Tracing Change: An Isotopic Investigation of Anglo-Saxon Childhood Diet

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Abstract

Stable isotopes of carbon, nitrogen and oxygen are used to assess diet and mobility in early medieval childhood. Multiple samples were taken from individuals buried in Newcastle upon Tyne and North Lincolnshire between the 8th and 12th centuries A.D.

Duration and intensity of breastfeeding varied within these populations, as evidenced by elevated $\delta^{15}N$ and $\delta^{18}O$ values in deciduous 2nd molars and, to a lesser extent, permanent 1st molar crowns. Weaning occurred during the formation of deciduous 2nd molar roots, and varied from a rapid reduction in breast feeding over a few months at 9 months to 1 year of age, to an extended period of partial breastfeeding during the 2nd year of life.

Overall, individuals' diet in childhood appears to have had a similar isotopic signal to their diet later in life. This picture is complicated by a uniform depletion in $\delta^{15}N$ in the permanent 2nd molar, formed between approximately 3 and 6 years of age. As this depletion has been observed in other populations (e.g. Fuller, *et al.*, 2003; Eriksson, 2004) there is likely to be a physiological aetiology, caused by growth.

Analysis of oxygen in permanent molars indicates geographically diverse origins in the populations under study. While some individuals have oxygen values consistent with residence in the area where they were buried, others may have come from the western coast of Britain, Ireland and central or northern Europe. A number of individuals changed their area of residence one or more times over the course of their childhood implying that they and possibly their communities were not sedentary in nature.

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Chapter 1: Introduction

The research context

This project is set in the context of a burgeoning interest amongst scholars in all aspects of children's lives, both past and present, and a growth in the use of scientific methods to answer archaeologically important questions pertaining to diet and migration. The 1990's saw the beginnings of an interest in the role of children in past societies, characterised by publications such as *Invisible People and Processes* (Moore and Scott), *Children and Material Culture* (Sofaer Deverenski, 2000), and *Childhood in Anglo-Saxon England* (Crawford). This interest has shown its latest developments in a conference at the University of Kent entitled *The Archaeology of Infancy and Childhood*. Attended by researchers from Britain, Europe and North America, the conference demonstrated the wide range of archaeological techniques currently in use to investigate past childhoods. A key theme of the conference was how integral the lives of children were and are to society and how their actions, and their parents methods of care can affect the communities in which the live.

A major strand of the conference papers, which is echoed in published literature, was the use of isotopic techniques to address questions of weaning age and mobility. Identifying the age of weaning in a population can aid assessments of birth spacing and levels of maternal investment in their offspring, which in turn reflect upon the priorities of the societies in which they live. Comparing place of childhood residence with place of burial can give indications both of immigrants into a cemetery population and the scale of migration in the period and region under study. Both these lines of investigation can be used to track long term changes in population dynamics, and when integrated with other lines of evidence, help to suggest causative factors.

The experience of children in early medieval England has been characterised by Sally Crawford (1999), who used both historical and archaeological

evidence to depict a childhood centred around a loving nuclear family. However Crawford's book was intended only as a starting point, and a call for further research to be carried out to add body to her findings. Beyond suggesting an age of weaning, the dietary experience of children in this period is not discussed by Crawford, nor does she give any indication of how mobile we might expect children in this period to be.

There are a number of options for approaching questions of diet within archaeological sciences. Palaeobotanical and zooarchaeological data can give indications of the range and quantities of different foodstuffs available to communities, and can detect changes over time and geography (Rackham, 1994). Such data can be used to determine the levels of investment accorded to (for example) cereal cultivation versus dairying. This can in turn be used to ascribe relative levels of economic wealth and status to the communities studied. However it is not always possible to match evidence excavated from settlements to a particular cemetery population. It is also difficult to determine how much of a particular resource would have been available to an individual, or whether there were differences in access to resources based on status, gender or age.

