggested that an expansion of the marine fishing industry took place on a large scale from around 1000AD in response to severe depletion of freshwater fish stocks, prior to which, most aquatic resources may have derived from freshwater environments (Beavan and Mays 2013, 131). Several investigations into later Anglo-Saxon and medieval diet have identified an increase in marine resource consumption from around the 9th century onwards, perhaps extending the date for a marine fishing expansion back by up to two centuries (e.g. Beavan *et al*. 2011; Müldner and Richards 2005; Müldner and Richards 2007). The four coastal sites included here date to the 6th to mid-10th centuries (Appendix 3: Table 2), and the isotope data obtained from each seems to accord with the scenario presented by the archaeological evidence.

The riverine sites display elevated δ^{15}N values (>10‰), whilst the coastal sites display lower δ^{15}N values (<10‰), with little variation across the latter four. Elevated δ^{15}N values

combined with a terrestrial $\delta^{13}C$ signal can result from the consumption of freshwater resources, and the $\delta^{15}N$ values plotted here may serve to separate a 'riverine' diet with elements of freshwater fish and eels for example, from a 'coastal' diet based primarily on terrestrial animal protein. Data from the coastal sites suggests a diet based on terrestrial animal protein, which appears to have been drawn from a single trophic level.

The inland sites exhibit a wide variation in $\delta^{15}N$ values (by around 4‰), which alludes to dietary variation across this group, most notably, resources at successive trophic levels such as herbivore and omnivore protein, and differing amounts of each. Elevated $\delta^{15}N$ values at inland sites are likely to reflect consumption of omnivore protein (pig and chicken, for example); it is very possible that the inland sites had access to freshwater resources as well, but confirmation of this would require scrutiny of the archaeological remains and any documentary sources pertaining to each site.

Categorisation of the data by region provided no significant correlations, as shown in Figures 5.7 to 5.9 below.

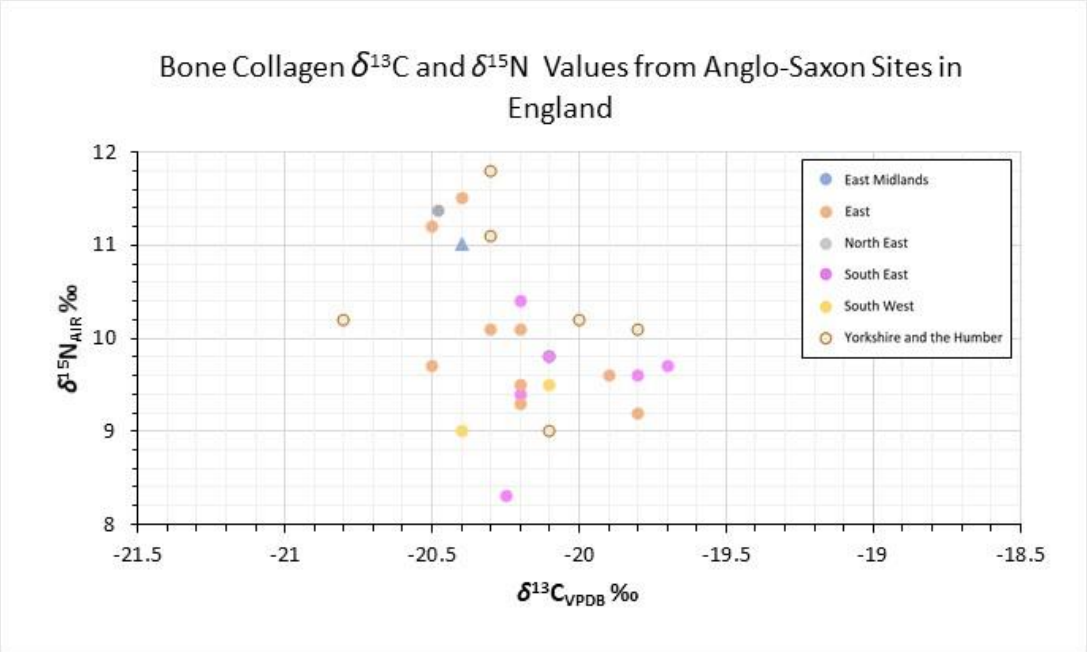

Figure 5.7: Mean $\delta^{13}C$ and $\delta^{15}N$ values obtained from bulk bone collagen analyses at Anglo-Saxon sites across England, organised according to region. 2σ not shown for Broughton Lodge as chart is illustrative only

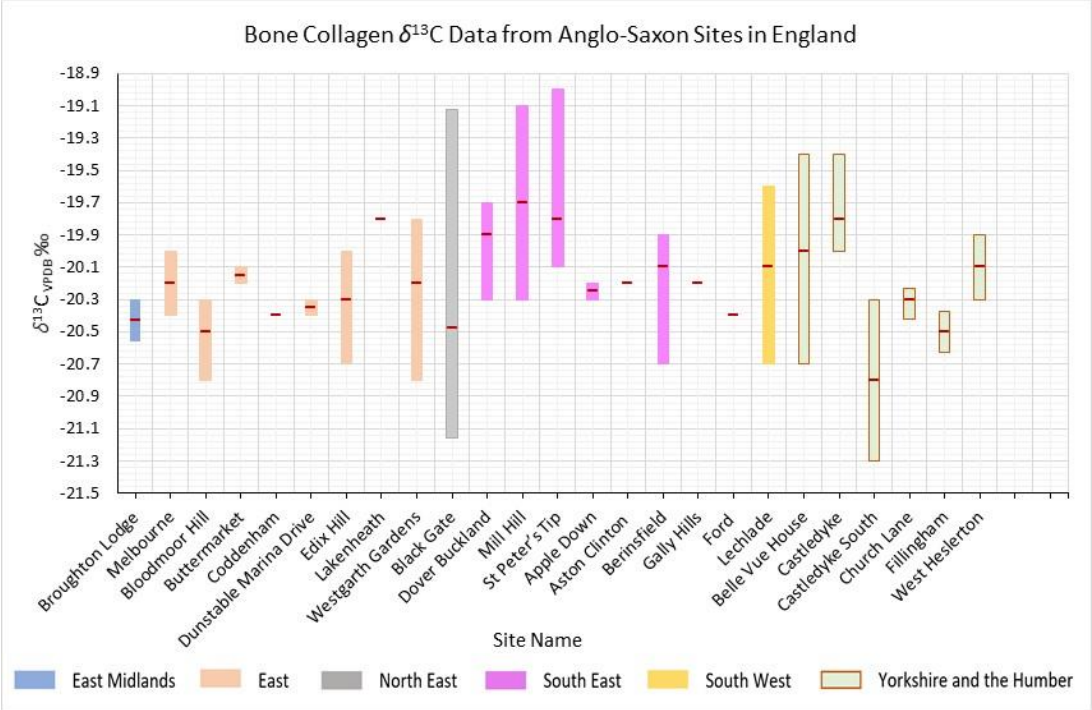

Figure 5.8: Ranges of δ^{13}C values from Anglo-Saxon sites in England, organised according to region

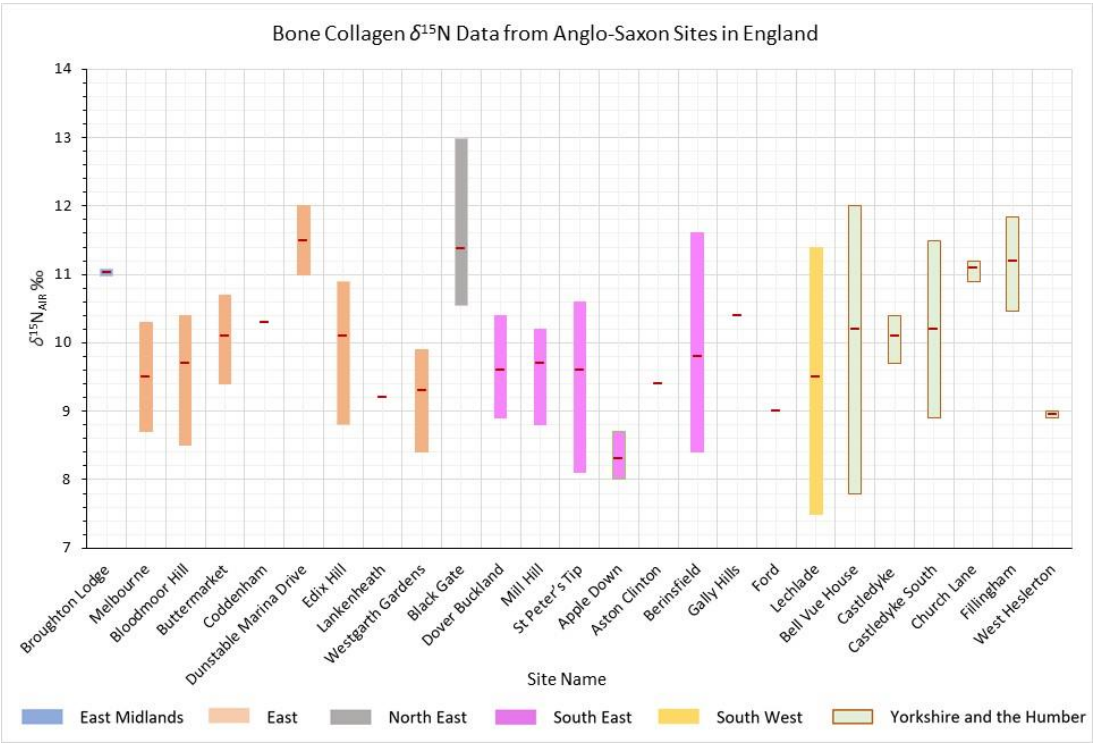

Figure 5.9: Ranges of δ^{15}N values from Anglo-Saxon sites in England, organised according to region

The obvious issue with the above representations is the lack of any comparable data for the Broughton Lodge site, thus far the only skeletal assemblage in the East Midlands which has been subject to adult bone collagen sampling for isotope analysis. In any case, the regional categorisation has not highlighted any strong correlations between sites, and any which do exist have found a more meaningful interpretation in terms of topographical location. It would seem then that a regional categorisation is not particularly useful here, other than confirming that variations in diet for Anglo-Saxon populations are to some extent dependent on topographical location, and by implication proximity to available resources, which is by no means a revelation.