Analysis of skeletal remains offers a number of options in assessing the health and hence the dietary status of individuals. The construction of growth curves and the determination of population heights can indicate whether diet during the period of growth was adequate, or was poor quality, leading to slowed growth trajectories and stunting. Assessment of pathological markers of metabolic diseases can indicate any deficiencies in the diet, such as anaemia. Such skeletal analysis can therefore indicate the general health status of a population as it relates to diet, and highlight any specific deficiencies, but cannot indicate the broader content of the diet. Specific information on dietary content can be gained from dental microwear analysis. This can indicate the level of abrasiveness of the diet, with different foodstuffs causing different patterns of scratches and pits on dental enamel (Hillson, 1996). However, as eating continually causes new patterns of microwear to form, this tool is not suitable for assessing long term diet, or

dietary change within individuals. Essentially microwear will record the last few meals of an individual's life.

Stable isotope analysis fills the gap in archaeological science between the detailed dietary snapshot of microwear analysis and the population level picture gained through skeletal, paleaobotanical and zooarchaeological analysis. It is used to determine the position of an individual within the local food web, and therefore assess the relative inputs of animal, marine and cereal protein into the diet. Depending on how the technique is applied, it can be used to assess long term diet in individuals and populations, or, by taking multiple samples from individuals, it is possible to track dietary variation throughout the life of an individual. Isotope analysis is also used to detect migrants into cemetery population, a method that is more reliable than using grave goods or craniometrics.

The aims of the project

This project aims to move beyond generalised inferences of childhood experience in the early medieval period and intensively investigate the dietary and migration histories of individuals from northern England. The use of permanent teeth enables serial samples to be taken from the same individual to track isotopic changes from birth to adulthood. This method also ensures that research is being carried out into the childhood of those who survived beyond this period and into adult life, a group that are not normally visible osteologically. In addition, deciduous molar teeth were used to obtain finer precision in the nature and timing of weaning activities. This enables an age of weaning to be established with far greater accuracy than the use of permanent molar crowns alone would allow. Establishing breast feeding and weaning patterns allows an insight to be gained into the lives of nursing women, in particular how long they would prioritise exclusive breast feeding over other duties.

The potential of stable isotope analysis to investigate the diet of children post-weaning has only just begun to be explored. The ability to contrast levels and sources of protein available in childhood to that of adulthood can

indicate whether or not children had the same access to foods as their adult contemporaries. If Crawford is correct in her interpretation of Anglo-Saxon childhood as one where children were important members of their families, we would expect children to have the same or better access to food as adults, which would be reflected in overlapping ranges for carbon and nitrogen stable isotopes. If children occupied a more liminal place in society, we might expect them to have reduced access to high protein resources, which would be reflected in lower carbon and nitrogen isotope ratios in their teeth as opposed to bone formed in adulthood. These scenarios may be termed nurture and nature, whereby in the first, nurture, scenario children are heavily invested in by both parents and society in order to give them the best chance of surviving into adulthood. In the nature scenario, we would interpret a lower level of parental investment in their offspring, perhaps preferring older children and adults who make a more substantial contribution to the household economy.

Although parental and societal attitudes to children are difficult to solely reconstruct from the archaeological record, there are enough ethnographic parallels to indicate that the western ideals of the child as innocent and helpless are not universal. Furthermore, western notions of childcare are not suitable in all contexts, and may be downright detrimental in some. In particular, Nieuwenhuys (1996), states that although explained away as play, education, training and socialisation, many children in the developing world are economically productive. In many poorer households, particularly those in rural or industrialised areas, a large number of children is seen as an important (and free) labour source. This source of labour can be particularly important in informal and domestic economies. Impoverished Brazilian children will often have street-based jobs, returning to their families at night and on days off. Although juvenile working is frowned upon by the developed world, a study by Campos *et al* (1994), indicated that the families of these street children buffered any negative impacts that such work might have had. This was in contrast to those children who both lived and worked on the street, who were more likely to be emotionally damaged.

Attitudes towards children are as varied as the many parents and societies that exist now, or have ever existed. Children may be doted on, marginalised, idolised, used, valued and ignored and their lives are acted upon both by themselves and by those in their surroundings. As one of the most fundamental aspects of life, eating and food can reflect some if not all of these attitudes and reflect upon the place of the child in their society. It is this placement of the child within Anglo-Saxon society that the isotopic study presented here hopes to shed light on.