There was no significant relationship identified across sites or topographical location from M2 and P2 crown dentine (reflecting ages of approximately 2.5 years to 8.5 years; see Chapter 3; Table 2.3) due in part to the small sample sizes (Appendix 3: Table 2). The data are plotted below in Figures 5.9 to 5.11.

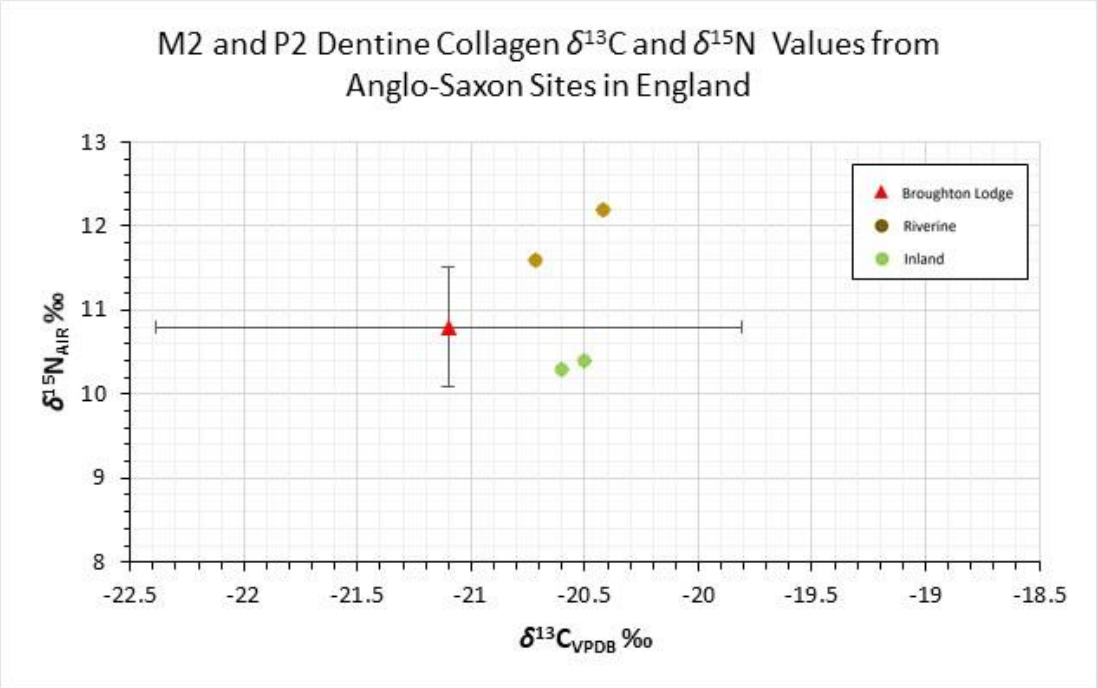

Figure 5.9: Mean $\delta^{13}C$ and $\delta^{15}N$ values obtained from M2 and P2 bulk dentine collagen analyses at Anglo-Saxon sites in England, organised according to topographical group. 2σ shown for Broughton Lodge as vertical and horizontal error bars

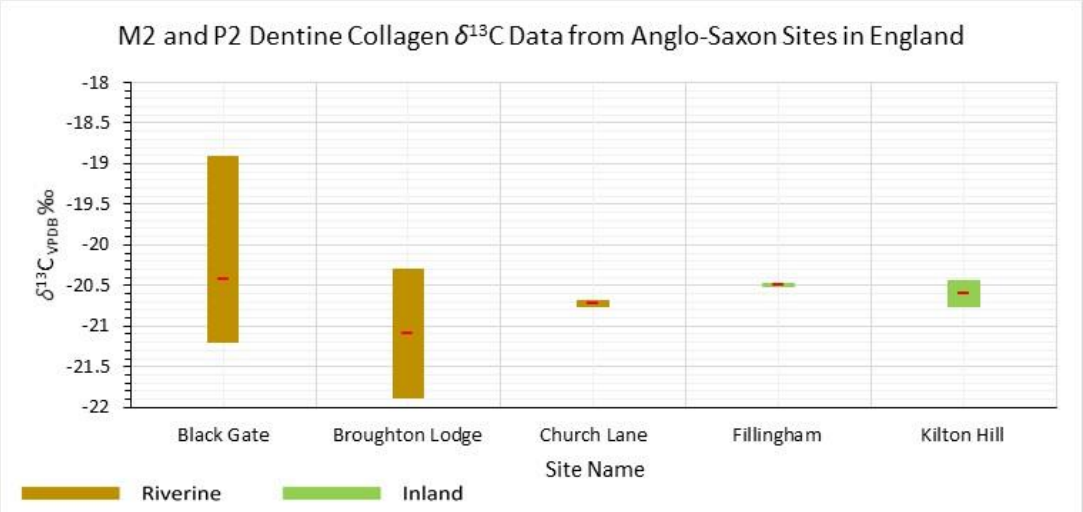

Figure 5.10: Ranges of $\delta^{13}C$ values obtained from M2 and P2 bulk dentine collagen analyses at Anglo-Saxon sites in England, organised according to topographical group

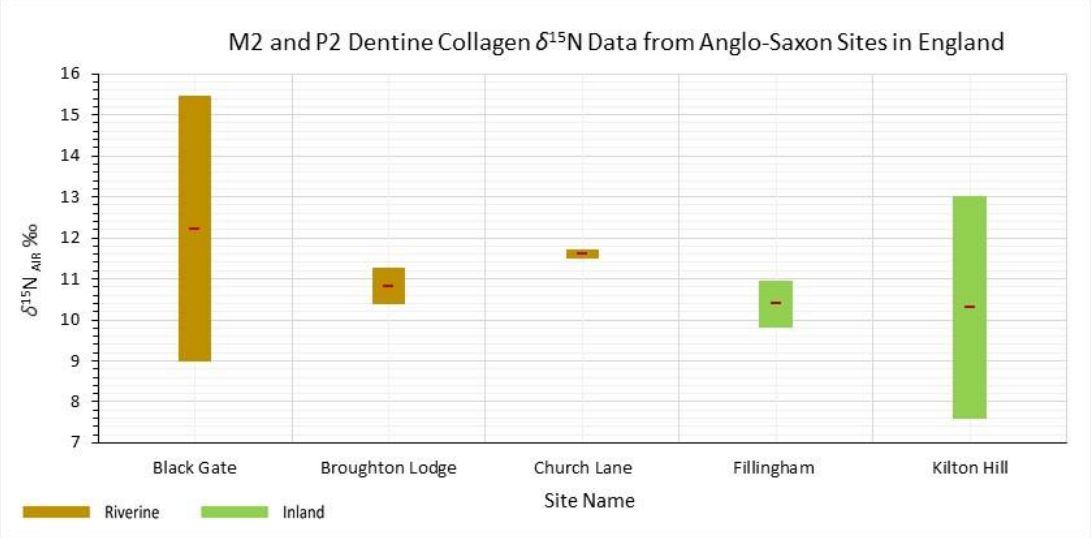

Figure 5.11: Ranges of $\delta^{15}N$ values obtained from M2 and P2 bulk dentine collagen analyses at Anglo-Saxon sites in England, organised according to topographical group

All four comparison sites display slightly elevated $\delta^{13}C$ values compared to Broughton Lodge (up to 0.6‰), but the difference is not such that any significant dietary differences can be inferred. All sites display a terrestrial $\delta^{13}C$ signal, reflecting a diet based largely on terrestrial animal protein. There is a much wider variation in $\delta^{13}C$ values from Black Gate and Broughton Lodge compared with the remainder of the sites, but this is

influenced by the sample sizes; only two samples were analysed from Chuch Lane, Fillingham and Kilton Hill.

Both riverine sites display elevated δ^{15}N values compared to the inland sites, which could be expected as per the discussion above; these may reflect some consumption of freshwater resources. δ^{15}N values for the inland sites are elevated to a degree such that consumption of omnivore protein or freshwater resources could be reflected, although at lower levels than at the riverine sites. There is wider variation in δ^{15}N values across all sites compared to δ^{13}C values, which is not surprising given the range of factors that influence δ^{15}N values. There is a difference in δ^{15}N values of around 2‰ between the highest and lowest δ^{15}N values, which may suggest a trophic level-related difference, although were animals from higher trophic levels being consumed at the riverine sites, they were consumed in small enough quantities to obscure a full trophic level enrichment. The values from Kilton Hill and Black Gate show a much wider range of δ^{15}N values than data from the other three sites (5-6‰ for both), which could reflect a significant dietary difference between individuals at the lower end and the upper end of the ranges. A closer examination of the individuals reflected by these isotope profiles could yield some interesting observations regarding gender or status, for example. In this instance the small sample size from Kilton Hill isn't sufficient to draw conclusions on the wider population, but is it interesting that such a large difference exists between two juvenile individuals from the same skeletal assemblage. There is the possibility that given the age of individuals reflected by these results that the values have been influenced by weaning signals, or nutritional stress resulting in elevated δ^{15}N values (Fuller *et al*. 2005).