Thesis structure

The concept and experience of childhood has been the focus of much recent research; the first part of chapter 2 gives an overview of this research and discusses what early medieval childhood might have been like. The second part of chapter 2 investigates research carried out on infant childhood and childhood diet, focussing first on anthropological investigations and then on what has been determined for dietary habits in the early medieval period. The use of stable isotopes in investigating palaeodiet is reviewed in chapter 3, including an introduction to the methods currently in use to extract isotopic information from human hard tissues. Chapter 4 introduces the sites and methods used in this project; and discusses the method development resulting in a protocol to sequentially extract the organic and inorganic components of tooth and bone. Chapters 5 and 6 present the results of dental anthropology and stable isotope analysis carried out for the Black Gate Cemetery, and sites in North Lincolnshire. These results are interpreted and discussed in chapter 7, where the social and scientific implications are drawn out. Chapter 8 summarises the major findings of the project and identifies areas for future research.

Chapter 2: Children, Diet and the Early Medieval Period

Concepts of children and childhood in the modern and historical eras and their value in investigating early medieval childhood and childhood diet.

What is a child?

In the contemporary western world the word 'child' is imbued with a specific set of 19th-, 20th- and 21st- century connotations that include vulnerability, lack of social agency and dependence on care provided within a nuclear family. Family is itself a concept that requires some exploration before it can be usefully employed. Our modern concepts of family do not necessarily translate well back into the near past, let alone the distant. For example, there are no terms in classical Greek or Latin that precisely correspond to our word 'family' (Herlihy, 1985). In records and discussions of what we might describe as family life, classical authors tend to use terms that signify all members of a household (including slaves and servants) who came under the authority of a head (*ibid.*: 2). Therefore when researching into an aspect of childhood experience in a particular period it is helpful to have an insight into how children and childhood have been regarded by different researchers and in different periods of the past.

This chapter consists of two themes. The first discusses how the concepts of children and family have changed over time and how these have been portrayed by the various researchers into these periods. Research into childhood in the early medieval period forms the final part of this section and the aim is to draw together aspects of research from this and other periods to give an outline of what the experience of childhood might have been like in this period. Secondly evidence for dietary practice, the focus of this thesis, is discussed. This is currently an under-researched field and while there has been some broadly thematic work published in this area, there is very little detailed evidence available from the documentary or archaeological record. Anthropology has, as a discipline, been traditionally more interested in the processes and practice of consumption and so evidence from the modern

world is presented before that of the historical from which parallels may be drawn. There is a broad variety of anthropological, and demographic, data on infant nutrition, morbidity and mortality; less research has been published on the diet and eating habits of older children. I conclude this chapter by discussing how diet can add to what is known about early medieval childhood and what further research can tell us. Specifically can we determine if children had the same diet as their parents and what does this mean if they did, or if they did not?

The classical child and the barbarian child

The experience and ideas of childhood and family in the early historic period can be divided on a roughly geographical basis into those areas influenced directly by, or within, the Greek and then Roman empires and those without such influences. The experience of the Classical Greek child essentially predates that of the Roman, but through the incorporation of aspects of Greek philosophy and the idealisation of Greek culture these experiences could have had an influence on Roman childhood. Experiences and concepts of children and family from within and without the classical world would come to have an influence on childhood in the later Anglo-Saxon period, through the teachings of Roman Christianity and the ideals developed in the Germanic homelands of the peoples who settled in England.

In the Classical, pre-Christian world *Familia* originally meant a band of slaves, (Herlihy, 1991), and then came to designate servants or serfs. Roman law described a family as a group of persons who are placed under the authority of a single person and could include from blood relatives, servants and the clients and retainers of a powerful person (*ibid.:* 3).