Social Influence in Dietary Variation

The small sample size from Broughton Lodge doesn't permit any meaningful assessment of diet in terms of social or biological factors such as age, gender roles, wealth and status, etc. Preliminary observations can however be made, in the context of published studies from the UK.

Age

The Broughton lodge dentine and bone collagen data are plotted below on Figure 5.12, annotated with the sex and age of each individual represented by the samples.

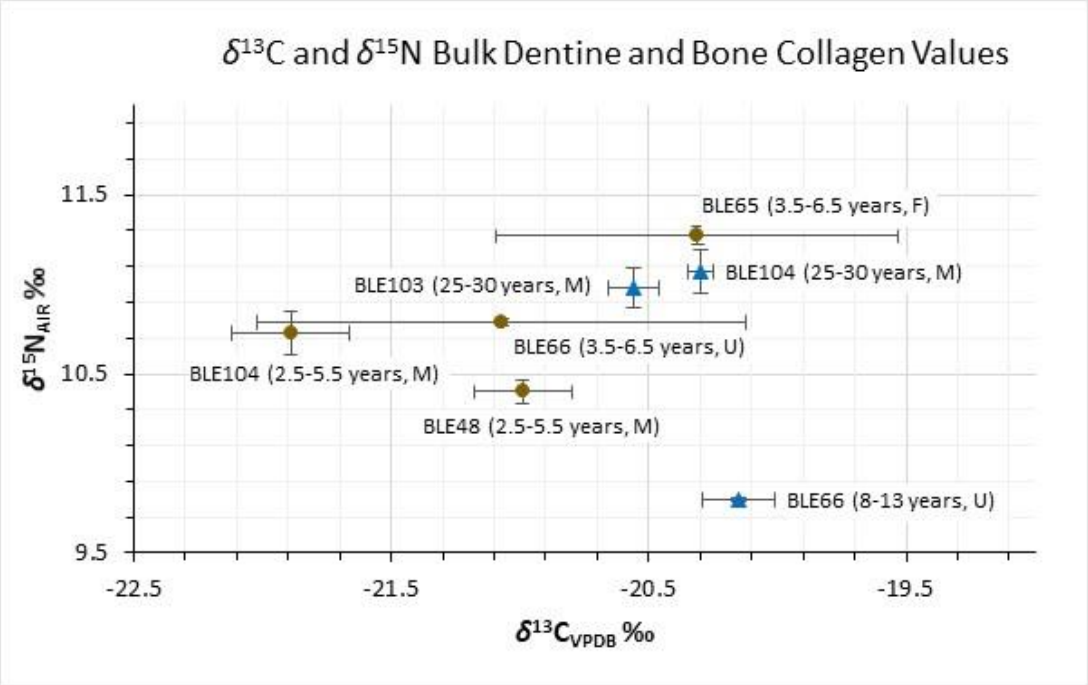

Figure 5.12: $\delta^{13}C$ and $\delta^{15}N$ values from Broughton Lodge bone and dentine collagen samples, with ages represented by each sample shown. Sex of each individual shown, where M = Male, F = Female and U = Unsexed. 2σ shown as error bars

There is no clear distinction between adults and juveniles in the Broughton Lodge sample, although it must be kept in mind that whilst direct comparisons of bone and dentine collagen values are valid, they should be made tentatively, due to the uncertainty surrounding bone collagen turnover times (A. Lamb, pers. comm.; Lamb *et al*. 2014, 560). If the 2σ values are considered, the range of $\delta^{13}C$ values encompasses around 2‰, but as shown on Figure 5.12, both adult and juvenile values extend across this range. Similarly, the extent of $\delta^{15}N$ values encompasses adults and juveniles, although it is interesting to note that the lowest $\delta^{15}N$ value, that of BLE66, is separated from the rest of the group by the largest margin, of around 0.6‰. Although not a large enough separation to suggest significant dietary differences, it is notable that this individual did not survive past 13 years of age. The dentine values for BLE66 show a drop in $\delta^{15}N$ compared to the bone collagen values, thereby indicating a decrease in $\delta^{15}N$ from the ages of 6.5 to approximately 13 years. If this were linked to general offsets in values between bone and dentine collagen, a similar decrease in $\delta^{15}N$ values from BLE104 might also be expected, which is not the

case. No pathologies have been recorded for BLE66 so an assessment of their general health is not possible, but it is tempting to suggest that their lower δ^{15}N value may in some way be linked to their early death. The obvious outlier in the dentine collagen group is BLE65, whose δ^{15}N values are elevated above the other samples. The elevated δ^{15}N level may reflect a weaning signal or nutritional stress in this individual, or could be related to perceived wealth and status.

Several previous studies have identified age-related variation in isotope profiles which can in turn be linked tentatively to gender roles and status. At Berinsfield in Oxfordshire a statistically significant relationship was found between δ^{15}N values and male adults over 30 (Privat and O'Connell 2002, 786). A similar relationship was noted by Beavan and Mays (2013, 128) who found that across a sample of seventy-six adults, males aged 30-49 were enriched in ^{15}N compared to males aged 18-29. At Butlers Field, Lechlade, males aged 30-35 years displayed elevated δ^{15}N values compared to older and younger males (O'Connell and Wilson 2011, 124). The correlation has been explained in terms of a possible age threshold occurring at 30 years of age, and at Lechlade, δ^{15}N values appeared to decline in older males, inferring that the increased status was temporary.

A number of age thresholds have been identified in Anglo-Saxon society, primarily from documentary sources; extant law codes for example suggest that 10 years old marks the age of inheritance and criminal responsibility (Härke 1997, 126). At Berinsfield, Härke identified distinct age groups with respect to weapon burials, observing that all male adults that had been buried with weapons were between 20 and 30 years of age, whilst all but two males buried without weapons were aged 30 or over (Härke 1995, 69).

The two male adult samples from Broughton Lodge do display elevated δ^{15}N values, but in the absence of any other data from adult males of varying ages, it isn't possible to confirm a relationship similar to that observed at Berinsfield. It is notable however that the two males were buried together in a double burial, with spears and at least one shield, covered with a layer of stones (Chapter 3: Table 3.1**;** Kinsley 1993, 50). The BLE103 and BLE104 double burial may reflect this age and status-related, gender-specific threshold, expressed in their relative isotope profiles as an increase in dietary

protein from sources enriched in ^{15}N, for example omnivore or freshwater protein (Beavan and Mays 2013, 128; O'Connell and Wilson 2011, 125). This is reflected at Lechlade, where elevated $\delta^{15}N$ values in 30-35-year-old males has been interpreted as increased consumption of freshwater fish (O'Connell and Wilson 2011, 125-127). At Berinsfield, an inverse relationship was observed, whereby males buried with weapons exhibited lower $\delta^{15}N$ values than those without (Privat and O'Connell 2002, 786). If weapon burials are conflated with higher status, it may be that the less wealthy members of society at Berinsfield were consuming more 'lower status' foods that produce higher $\delta^{15}N$ values, i.e. wild resources such as freshwater protein, whilst the wealthy were consuming more labour intensive, domesticated omnivores and dairy products (Privat and O'Connell 2002, 786). At Lechlade however, it seems to have been the higher status males consuming freshwater fish, whilst the less wealthy individuals relied largely on herbivore meat (O'Connell and Wilson 2011, 125).

Wealth and Status

To examine relative wealth and by implication, status, from burial morphology, the burials from Berinsfield were separated into wealth categories based on the number of grave goods present (Boyle and Dodd 1995, 127-133). Privat and O'Connell later identified a possible distinction between diet and grave wealth, whereby individuals with few or no grave goods placed in 'poor' category had elevated $\delta^{15}N$ values over the 'intermediate' and 'wealthy' individuals, or those with increasing numbers of grave good types (Privat and O'Connell 2002, 786). If a similar, albeit more rudimentary approach is taken with the Broughton Lodge burials, it can be observed that those with the highest number of grave goods ('wealthy' burials), BLE65, BLE103 and BLE104 exhibit elevated $\delta^{13}C$ and $\delta^{15}N$ values compared to the rest of the group (Figure 5.12; Chapter 3: Table 3.1). Two of these, BLE103 and BLE104 constitute weapon burials, and should perhaps be considered a distinct category, but BLE65, a 30-35-year-old female, was buried with the highest number of grave goods of all six burials sampled, and exhibits childhood $\delta^{15}N$ values which are elevated above the rest of the samples. The 'poorest' burial from the sampled group, BLE48, a 40-year-old male buried with a knife and fragments of animal bone, exhibits the lowest $\delta^{15}N$ values from the childhood sample group, and the lowest but one from the entire group; only BLE66 showed lower $\delta^{15}N$ values. It can be tentatively suggested that 'wealthy' individuals were consuming more protein from higher trophic levels, or perhaps freshwater resources, than 'poor' individuals.

The limitations and subjectivity of such assessments of wealth and status have been widely criticised (e.g. Parker Pearson 1999), and as such, categorisations of wealth from grave goods should be adopted with caution.

Gender

There is only one female sample from Broughton Lodge, therefore even a cursory assessment of gender-based differences in diet is not possible at this stage. Previous studies have not identified any significant relationships between $\delta^{13}C$ and $\delta^{15}N$ profiles and biological sex (for example, Beavan and Mays 2011, O'Connell and Lawler 2009, O'Connell and Wilson 2011, Privat and O'Connell 2002)**.** A distinction between male and female burials is evident from grave good assemblages however, and a lower life expectancy for Anglo-Saxon women compared to men has been noted (Boyle and Dodd 1995, 131; Brothwell 1972, 83; Härke 1997, 73)**.** The latter could potentially be linked to differential access to food, and there are various dietary differences that cannot be isolated by stable isotope analysis alone, for example, different products from the same species (i.e. meat versus dairy from cattle), and the quality of the food consumed (Eerkens and Bartelink 2013, 480; O'Connell and Lawler 2009, 320; O'Connell and Wilson 2011, 123).