Despite this, the concept of childhood was clearly defined. Classical Greek civilisation formed ideas on childhood and adolescence, which was displayed in their language and iconography. Classical iconography depicts three stages of life before adulthood: infancy, childhood and adolescence. In her study on Athenian adolescence, Beaumont notes that both male and female adolescents receive characteristic, gendered depictions in art (2000), and

that the difference in the representation of males is due to their protracted period of social adolescence.

Late Roman writings identify tolerance for slow growth and an enjoyment of children; paradoxically there is also a sense of resignation and fatalism towards child-rearing (Lyman, 1974). Sons were generally far more important than daughters, as the essential purpose of the child was to bring pleasure and honour to the parent (*ibid).*

Population size in late antiquity remained stable with small families[1], Herlihy attributes this to the view that the world was over crowded and (in the Christian era) coming to an end, leading couples deliberately to limit the number of offspring (1985: 26). This assertion raises the question of how parents might view their offspring: in part they must surely have felt the importance of heirs to carry on the family name and support them in their old age; demographic research indicates that in pre-modern societies, particularly those without state support for the elderly, the primary purpose of having children was as an investment for the future (Reher, 1995). Paradoxically, some Christians felt that reproducing at all was in some sense against their religion; yet the advent of Christianity profoundly influenced the treatment of children, condemning traditional methods of controlling family size such as exposure of infants and infanticide (*ibid.*). The doctrine of the Church fathers encouraged a softening of attitudes to children, while simultaneously introducing the concept of original sin and an irrepressible appetite for evil. Augustine advocated the hard and frequent punishment of the child while romanticising the period of childish innocence (*ibid.:* 27-8).

Outside the borders of the Roman Empire, other societies also had complex ideologies and social webs relating to kin and family. These societies would also influence the subsequent early medieval period through the missionary

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[1]Herlihy cites Brunt (1971 p131) who asserts that any growth in population in ancient Italy can be fully accounted for by the accretion of slaves, while the old Italian stocks had dwindled. Russell (Russell, 1958) states that the average household in the Roman Empire consisted of a man-wife-child unit, but that the actual population size declined between the time of Augustus and the fourth century AD.

work, migrations and settlements of their descendents. In Ireland contemporary sources indicate that, although monogamy was prevalent, this did not prevent powerful men having extra wives and concubines (Herlihy, 1985: 34). Nevertheless the tradition of tracing descent in a bilineal manner (i.e. through both parents) meant that women were of great importance in defining familial relationships. Women were commonly located in a small number of households as wives, concubines and slaves and this raised a number of problems. Firstly, Herlihy suggests, children could be at risk from jealous stepmothers, trying to ensure the ascendancy of their own offspring. This may have contributed to the common practice of fostering in powerful households, the safety of the child as well as the forming of alliances was important. In practice this often meant that the foster children were incorporated into their foster families, reflected in the extension of incest laws to cover foster-siblingship (Parkes, 2003: 755-6).

Parkes (2003) states that the fostering out the offspring of an important family precipitated often violent conflicts when the head of the family died and a successor was to be selected. This also occurs in medieval Wales, which had a similar system of fosterage: Gerald of Wales states that the Welsh princes' habit of fostering out their sons to different noblemen in their territory meant that if the prince dies, each nobleman plots to ensure that his foster son is the successor and achieves dominance over his other blood brothers (*ibid.*:755).

Secondly, Herlihy believes that as there were far fewer women available for lower class males, bands of vagrants and armed robbers were encouraged (Herlihy, 1985). Finally, the multiplicity of women, combined with male dependents and servants in one household could create extreme difficulty in ensuring that all offspring were sired by the head of the household. This meant that the relationship between and a man and his sisters child was extremely important, it was only through this relationship that he could be sure that the child was his blood kin (*ibid.*:35-42).

Polygyny (having multiple wives) was probably also common amongst the Germanic peoples, for example even after their conversion to Christianity, the Merovingian kings kept several wives and concubines (Herlihy, 1985: 49). Like the Irish this was a resource polygyny: those who could afford to kept more than one wife. The German Sippe or kin group was also bilineal and laid great importance on relationships traced through women. While men were favoured, women indicated whom amongst them should be preferred (*ibid.*: 51). Tacitus implies that the Germans reared many children (unlike the Romans they did not systematically practice infanticide), but did not invest heavily in their upbringing, whether psychologically or materially[2].

There was then a variety of beliefs and attitudes to children and their upbringing in pre- and early-Christian Europe whose traditions could have been known in one form or another to their later Christian descendents. However, it is possible that early Anglo-Saxon England displayed little or no connection with the earlier British kingdoms, and still less to the days of the Roman Province of Britannia (Stenton, 1947; Hinton, 1990). The new inhabitants seemingly had more in common with their Germanic neighbours and forebears. With the acceptance of the overlordship of the Roman Church in English Christianity in the seventh century those teachings on children prevalent in the Mediterranean could have been disseminated across England. However, the writings of the earlier, pagan, Greek and Roman are unlikely to have become widely known in Britain to any but the well travelled and educated few, until the later medieval period, and thus may not have influenced Anglo-Saxon attitudes to children.

Later Medieval childhood

Before discussing the sparse evidence for childhood in the early medieval period, it is apposite to review research carried out into childhood in the later medieval period. This can be used to further illuminate what we do know about childhood in the earlier period, working on the principle that while

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[2] "The young master is not distinguished from the slave by any pampering in upbringing. They live together among the same flocks and on the same earthen floor" (Tacitus, 1970: f20).

societies are in continual flux, changes in day to day living, for example how children are treated and viewed, occur extremely slowly. Documentary and, to an extent, archaeological evidence gives us a clearer picture of both the concept of children and childhood, and the lives they may have led, which can then be used as a comparative tool to assess the evidence for children and childhood in Anglo-Saxon England. Research into medieval childhood has evolved from its beginnings in the sixties as a dispiriting view of a hard, dangerous and sometimes cruel childhood to one where a close, affectionate family is paramount. An excellent overview of historical research on childhood has been written by Cunningham, who asserts that the lives of children reflect both their biology and the cultural assumptions of the time and place in which they live.

The development of research into medieval childhood

Often discussed by subsequent authors, Philippe Ariès book *Centuries of Childhood* (1962) has been portrayed variously as giving a too gentle view of childhood by psychoanalytic historians, such as de Mause (1974a), and a too harsh by social historians such as Orme (2001). This is in some respects to misinterpret what Ariès was trying to do. In his introduction, Ariès states that the book is about the *idea* of family life, rather than the family as a reality (1962: 9) and that this idea of family, and thus children as members of such a unit did not come into being until the end of the medieval period. One of the weaknesses of Ariès research is the nature of the evidence he uses to make suppositions on medieval attitudes towards family and childhood. The statement that early medieval artists were unable to depict children except as men of a smaller scale is unsupported by any evidence in the text. A quick search through Crawford's *Childhood in Anglo-Saxon England* (1999), amply illustrated by early medieval illustrations, shows that while many illuminations depict children with a certain adult cast, they are still distinguishable as children, distinct from their accompanying adults. Much of the evidence used by Ariès to illustrate the lack of childhood and family life in the medieval period dates from 15th- and 16th- century memoirs; all of these derive from the ruling sectors of French society and therefore have little relevance to the rest of the population. These are used to show that the idea of childhood

was bound up with the idea of dependence, leading dependant adults in France to be referred to by the same words as those used for child and children. Ariès succumbs to the temptation of using evidence from the late medieval and renaissance elites to draw general conclusions throughout the whole of medieval Europe. Such conclusions would be shown to be unsubstantiated when subsequent researchers, such as Attreed (1983) discussed below entered the field of medieval family and childhood.