Breast-feeding and Weaning at Broughton Lodge

Initial examination of the results from the incremental analysis of M1 dentine collagen from two of the Broughton Lodge individuals, BLE26 and BLE66 concluded that no coherent weaning signal could be identified from either. In terms of general diet, the $\delta^{13}C$ values across both isotope profiles reflect a very similar diet to those of the older childhood and adult bulk dentine and bone samples, i.e. terrestrial protein based on C3 plants and their consumers. The lack of any female adult $\delta^{13}C$ and $\delta^{15}N$ comparison data from the cemetery population has hindered a meaningful interpretation of the incremental dentine data, but even so, the 'trophic level' decrease in $\delta^{15}N$ values which could be expected following cessation of breast-feeding, is absent from both M1 isotope profiles. This may not however preclude the presence of a weaning signal.

Due to the numerous non-dietary factors which influence the preferential incorporation of ^{15}N into body tissues, $\delta^{13}C$ values have been suggested as a more accurate tracer of breastfeeding and weaning (Beaumont *et al*. 2015, 453). $\delta^{13}C$ values can be observed to increase by around 1‰ over the weaning period before settling at typical adult levels

following cessation of weaning, reflecting the gradual introduction of low protein supplementary foods (Dupras and Tocheri 2007, 70 – 72; Fuller *et al*. 2003, 1673; Fuller *et al*. 2006, 279; Haydock *et al*. 2013, 604; Richards *et al*. 2002, 207 – 209). This can be observed to a certain extent from the profiles of both BLE26 and BLE66; BLE26 experiences a decrease in δ^{13}C values of around 0.7‰ from 0-8 years old, whilst BLE66 shows an overall decrease of around 0.5‰ from 0-7 years old (Chapter 4: Figure 4.10). Although the increase in both is less than the 1‰ which should be expected, there is a definite impression of the introduction of foods other than maternal milk, most likely terrestrial C3 plant-based foods.

Previous methodologies, based primarily on bone collagen analyses, held that a breastfeeding and weaning profile should display a regular decrease in δ^{15}N values from the beginning to the end of the weaning period, as shown below in Figure 5.13.

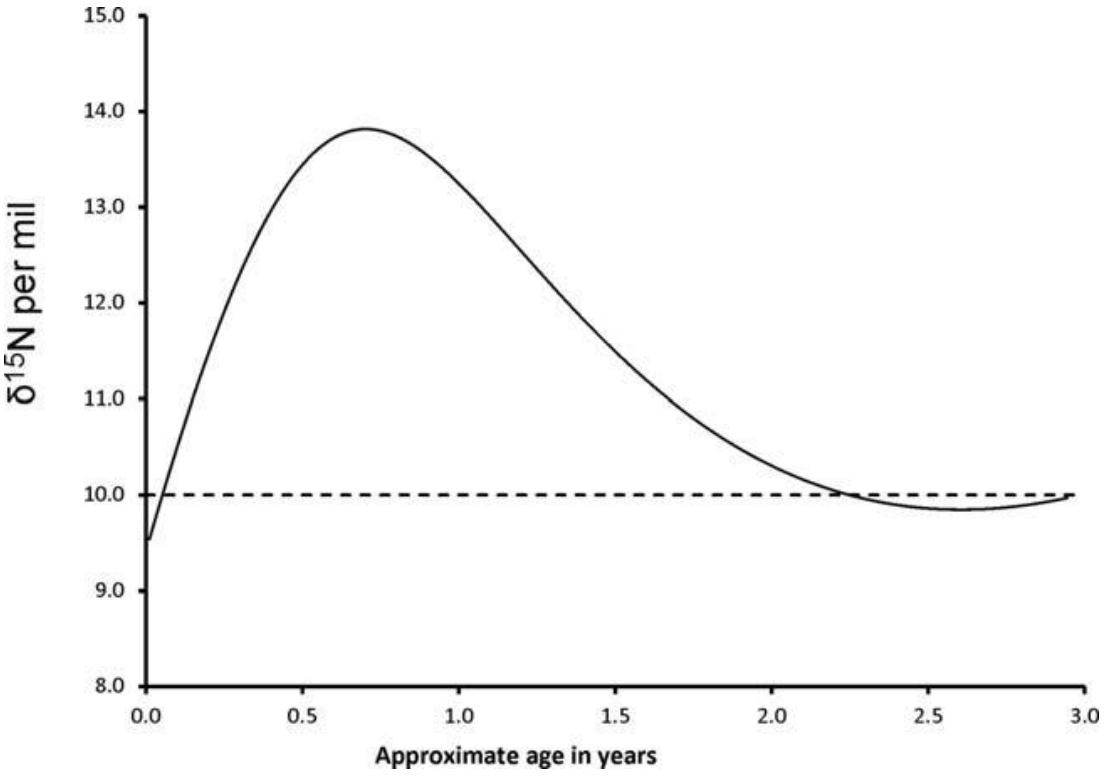

Figure 5.13: Indicative isotopic profile reflecting weaning in children, as compiled from bone collagen analyses (Beaumont *et al*. 2015, 443)

The lowest value at birth is assumed identical to the child's mother before breastfeeding begins, after which the δ^{15}N values increase by a trophic level enrichment factor of around 4‰ (Beaumont 2015, 443; Haydock 2013, 605). Once weaning commences and

supplementary foods are gradually introduced to the diet, the δ^{15}N values should eventually return to the level of the mother's, over the course of the weaning period (Katzenberg *et al*. 1996, 118; Schurr 1997, 924-925). Several issues have been identified with this model, one of which is directly relevant to the results here, i.e. the various non-dietary factors which affect δ^{15}N values were not always considered, some of which could potentially mask a weaning signal completely (Beaumont *et al*. 2015, 454). This has meant that isotope profiles which didn't adhere to the accepted model were taken to reflect an absence of breastfeeding, when they may instead have been caused by physiological stress in the child, in response to nutritional deficit or increased demands on the body arising from illness, for example (Beaumont *et al*. 2015, 453; Katzenberg and Lovell 1999, 321-322).

BLE26

BLE26 displays an erratic δ^{15}N pattern, with no significant decline in δ^{15}N (Chapter 4: Figure 4.9). There is a decrease in δ^{15}N from 0-12 months which may reflect the beginning of the weaning period, perhaps followed by a period of nutritional stress. A simultaneous increase in δ^{13}C values would support this, and if the 2σ value for Increment 1 (0-6 months) is considered, there is the potential for such an increase. It may be the case however that an unchanging δ^{13}C value from 0-12 months reflects low trophic level weaning foods (Beaumont 2015, 454). Similar examples are known; in their investigation of Irish Famine victims, for example, Beaumont *et al*. (2015, 454) recorded a similar profile from one individual, which showed a similar downward shift in δ^{15}N which then levelled out, which they interpreted as an indicator of nutritional stress. From 5-6 years old, BLE26 exhibits rising δ^{15}N alongside decreasing δ^{13}C values, similar to an example from a prehistoric assemblage in Central California, which was again interpreted as nutritional stress during weaning coupled with very low trophic level food sources (Eerkens and Bartelink 2013, 477; Beaumont *et al*. 2015, 454). Montgomery *et al*. (2013) interpreted elevated δ^{15}N values without a corresponding increase in δ^{13}C values from Neolithic Shetland data as reflective of nutritional stress resulting from crop failure. Conversely, the initial drop in δ^{15}N and consistent δ^{13}C values from 0-12 months could simply suggest that the infant was not breastfed; similar δ^{15}N profiles have been observed in modern, bottle-fed infants (Burt and Garvie-Lok 2013, 3855-3858). It is interesting to note that BLE26 died during early adulthood, between the ages of 15 and 20, and it is tempting to suggest that their early death may have been an eventual result of early childhood malnutrition or illness, and/or poor health in later life resulting from

the absence of essential nutrients supplied by maternal milk. No pathologies were noted for this individual, so the manner of their death remains unknown (Chapter 3: Table 3.1).

BLE66

The isotope profile obtained from BLE66 resembles what could be expected for a breastfed and weaned child. There is an initial rise in δ^{15}N coupled with a slight decrease in δ^{13}C, which may reflect the introduction of maternal milk (Beaumont *et al*. 2013, 292). A steady decrease in δ^{15}N from the age of 6-12 months combined with a gradual increase in δ^{13}C is strongly suggestive of the introduction of low-protein weaning foods at around 1 year, and the subsequent rise in δ^{15}N and δ^{13}C from around 4-5 years of age strongly suggests the cessation of weaning and the complete adoption of 'adult' foods from increasing trophic levels.

The lack of a clear weaning related trophic level drop in the δ^{15}N values of both individuals may result from limited breastfeeding of both individuals. At Wetwang Slack, East Yorkshire, Jay *et al*. (2008) reported that none of the δ^{13}C or δ^{15}N values from the childhood samples tested reflected trophic level enrichment indicative of exclusive breastfeeding; mean δ^{15}N values from infants were enriched by around 0.5‰ compared with the adult female means (Jay *et al*. 2008, 339). They suggest limited breastfeeding took place at Wetwang Slack, which was supplemented at an early age by animal milk or plant-based foods, which would have kept δ^{15}N values low in infants (Jay *et al*. 2008, 336). It is possible that this may have contributed to the early deaths of both BLE26 and BLE66; however, such an assertion is purely conjectural.