Ariès states that "People could not allow themselves to become too attached to something that was regarded as a probable loss" (1962: 38). The fragility of the medieval child's life is used to explain his claim that parents did not bond to their children in the same way as modern parents do, and thus did not construct a modern family in their relations. This lack of construction of childhood is also, he believes, shown in children's dress. His statement that "Nothing in medieval dress distinguished the child from the adult" (*ibid.*:50), is belied by the fact that most representations of dress for this period would have been in stylised representations of the elite, who perhaps wished to emphasise the social status of an individual or their family, rather than their age status. Religious representations of children would also carry messages to the viewer other than the simple picture of a child. There are two further considerations to take into account: amongst the poorer levels of society, it would have been important to make clothes that lasted and conformed to the prevailing social conventions rather than distinguishing children from adults. This could surely have been done, if necessary, on physical appearance such as hairstyle, accessories, and so on. Secondly Ariès was writing at a time when there was an obvious distinction in the dress of children, and increasingly teenagers from members of adult society. This started amongst the Victorian elite with their idealisation of childhood, gradually spreading through emulation to other social strata and increased in the post-war era with the advent of the teenager (Holland, 1992). Today we see a gradual decrease in the differentiation of child's dress from that of adults, particularly in the everyday casual wear so many of us prefer, in which children's clothes are often miniaturised versions of adult attire. I would hesitate to argue that there was a lack or family, of concept of children and childhood today.

Centuries of Childhood traces a picture of the development of the ideas of childhood and family from an unconscious to a conscious social construct. Games and pastimes are gradually seriated according to the age of the participants; school systems slowly become more complex and the period spent in education extends. In profane iconography Ariès describes a changing style, moving from a focus on trades and crafts in the medieval period, to the gradual introduction of depictions of family and private life in the fifteenth and sixteenth centuries; he believes the visual depiction of family life achieves full expression in the seventeenth century. The slow development of an idea of family is linked to the gradual deterioration of the wife's position in the family from the fourteenth century. The beginnings of Ariès conception of the modern patriarchal family, a strong male head with his wife and children subject to him, is placed in the sixteenth century when a wife becomes unable to do anything without the authority of her husband or the law. Ariès believes that the importance of children to the medieval parent was not so much the love they felt for them, but the "contribution those children could make to the common task. The family was a moral and social rather than a sentimental reality" (Ariès, 1962: 368).

There have been numerous subsequent critiques of Ariès work, Attreed (1983) uses evidence from narrative literature to contradict his neglect thesis and suggest a caring treatment of children. She points out that Ariès fails to explain how any children could have survived such an atmosphere of neglect as that which he suggests is pervasive throughout medieval society and that in his reliance chiefly on early modern French data he has ignored the other sources of evidence available to him. Attreed believes that the evidence of narrative literature, and the public reaction to the behaviour of Richard IIIs towards his two nephews at the very least indicates that medieval children were no more spoiled or neglected than those of today. However as Cunningham points out:

> It was Ariés' achievement to convince nearly all his readers that childhood had a *history*: that over time and in different cultures, both ideas about childhood and the experience of being a child had changed. (1998: 1197).

Ariès believed that

> In medieval society the idea of childhood did not exist ... The idea of childhood is not to be confused with affection for children: it corresponds to an awareness of the particular nature of childhood...this awareness was lacking ... [A]s soon as the child could live without the constant solicitude of his mother ... he belonged to adult society. (1962: 128).

In the book *A History of Childhood* (1974b), de Mause developed this idea to its fullest expression. His central thesis posits that the further back in history one looks, the lower the level of childcare and the more likely children are to be killed, abandoned, beaten, terrorised and sexually abused. He uses the psychoanalytical theory that childrearing practices are the basis of adult personality to put forward the psychogenic hypothesis that the central force of historical change "is neither technology nor economics, but the 'psychogenic' changes in personality occurring because of successive generations of parent-child interactions" (deMause, 1974a: 3). De Mause suggests that changes in parenting over time are brought about not by societal or economic pressure but by a generational impulse born of the anxiety of one generation to treat the next generation of children better than they had been treated by their parents. Only a few examples are used to illustrate his thesis of generalised cruelty to children in the pre-modern period, perhaps claiming the exception to be the rule. De Mause suggests that parents in history projected their adult wants onto their children rather than empathising and giving them what they need. Although they loved their children he felt that parents lacked the emotional maturity to see the child as a separate being. Homicidal tendencies towards infants were widespread, and judging from those patients in psychoanalysis, this is still widespread today. This last point serves to illustrate the extent to which de Mause's theories have been skewed by his psychoanalytical perspective. His experience in this field appears to have produced a tendency to generalise the worst tendencies of a minority across whole populations and eras. There is also a tendency to use emotive writing rather than evidence to make his points.

De Mause's ideas have led him to define 6 modes of parent-child relations across history: (1974a: 51-4)

1. Infanticidal Mode (Antiquity – 4th century AD)
2. Abandonment Mode (4th – 13th centuries)
3. Ambivalent Mode (14th – 17th centuries)
4. Intrusive Mode (18th century)
5. Socialisation Mode (19th – mid-20th centuries)
6. Helping Mode (mid-20th century -)

These catagories trace an evolution of parent-child relations from the harsh Greek or Roman parent through to the caring modern family. Specifically for the early and later medieval period, de Mause identifies an abandonment, then ambivalent mode of child care. This abandonment mode is defined as the spatial and emotional distancing of parents from their children. Offspring are sent away as soon as is possible and do not return home until they are grown, thus preventing the formation of close bonds between parent and child. These ideas are gained from research into the elite members of society, who followed different conventions and norms from their social inferiors. However true such theories are for one section of society, they cannot be easily more broadly applied. Subsequent historical research has indicated that there was a significant level of parental investment in children throughout the medieval period. Even in those instances where children were sent away from home, there is evidence that in many cases parents still felt solicitude for their children, as Hanawalts (1996) work on Lady Lisle, discussed below shows.

Researchers such as Hanawalt contend that sources covering a wider range of society indicate that there was both an idea of children and childhood and that parents and families acted on these ideas, including accepted moral codes, to raise their offspring as best they could. Coroners rolls indicate that accidents involving children "could cause distress to the villagers who commented on the quality of child care or the lack thereof." (Hanawalt, 1988: 41). Children were viewed as a trust from God and considered alternately vessels of sin, a parents' burden and innocent and pure (Shahar, 1990), such conflicting ideas from church and society inevitably placed the onus on

parents to raise their children as best they could within the confines of acceptable behaviour at the time. While there was undoubtedly disease, neglect and abuse, as suggested by Ariès and de Mause, more recent authors have asserted that, as is the case today, most parents tried to love and protect their children (Hanawalt, 1986a, 1993, 1998; Orme, 2001).

A more recent discussant of the history of childhood has outlined a number of ways that we might carry research forward, for all periods of history. Drawing on the sociological theories of childhood outlined above, Heywood (2001) suggests that while medieval societies did have a concept of childhood, they understood this as a process of development, rather than a fixed state. He also believes that medieval childhood and adolescence was less distinct and special, lacking "the element of choice and experimentation which makes these stages of life so critical for the individual today" (*ibid.*:18). As a generalised statement, this is certainly more appealing than the benign neglect postulated by Ariès, or the brutality depicted by de Mause, although research into the level of social experimentation available to medieval children and adolescents may bear interesting fruit, and reveal whether the degree of choice and particularly experimentation available to the medieval young was greater or lesser than today.

The flaws in the research of Ariès and others remind us that it is important not to reflect our own understanding of childhood and family back onto the past. Such anachronistic research techniques prevent us from gaining information on the realities of childhood in other periods. The diversity of modern childhood and family experiences serves to remind us that there can be differences within societies, and within individuals as well as between them. It is this concept that we should try to keep in mind when looking back to the past.

What might medieval childhood have been like?

There are a number of literary sources available to the medieval historian when researching childhood. All have strengths and weaknesses, but used in combination they can at least give us some idea of both how children were

viewed and the common events of their daily lives. Medieval theorists, such as Isidore of Seville, who used the Ptolemaic system of seven ages to divide human life into a series of stages divided childhood into three parts: *infantia* (birth to seven years), *pueritia* (seven to fourteen) and *adolescentia* (fourteen to the age of majority) (Orme, 2001). During the medieval period the age of majority for males was increasingly seen to be twenty one, meaning that individuals came of age almost ten years later than in the early medieval period. However the teenage years still saw a number of landmarks for both males and females, such as the ability to hold non military tenancy's and give testament (Flemming, 2001).