There may be a tentative correlation with status emerging, if the above interpretation is accurate. BLE26 was characterised as a lower wealth burial previously, and the wealth and status of their care-givers may have indirectly led to the nutritional stress which may be reflected in their M1 isotope profile. If the age suggested as the beginning of the weaning period is accurate, i.e. around 6 months old, this reflects a much shorter breastfeeding period than BLE66, who, by contrast, was part of a 'wealthy' double burial, and doesn't appear to exhibit any signs of nutritional stress in childhood. A much longer weaning period for BLE66 is suggested by the incremental dentine analysis. BLE66 did however die in later childhood, at the age of around 13. This appears to be unrelated to their health in infancy, and seemingly resulted from an unrelated illness or event that hasn't resulted in any pathological indications (Chapter 3: Table 3.1). It is interesting to note that the δ^{13}C and δ^{15}N obtained

from this individual's bulk bone collagen analysis exhibit the lowest δ^{15}N values from the sample group. Although not reflective of nutritional stress, which would be indicated by elevated δ^{15}N values, the decline in δ^{15}N from the period reflected by the bulk dentine (i.e. 3.5 to 6.5 years) to the period reflected by the bone collagen values (the last few years of life), may somehow relate to their early death.

If the profile obtained from BLE66 does represent a weaning signal, then this suggests a much later age for completion of weaning, and a much longer duration, than currently agreed for the Anglo-Saxon period (Crawford 1999, 73). Published isotope data for the Anglo-Saxon period both supports and contradicts the accepted age of weaning. At Raunds Furnell, Northamptonshire for example, isotope profiles supported the suggested Anglo-Saxon weaning age of around 2 years old, and suggested that weaning lasted for around a year, reaching completion at around 3 years old (Haydock *et al*. 2013, 608). MacPherson *et al*. (2007) reported that at Black Gate, Newcastle, breastfeeding lasted for around 6 – 9 months from birth, and although exact ages of individuals weren't ascertained, the data suggested that children had been fully weaned by around 3 – 6 years. The latter is in tentative agreement with the results obtained from BLE66, but the overall dataset for the Anglo-Saxon period is relatively small.

Placed in a wider chronological context, later medieval weaning patterns appear to be similar to those during the Anglo-Saxon period, if the data obtained from Wharram Percy can be assumed representative. Richards et al (2002) have suggested an age of around 2 years old for completion of weaning, which agrees with the documentary evidence for this period (Haydock *et al*. 2013, 608; Richards *et al*. 2002, 209). At the sub-Roman site of Queenford Farm, Oxfordshire, weaning appears to have lasted longer than during the Anglo-Saxon or medieval periods, beginning in some infants around 1.5 years of age and lasted until around 4 years old (Fuller *et al* 2006, 51-52).

6. Conclusions

To the best of the author's knowledge, this study represents the first stable isotope dietary investigation on an Anglo-Saxon cemetery population in the Trent valley. The four research aims outlined in Chapter 1 have been fulfilled where possible, discussed below.

The results from a preliminary analysis of bone and tooth dentine have shown that the diet of the Broughton Lodge population was very similar to that of other Anglo-Saxon populations in England during the centuries following the end of Roman rule. Animal protein, most likely from domesticated cattle, sheep, pigs and fowl appears to have comprised the major portion of the diet, which was supplemented by the exploitation of wild resources such as fish and eel from the River Trent (1).

Bulk dentine collagen analysis of second permanent molars and premolars (M2 and P2), and bulk bone collagen analysis of rib fragments was carried out to obtain childhood dietary profiles for four individuals. Bulk bone collagen analysis of rib fragments was carried to obtain adult dietary profiles for two individuals. No significant differences in basic sources of dietary protein were observed between adult and childhood diets, but differences in the amounts and potentially the quality of dietary protein were possibly reflected. Two adult males, BLE103 and BLE104 are thought to have consumed larger amounts of higher trophic level animal and possibly freshwater fish protein, compared to all but one of the remaining individuals. They are, however, unlikely to represent the wider adult cemetery population, for the reasons outlined below (2).

Burials were targeted to obtain information on specific groups of people, i.e. adults and children, high-status, wealthy and lower-status, less wealthy individuals; and male and female individuals. Despite the limited sample size, a variegated social structure is implied. BLE65, a comparatively 'wealthy' burial displayed childhood δ^{15}N values elevated above the rest of the sample group, which may reflect increased consumption of omnivore or freshwater protein compared to the rest of the sample population. A similar observation was made regarding the two adult males with elevated δ^{15}N values discussed above, who were buried together with weapons. They may have been afforded a higher status due to their age and gender, in line with the idea of an age threshold for Anglo-Saxon males at 30 years of age (Härke 1995, 69; Privat and O'Connell 2002; 786). In this light, it may be more appropriate to consider them within a distinct 'weapon burial' group. A less wealthy and

possibly lower-status individual, BLE48, was found to exhibit relatively low δ^{15}N values within the childhood sample group, which may reflect limited access to higher trophic level terrestrial and freshwater protein sources (3).

Analysis of increments of dentine collagen from two M1 teeth provided the opportunity to investigate the early childhood diets of one individual who survived childhood, and one who did not. BLE26 was found to have possibly experienced some nutritional stress in infancy and early childhood, or alternatively, may not have been breastfed. It is tentatively suggested that either possibility may have contributed to their early death. BLE66, an individual who died around the age of 13, was found to have had good health in infancy, but may not have been exclusively breastfed; it is suggested that their diet may have been supplemented from an early stage by foods other than maternal milk, for example animal milk. A status relationship is tentatively suggested whereby the potentially lower-status individual, BLE26, if breastfed, may have been weaned much earlier than BLE66, a possible higher-status individual. An age of weaning of around 5-6 years old is tentatively suggested for BLE66, which is longer and occurs at a much later stage than weaning during the Anglo-Saxon period, as suggested by documentary and archaeological evidence. It should be noted however that neither isotope profile provided conclusive results as to the occurrence of breastfeeding, or the duration and age of weaning.

The above observations are preliminary and drawn from a limited sample size. It is evident that an extensive programme of further research into the Broughton Lodge population, and the wider Trent valley, is needed.

Recommendations for Further Research

In the first instance, the Broughton sample population should be widened to include as many burials as are available for study, and include a wide variety of burial types, for example, single and multiple burials, horse burials, weapon burials; and burials with varying quantities and types of grave goods, enabling a meaningful investigation of dietary profiles with respect to age, sex and gender, and status. An equal proportion of male and female adults, and juveniles should be sampled, to examine any dietary differences between men, women and children. Faunal remains from Broughton Lodge should be analysed, if available, to allow the construction of an accurate baseline for comparison with human δ^{13}C and δ^{15}N values. If no faunal remains from Broughton Lodge are available then attempts should be made to sample faunal remains from the wider Trent valley area.

Further investigation into breastfeeding and weaning practices should be carried out, from as many individuals as possible. The two incremental analyses carried out here proved inconclusive, and have not succeeded in establishing within any certainty a weaning age for the Broughton Lodge population. Male and female individuals should be sampled, as well as individuals of high, low and intermediate status, as reflected by grave good assemblages, where available. This will allow a thorough investigation into parental investment and its relation to gender and status.

Strontium (Sr) and Oxygen (O) isotope analyses should be carried out on as many individuals as possible, to investigate the movement of people to and within Britain. Dietary profiles could then be examined in terms of migration. The Broughton Lodge cemetery represents an opportunity to examine migration to the Trent valley during the so-called 'Migration Period' and the centuries immediately following the *adventus Saxonum* (Brettell *et al*. 2012, 118).

Finally, additional Anglo-Saxon cemetery populations from the Trent valley should be targeted, and the above analyses carried out. This will allow a wider investigation of the Anglo-Saxon kingdom of Mercia, which as noted, remains a very much understudied region of Anglo-Saxon England.

It is hoped that the data and interpretations presented within this thesis, along with the further research points identified above will add to the growing corpus of information on past diet and subsistence strategies, and the wider societal structure of post-Roman England, a period of social, political and economic upheaval.

Appendix 1

BLE26					
Increment	**Length (mm)**	**Weight (mg) (pre de-mineralisation and freeze dying)**	**Weight (mg) of collagen extracted**	**% Collagen yield**	**Notes**
1	2	12.024	2.026	16.85	Crown
2	2	7.973	0.975	12.23	
3	2	19.313	3.157	16.35	
4	1.5	27.165	4.701	17.31	
5	1	35.612	6.749	18.95	
6	1	18.32	3.512	19.17	
7	1	15.702	1.127	7.18	
8	1	19.985	2.904	14.60	
9	1.5	11.23	1.673	14.90	
10	2	12.176	2.536	20.83	Root tip

Table 1: Lengths and weights of BLE 26 dentine increments sampled, and collagen yield from each

BLE 66					
Increment	**Length (mm)**	**Weight (mg) (pre de-mineralisation and freeze dying)**	**Weight (mg) of collagen extracted**	**% Collagen yield**	**Notes**
1	1	38.821	6.42	16.54	Crown
2	1	46.683	6.95	14.89	
3	1	42.393	6.939	16.37	
4	1	26.507	4.682	17.66	
5	1	27.113	4.922	18.15	
6	1.5	65.563	12.218	18.64	
7	1.5	47.263	3.115	6.59	
8	1.5	37.312	5.576	14.94	
9	2	25.702	3.553	13.82	
10	2	17.782	3.183	17.90	Root Tip

Table 2: Lengths and weights of BLE 66 dentine increments sampled, and collagen yield from each

Skeleton	Weight (mg) of bulk dentine extracted from each tooth	Weight (mg) of collagen extracted from each tooth's bulk dentine	% Collagen Yield
BLE26	153	0	0
BLE48	103	1.155	1.12
BLE65	105	3.458	3.34
BLE66	90	4.275	4.75
BLE103	133	1.215	0.91
BLE104	216	2.929	1.34

Table 3: Extracted amounts of bulk dentine by weight, and collagen yield from each

Skeleton	Weight (mg) of rib material extracted from each individual	Weight (mg) of collagen extracted from each rib fragment	% Collagen yield
BLE66	300	36.01	12.00
BLE104	331.19	16.00	4.83
BLE103	442.93	12.12	2.74

Table 4: Extracted amounts of rib material by weight, and collagen yield from each

Number in sample tray	Identifier 1	Weight (mg)	Carousel number
A1	Empty cap	0	1
A2	M1360P-01	0.634	2
A3	M1360P-02	0.656	3
A4	M1360P-03	0.598	4
A5	M1360P-04	0.6	5
A6	M1360P-05	0.621	6
A7	M1360P-06	0.635	7
A8	M1360P-07	0.613	8
A9	M1360P-08	0.59	9
A10	M1360P-09	0.624	10
A11	M1360P-10	0.646	11
A12	M1360P-11	0.6	12
B1	M1360P-12	0.585	13
B2	BLE26-04-01	0.619	14
B3	BLE26-10-02	0.601	15
B4	BLE26-01-01	0.621	16
B5	BLE66-06-02	0.61	17
B6	BLE66-10-02	0.607	18
B7	M1360P-13	0.587	19
B8	SADCOW	0.614	20
B9	BLE66-04-02	0.621	21
B10	BLE66-RIB-01	0.607	22
B11	BLE-26-01-02	0.615	23
B12	BLE103-RIB-02	0.594	24
C1	M1360P-14	0.628	25
C2	BLE66-04-01	0.622	26
C3	BLE66-09-01	0.616	27

C4	BLE26-05-01	0.608	28
C5	BLE103-01	0.593	29
C6	BLE66-01-01	0.617	30
C7	M1360P-15	0.583	31
C8	BLE66-08-02	0.593	32
C9	Empty cap	0	33
C10	BLE26-03-01	0.609	34
C11	BLE66-01-02	0.599	35
C12	BLE-66-09-02	0.62	36
D1	Empty cap	0	37
D2	M1360P-16	0.605	38
D3	BLE66-03-01	0.599	39
D4	BLE66-RIB-02	0.603	40
D5	Empty cap	0	41
D6	BLE66-06-01	0.612	42
D7	BLE66-02-02	0.603	43
D8	M1360P-17	0.587	44
D9	SADCOW	0.604	45
D10	BLE104-RIB-02	0.598	46
D11	Empty cap	0	47
D12	BLE66-02-01	0.602	48
E1	BLE26-02-01	0.603	49
E2	BLE66-03-02	0.593	50
E3	M1360P-18	0.581	51
E4	BLE26-04-02	0.508	52
E5	BLE26-09-02	0.344	53
E6	BLE26-07-01	0.615	54
E7	Empty cap	0	55
E8	BLE65-02	0.612	56
E9	M1360P-19	0.574	57
E10	Empty cap	0	58

E11	BLE26-06-02	0.595	59
E12	BLE104-RIB-01	0.611	60
F1	BLE66-07-01	0.611	61
F2	Empty cap	0	62
F3	M1360P-20	0.601	63
F4	BLE103-02	0.608	64
F5	BLE66-05-02	0.624	65
F6	BLE104-01	0.622	66
F7	BLE66-10-01	0.622	67
F8	SADCOW	0.599	68
F9	M1360P-21	0.618	69
F10	BLE65-01	0.615	70
F11	BLE26-06-01	0.603	71
F12	BLE66-07-02	0.597	72
G1	BLE26-07-02	0.606	73
G2	BLE66-02	0.616	74
G3	M1360P-22	0.584	75
G4	BLE103-RIB-01	0.595	76
G5	BLE26-08-01	0.595	77
G6	BLE48-02	0.572	78
G7	BLE26-09-01	0.608	79
G8	BLE104-02	0.619	80
G9	M1360P-23	0.62	81
G10	BLE48-01	0.605	82
G11	BLE66-05-01	0.616	83
G12	BLE26-02-02	0.582	84
H1	Empty cap	0	85
H2	BLE26-05-02	0.604	86
H3	M1360P-24	0.602	87
H4	BLE26-08-02	0.611	88
H5	BLE66-01	0.599	89

H6	BLE26-03-02	0.616	90
H7	BLE66-08-01	0.607	91
H8	Empty cap	0	92
H9	BLE26-10-01	0.621	93
H10	M1360P-25	0.613	94
H11	M1360P-26	0.581	95
H12	Empty cap	0	96

Table 5: Sample tray and carousel numbers for each sample, standard and blank

Line	Identifier	%C	%N	C/N ratio	δ13C $_{VPDB}$ (‰)	Mean and 2SD (‰)	δ15N $_{AIR}$ (‰)	Mean and 2SD (‰)
16	BLE26-01-01	41.3	14.6	3.3	-20.3	-20.31±0.02	11.5	11.52±0.12
23	BLE26-01-02	41.4	14.7	3.3	-20.3		11.6	
49	BLE26-02-01	42.7	15.2	3.3	-20.1	-20.14±0.04	11.3	11.35±0.03
84	BLE26-02-02	42.5	15.2	3.3	-20.2		11.4	
34	BLE26-03-01	40.4	14.3	3.3	-20.1	-20.11±0.08	11.1	11.22±0.22
90	BLE26-03-02	40.6	14.4	3.3	-20.1		11.3	
14	BLE26-04-01	41.0	14.6	3.3	-20.1	N/A	11.6	N/A
52	BLE26-04-02	43.3	13.6	3.7	-21.1		11.3	
48 Repeat run	BLE26-04-03	44.6	14.2	3.7	-21.1		11.4	
28	BLE26-05-01	44.5	15.9	3.3	-20.4	-20.35±0.01	11.6	11.64±0.08
86	BLE26-05-02	39.5	14.0	3.3	-20.3		11.7	
71	BLE26-06-01	37.4	13.3	3.3	-20.3	-20.26±0.04	11.6	11.55±0.10

59	BLE26-06-02	39.4	13.9	3.3	-20.2		11.5	
54	BLE26-07-01	40.9	14.6	3.3	-20.3	-20.29±0.02	11.6	11.64±0.18
73	BLE26-07-02	42.5	15.1	3.3	-20.3		11.7	
77	BLE26-08-01	42.7	15.2	3.3	-20.3	-20.34±0.03	11.4	11.48±0.15
88	BLE26-08-02	42.3	15.1	3.3	-20.4		11.5	
79	BLE26-09-01	41.7	14.8	3.3	-20.8	-20.80±0.03	11.2	11.20±0.12
53	BLE26-09-02	41.6	14.3	3.4	-20.8		11.2	
93	BLE26-10-01	42.0	14.9	3.3	-20.9	-20.80±0.19	11.8	11.76±0.24
15	BLE26-10-02	42.6	15.3	3.3	-20.7		11.7	

Table 1: Mass spectrometer results for **BLE26** incremental dentine analysis; shaded values have been excluded from the overall analysis due to the insufficient preservation of the sample

Line	Identifier	%C	%N	C/N ratio	δ13C $_{VPDB}$ (‰)	Mean and 2σ (‰)	δ15N $_{AIR}$ (‰)	Mean and 2σ (‰)
30	BLE66-01-01	41.7	15.0	3.3	-20.2	-20.24±0.07	11.1	11.15±0.10
35	BLE66-01-02	41.9	15.0	3.3	-20.3		11.1	
48	BLE66-02-01	40.5	14.4	3.3	-20.2	-20.16±0.01	10.9	10.90±0.01
43	BLE66-02-02	40.9	14.7	3.3	-20.2		10.9	
39	BLE66-03-01	40.4	14.4	3.3	-20.6	-20.59±0.03	10.3	10.34±0.08
50	BLE66-03-02	41.9	14.9	3.3	-20.6		10.4	
26	BLE66-04-01	41.3	14.8	3.3	-20.7	-20.65±0.03	10.0	10.01±0.07
21	BLE66-04-02	42.7	15.2	3.3	-20.6		10.0	
83	BLE66-05-01	41.5	14.9	3.3	-20.5	-20.54±0.01	10.2	10.15±0.17
65	BLE66-05-02	41.7	14.9	3.3	-20.5		10.1	
42	BLE66-06-01	37.8	13.4	3.3	-20.5	-20.51±0.12	10.3	10.28±0.00
17	BLE66-06-02	43.5	15.5	3.3	-20.5		10.3	
61	BLE66-07-01	42.1	14.8	3.3	-20.6	-20.63±0.04	10.5	10.47±0.01
72	BLE66-07-02	42.1	15.2	3.3	-20.6		10.5	
91	BLE66-08-01	42.0	14.9	3.3	-20.7	-20.65±0.19	11.1	11.05±0.18

32	BLE66-08-02	42.5	15.2	3.3	-20.6		11.0	
27	BLE66-09-01	41.5	14.4	3.4	-20.9	-20.79±0.17	11.4	11.46±0.10
36	BLE66-09-02	40.0	14.2	3.3	-20.7		11.5	
67	BLE66-10-01	35.9	12.7	3.3	-20.7	-20.71±0.08	11.3	11.29±0.13
18	BLE66-10-02	41.8	14.9	3.3	-20.7		11.3	

Table 2: Mass spectrometer results for **BLE66** incremental dentine analysis

Line	Identifier	%C	%N	C/N ratio	$\delta 13C_{VPDB}$ (‰)	Mean and 2σ (‰)	$\delta 15N_{AIR}$ (‰)	Mean and 2σ (‰)
82	BLE48-01	43.6	43.6	3.5	-21.1	-20.99±0.19	10.4	10.40±0.07
78	BLE48-02	42.7	42.7	3.5	-20.9		10.4	
70	BLE65-01	44.6	14.3	3.7	-21.0	N/A	11.1	N/A
56	BLE65-02	42.8	14.0	3.6	-20.7	-20.31±0.78	11.3	11.27±0.05
46 Repeat Run	BLE65-03	41.8	14.5	3.4	-20.1		11.3	
47 Repeat Run	BLE65-04	41.5	14.4	3.4	-20.1		11.3	
89	BLE66-01	42.6	13.8	3.6	-21.4	-21.07±0.95	10.8	10.79±0.02
74	BLE66-02	42.6	14.6	3.4	-20.7		10.8	
29	BLE103-01	42.2	12.9	3.8	-21.3	N/A	10.6	N/A
64	BLE103-02	40.8	13.3	3.6	-20.7		10.5	
66	BLE104-01	43.2	13.7	3.7	-21.6		10.7	

80	BLE104-02	41.8	14.1	3.5	-21.0	-20.89±0.23	10.7	10.73± 0.12
50 Repeat run	BLE104-03	39.6	13.5	3.4	-20.9		10.7	
51 Repeat run	BLE104-04	40.8	14.0	3.4	-20.8		10.8	

Table 3: Mass spectrometer results for bulk dentine analysis; shaded values have been excluded from the overall analysis due to the insufficient preservation of the sample

Appendix 2

Line	Identifier	%C	%N	C/N ratio	δ13C $_{VPDB}$ (‰)	Mean and 2SD (‰)	δ15N $_{AIR}$ (‰)	Mean and 2SD (‰)
16	BLE26-01-01	41.3	14.6	3.3	-20.3	-20.31±0.02	11.5	11.52±0.12
23	BLE26-01-02	41.4	14.7	3.3	-20.3		11.6	
49	BLE26-02-01	42.7	15.2	3.3	-20.1	-20.14±0.04	11.3	11.35±0.03
84	BLE26-02-02	42.5	15.2	3.3	-20.2		11.4	
34	BLE26-03-01	40.4	14.3	3.3	-20.1	-20.11±0.08	11.1	11.22±0.22
90	BLE26-03-02	40.6	14.4	3.3	-20.1		11.3	
14	BLE26-04-01	41.0	14.6	3.3	-20.1	N/A	11.6	N/A
52	BLE26-04-02	43.3	13.6	3.7	-21.1		11.3	
48 Repeat run	BLE26-04-03	44.6	14.2	3.7	-21.1		11.4	
28	BLE26-05-01	44.5	15.9	3.3	-20.4	-20.35±0.01	11.6	11.64±0.08
86	BLE26-05-02	39.5	14.0	3.3	-20.3		11.7	

71	BLE26-06-01	37.4	13.3	3.3	-20.3	-20.26±0.04	11.6	11.55±0.10
59	BLE26-06-02	39.4	13.9	3.3	-20.2		11.5	
54	BLE26-07-01	40.9	14.6	3.3	-20.3	-20.29±0.02	11.6	11.64±0.18
73	BLE26-07-02	42.5	15.1	3.3	-20.3		11.7	
77	BLE26-08-01	42.7	15.2	3.3	-20.3	-20.34±0.03	11.4	11.48±0.15
88	BLE26-08-02	42.3	15.1	3.3	-20.4		11.5	
79	BLE26-09-01	41.7	14.8	3.3	-20.8	-20.80±0.03	11.2	11.20±0.12
53	BLE26-09-02	41.6	14.3	3.4	-20.8		11.2	
93	BLE26-10-01	42.0	14.9	3.3	-20.9	-20.80±0.19	11.8	11.76±0.24
15	BLE26-10-02	42.6	15.3	3.3	-20.7		11.7	

Table 1: Mass spectrometer results for **BLE26** incremental dentine analysis; shaded values have been excluded from the overall analysis due to the insufficient preservation of the sample

Line	Identifier	%C	%N	C/N ratio	δ13C $_{VPDB}$ (‰)	Mean and 2σ (‰)	δ15N $_{AIR}$ (‰)	Mean and 2σ (‰)
30	BLE66-01-01	41.7	15.0	3.3	-20.2	-20.24±0.07	11.1	11.15±0.10
35	BLE66-01-02	41.9	15.0	3.3	-20.3		11.1	
48	BLE66-02-01	40.5	14.4	3.3	-20.2	-20.16±0.01	10.9	10.90±0.01
43	BLE66-02-02	40.9	14.7	3.3	-20.2		10.9	
39	BLE66-03-01	40.4	14.4	3.3	-20.6	-20.59±0.03	10.3	10.34±0.08
50	BLE66-03-02	41.9	14.9	3.3	-20.6		10.4	
26	BLE66-04-01	41.3	14.8	3.3	-20.7	-20.65±0.03	10.0	10.01±0.07
21	BLE66-04-02	42.7	15.2	3.3	-20.6		10.0	
83	BLE66-05-01	41.5	14.9	3.3	-20.5	-20.54±0.01	10.2	10.15±0.17
65	BLE66-05-02	41.7	14.9	3.3	-20.5		10.1	
42	BLE66-06-01	37.8	13.4	3.3	-20.5	-20.51±0.12	10.3	10.28±0.00
17	BLE66-06-02	43.5	15.5	3.3	-20.5		10.3	
61	BLE66-07-01	42.1	14.8	3.3	-20.6	-20.63±0.04	10.5	10.47±0.01
72	BLE66-07-02	42.1	15.2	3.3	-20.6		10.5	
91	BLE66-08-01	42.0	14.9	3.3	-20.7	-20.65±0.19	11.1	11.05±0.18

32	BLE66-08-02	42.5	15.2	3.3	-20.6		11.0	
27	BLE66-09-01	41.5	14.4	3.4	-20.9	-20.79±0.17	11.4	11.46±0.10
36	BLE66-09-02	40.0	14.2	3.3	-20.7		11.5	
67	BLE66-10-01	35.9	12.7	3.3	-20.7	-20.71±0.08	11.3	11.29±0.13
18	BLE66-10-02	41.8	14.9	3.3	-20.7		11.3	

Table 2: Mass spectrometer results for **BLE66** incremental dentine analysis

Line	Identifier	%C	%N	C/N ratio	$\delta 13C_{VPDB}$ (‰)	Mean and 2σ (‰)	$\delta 15N_{AIR}$ (‰)	Mean and 2σ (‰)
82	BLE48-01	43.6	43.6	3.5	-21.1	-20.99±0.19	10.4	10.40±0.07
78	BLE48-02	42.7	42.7	3.5	-20.9		10.4	
70	BLE65-01	44.6	14.3	3.7	-21.0	N/A	11.1	N/A
56	BLE65-02	42.8	14.0	3.6	-20.7	-20.31±0.78	11.3	11.27±0.05
46 Repeat Run	BLE65-03	41.8	14.5	3.4	-20.1		11.3	
47 Repeat Run	BLE65-04	41.5	14.4	3.4	-20.1		11.3	
89	BLE66-01	42.6	13.8	3.6	-21.4	-21.07±0.95	10.8	10.79±0.02
74	BLE66-02	42.6	14.6	3.4	-20.7		10.8	
29	BLE103-01	42.2	12.9	3.8	-21.3	N/A	10.6	N/A
64	BLE103-02	40.8	13.3	3.6	-20.7		10.5	
66	BLE104-01	43.2	13.7	3.7	-21.6		10.7	

80	BLE104-02	41.8	14.1	3.5	-21.0	-20.89±0.23	10.7	10.73± 0.12
50 Repeat run	BLE104-03	39.6	13.5	3.4	-20.9		10.7	
51 Repeat run	BLE104-04	40.8	14.0	3.4	-20.8		10.8	

Table 3: Mass spectrometer results for bulk dentine analysis; shaded values have been excluded from the overall analysis due to the insufficient preservation of the sample

Line	Identifier	%C	%N	C/N ratio	δ13C $_{VPDB}$ (‰)	Mean and 2σ (‰)	δ15N$_{AIR}$ (‰)	Mean and 2σ (‰)
22	BLE66-RIB-01	42.6	15.0	3.3	-20.2	-20.15±0.14	9.8	9.80±0.01
40	BLE66-RIB-02	41.9	14.8	3.3	-20.1		9.8	
76	BLE103-RIB-01	40.0	13.7	3.4	-20.5	-20.56±0.10	11.0	10.98±0.11
24	BLE103-RIB-02	40.5	13.9	3.4	-20.6		10.9	
60	BLE104-RIB-01	40.6	14.0	3.4	-20.3	-20.30±0.05	11.1	11.07±0.12
46	BLE104-RIB-02	39.4	13.7	3.4	-20.3		11.0	

Table 4: Mass spectrometer results for bulk bone collagen

Line	Identifier	%C	%N	C/N ratio	$\delta 13C_{VPDB}$ (‰)	Mean and 2σ (‰)	$\delta 15N_{AIR}$ (‰)	Mean and 2σ (‰)
20	SADCOW	43.3	15.3	3.3	-22.3	-27.27±0.02	4.6	4.62±0.12
45	SADCOW	42.9	15.1	3.3	-22.3		4.6	
68	SADCOW	43.3	15.2	3.3	-22.3		4.7	
Repeat Mass Spectrometer Run								
15	SADCOW	43.0	15.3	3.3	-22.3	-22.3±0.11	4.6	4.58±0.18
30	SADCOW	43.1	15.2	3.3	-22.2		4.5	

Table 5: Mass spectrometer results, including repeat run, for lab standard SADCOW. The expected long-term values for SADCOW are -22.2±0.3‰ for $\delta^{13}C$ and 4.6±0.05‰ for $\delta^{15}N$

Appendix 3

Site	Location & NGR	Period	Fauna sampled	No. of samples	Range $\delta^{13}C_{VPDB}$ (‰)		Mean $\delta^{13}C_{VPDB}$ (‰)	Range $\delta^{15}N_{AIR}$ (‰)		Mean $\delta^{15}N_{AIR}$ (‰)	Reference
					Lower	Upper		Lower	Upper		
Fishergate	York SE6075050967	Late 7th – early 8th centuries AD	Cow	3	-22.7	-21.5	-22.2	4.2	5.2	4.8	Müldner and Richards 2007
			Pig	6	-21.9	-21.4	-21.7	5.9	8.6	7.4	
			Sheep / goat	4	-21.9	-21.1	-21.5	4.4	6.1	5.5	
			Domestic fowl	2	-21.1	-19.7	-20.4	9.9	12.4	11.2	
			Carp	1	-23.6	-23.6	-23.6	11.0	11.0	11.0	
			Eel	2	-25.0	-24.5	-24.8	8.8	9.0	8.5	
			Herring	1	-15.2	-15.2	-15.2	11.0	11.0	11.0	
			Pike	1	-22.7	-22.7	-22.7	12.5	12.5	12.5	
Berinsfield	Oxfordshire SU581955	Mid-5th to late 6th /	Cow	4	-21.8	-21.4	-21.6	5.3	5.3	5.8	
			Pig	1	-20.9	-20.9	-20.9	6.0	6.0	6.0	

		early 7th centuries	Sheep/goat	2	-21.4	-21.2	-21.8	5.8	6.4	6.1	Privat and O'Connell 2002
			Fox	3	-21.6	-21.1	-21.4	9.0	10.0	9.4	
			Dog	1	-20.0	-20.0	-20.0	8.1	8.1	8.1	
			Horse	3	-22.4	-22.3	-22.4	5.0	5.5	5.2	
Bloodmoor Hill	Suffolk TM5251090454	6th to mid-10th centuries	Cow	7	-23.0	-21.7	-22.5	1.4	6.5	3.8	O'Connell and Lawler 2009
			Pig	5	-22.0	-21.3	-21.5	2.5	6.1	4.4	
			Sheep/goat	5	-23.1	-21.3	-22.0	3.5	6.7	5.3	
			Chicken	1	-20.4	-20.4	-20.4	10.3	10.3	10.3	
West Halton	North Lincolnshire SE9041021072	8th to 11th centuries AD	Cow	2	-22.81	-21.32	-21.4	3.91	9.08	7.65	MacPherson 2005
			Pig	2	-21.71	-21.61	-21.7	10.6	12.1	11.4	
			Sheep/goat	3	-22.26	-21.44	-20.6	8.0	9.48	9.0	
			Dog	1	-20.6	-20.6	-20.6	11.4	11.4	11.4	

Table 1: Faunal stable isotope data published from Anglo-Saxon archaeological sites in England. For sites where detailed information wasn't available, NGR and Period of Use are approximate

Appendix 3

Site	Location, NGR and topographical classification	Period of Anglo-Saxon Cemetery Use	Material Sampled	No. of Samples	Range $\delta^{13}C_{VPDB}$ (‰)		Mean $\delta^{13}C_{VPDB}$ (‰)	Range $\delta^{15}N_{AIR}$ (‰)		Mean $\delta^{15}N_{AIR}$ (‰)	Reference
					Lower	Upper		Lower	Upper		
Apple Down	West Sussex TQ3456834514 Inland	Mid-late 7th century	Adult bone	3	-20.3	-20.2	-20.3	8.0	8.7	8.3	Mays and Beavan 2013
Aston Clinton, Tring Hill	Buckinghamshire SP9014011326 Inland	Mid-late 7th century	Adult bone	1	-20.2	-20.2	-20.2	9.4	9.4	9.4	Mays and Beavan 2013
Belle Vue House, York	North Yorkshire SE 59335095 Riverine	Late 7th to early 8th centuries	Adult bone	33	-20.7	-19.4	-20.0	7.8	12.0	10.2	Müldner and Richards 2007

Berinsfield	Oxfordshire SU 58187 91130 Inland	Mid-5th to late 6th / early 7th centuries	Adult bone	72	-20.7	-19.9	-20.1	8.4	11.6	9.8	Privat and O'Connell 2002
Black Gate	Newcastle NZ2501263924 Riverine	Late 7th to early 12th centuries	Adult rib	24	-21.2	-19.1	-20.5	10.5	13.0	11.4	MacPherson 2005
			M2	19	-21.2	-18.9	-20.4	9.0	15.5	12.2	
Bloodmoor Hill	Suffolk TM5251090454 Coastal	6th to mid-10th centuries	Adult bone	12	-20.8	-20.3	-20.5	8.5	10.4	9.7	O'Connell and Lawler 2009
Buttermarket	Ipswich TM16384450 Coastal	Anglo-Saxon. Late 6th to early 7th centuries	Adult bone	2	-20.2	-20.1	-20.2	9.4	10.7	10.1	Beavan and Mays 2013; Scull and Bayliss 1999
Castledyke	North Lincolnshire TA 03340 22018 Riverine	Early 6th to late 7th centuries	Adult bone	3	-20.0	-19.4	-19.8	9.7	10.4	10.1	Beavan *et al*. 2011

Castledyke South	North Lincolnshire TA 03340 22018 Riverine	Anglo-Saxon 7th to 8th centuries	Adult bone	7	-21.3	-20.3	-20.8	8.9	11.5	10.2	Mays and Beavan 2013
Church Lane, Whitton	North Lincolnshire SE90317 4485 Riverine	Mid-6th to mid-10th centuries	Adult bone	2	-20.42	-20.23	-20.3	10.9	11.2	11.1	MacPherson 2005
			M2	2	-20.8	-20.7	-20.7	11.5	11.7	11.6	
Coddenham	Suffolk TM1326354211 Inland	Mid-late 7th century	Adult bone	1	-20.4	-20.4	-20.4	10.3	10.3	10.3	Mays and Beavan 2013
Dover Buckland	Kent TR3061242755 Coastal	Mid-late 7th century	Adult bone	8	-20.3	-19.7	-19.9	8.9	10.4	9.6	Mays and Beavan 2013
Dunstable Marina Drive	Bedfordshire TL0009921316 Inland	Mid-late 7th century	Adult bone	2	-20.4	-20.3	-20.4	11.0	12.0	11.5	Mays and Beavan 2013

Edix Hill, Barrington	Cambridgeshire TL3965349854 Inland	Mid-late 7th century	Adult bone	9	-20.7	-20.0	-20.3	8.8	10.9	10.1	Mays and Beavan 2013
Fillingham	North Lincolnshire SK9466185823 Inland	Mid-7th to Late Anglo-Saxon period	Adult bone	2	-20.6	-20.4	-20.5	10.45	11.8	11.2	MacPherson 2005
			M2	2	-20.5	-20.5	-20.5	9.8	10.9	10.4	
Ford, Laverstock	Wiltshire SU1616030823 Inland	Mid-late 7th century	Adult bone	1	-20.4	-20.4	-20.4	9.0	9.0	9.0	Mays and Beavan 2013
Gally Hills, Banstead Down	Surrey TQ2521361602 Inland	Mid-late 7th century	Adult bone	1	-20.2	-20.2	-20.2	10.4	10.4	10.4	Mays and Beavan 2013
Kilton Hill	Nottinghamshire SK5938580062 Inland	Probable Anglo-Saxon	M2	2	-20.8	-20.5	-20.6	7.6	13.0	10.3	Mays and Beavan 2013

Lankenheath, Eriswell	Suffolk TL 7437581692 Inland	Mid-late 7th century	Adult bone	1	-19.8	-19.8	-19.8	9.2	9.2	9.2	Mays and Beavan 2013
Lechlade, Butler's Field	Gloucestershire SP21160014 Inland	Anglo-Saxon mid-5th to late 7th / early 8th centuries	Adult bone	127	-20.71	-19.6	-20.1	7.5	11.4	9.5	O'Connell and Wilson 2011
Melbourne, Water lane	Cambridgeshire TL3823844169 Inland	Mid-late 7th century	Adult bone	9	-20.4	-20.0	-20.2	8.7	10.3	9.5	Mays and Beavan 2013
Mill Hill, Deal	Kent TR3645451251 Coastal	Mid-late 7th century	Adult bone	8	-20.3	-19.1	-19.8	8.8	10.1	9.7	Mays and Beavan 2013
St Peter's Tip, Broadstairs	Kent TR3902867935 Coastal	Mid-late 7th century	Adult bone	12	-20.1	-19.0	-19.8	8.1	10.6	9.6	Mays and Beavan 2013

West Heslerton	North Yorkshire SE9097076003 Inland	Mid-late 7th century	Adult bone	2	-20.3	-19.9	-20.1	9.0	8.9	9.0	Mays and Beavan 2013
Westgarth Gardens	Suffolk TL8436763514 Inland	Mid-late 7th century	Adult bone	3	-20.8	-19.8	-20.2	8.4	9.9	9.3	Mays and Beavan 2013
Yarnton	Oxfordshire SP462112 Inland	Anglo- Saxon	Adult bone	5	-19.9	-19.6	19.7	9.9	13.5	11.8	Lightfoot *et al*. 2009

Table 2: Human stable isotope data published from Anglo-Saxon archaeological sites in England. For sites where detailed information wasn't available, NGR and Period of Use are approximate

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