Adult responsibility for children was reinforced through law and folklore (Hanawalt, 1998: 159). Coroner's reports can give detailed information on the short periods of everyday life preceding an accidental death or crime. These show divisions of labour for adults and children, again along gendered lines. Hanawalt (1986b: 8) has shown that the patterns of accidental death of children reflect those of their parents of the same gender from the ages of two or three. This was possibly due to children following their same gender parent around as they worked, learning their skills. Accidents outside the home accounted for 64% of boys but only 44% of girls' deaths. Coroner's reports also indicate that community values accorded a special status to childhood; the innocent nature of children is also reinforced by miracle stories (*Ibid.:* 160-1).

Advice to parents was given by the Church, often through sermons. Swanson discusses late thirteenth century *ad status* sermons written by friars (1990), demonstrating a trend towards increased awareness of children as a group with specific characteristics and needs. These sermons were used by parish priests and itinerant preachers and the idea that children were intrinsically good despite the sins characteristic of childhood would have percolated throughout society.

Information on the activities of children is also found in hagiographies, and such sources indicate that childhood was gendered. Although such

representations often depict an idealised rather than a real childhood, they still give information on childhood activities. Female visionaries are often depicted cooking and sewing as children, as well as playing; such girl children are presented as pious and inclining towards the religious life (Voaden and Volf, 2001: 144). Conversely, accounts of male visionaries usually focus on a mis-spent youth followed by a secular and materialistic young manhood (*ibid.:* 145). These sources illustrate the conflicting views of the church on families. The church was suspicious of families as they saw their claims as competing with those of God; at the same time they idealised the holy family as a model to which all could aspire.

The lives of saints make use of family images as metaphorical descriptions of saints' mystical experiences (Herlihy, 1985: 115). Many female saints nurse the infant Jesus; this was seen to promote affection between nutritor and nutritee. Just as the cult of the baby Jesus was the chief arena for expressions of both sacred and profane sentiments concerning childhood, the cult of Joseph was the chief source of images of fatherhood. Joseph is bound to his wife and child by bonds of deep affection. Interestingly, this latter cult did not appear until the later medieval period, probably promoted by the Church when populations had been decimated by plague, famine and war (*ibid.:* 125-8).

Fictional writing from the medieval period can also tell us about the lives of families and children. In these accounts, the male and female spheres are often divided from each other in both physical environment and types of work. Hanawalt gives a number of examples of this (1986b: 7):

> When Adam delved and Eve Span
> Where then were the gentlemen
>
> The good-wyfe came out in her smok,
> And at the fox she threw hir rok [spindle].
> The good-man came out with his flayle,
> And smote the fox upon the tayle

From these two rhymes we can see the accepted gender divisions amongst agricultural communities. Males were farmers, tilling the fields, while females

produced domestic commodities such as cloth. Spinning remained a female domestic activity throughout the medieval period; women of all ranks are often depicted with a spindle and any spare time was supposed to be occupied with spinning yarn. This domestic activity fed directly into the commercial activity of weaving. Dominated by men since the invention of the horizontal loom in the 12th century (Walton, 1991), cloth production still relied on the yarn provided by women, enabling females to make an additional contribution to the household economy.

Finally, medical and other didactic sources of literature can also give us some indication of how children were viewed and cared for. While these sources would not have been available to all members of medieval society, their tenets would have percolated through the teachings of clergy and the observation of other classes. Western medieval medical writers, building on earlier Greek and Arabic medical knowledge developed a series of paediatric, obstetric and gynaecological treatises which provided practical advice and theoretical insight into child rearing. High medieval writers "believed that the child in its earliest stages of growth was inherently fragile and susceptible to disease and could succumb quickly to physical ailments" (MacLehose, 1996: 3). As many believed that mother's milk was actually a form of digested menstrual blood, and therefore potentially dangerous as well as nutritious, advice was given on how to care for both mother (or wet nurse) and infant so that the child was not inadvertently poisoned by the corrupt humors of maternal milk (*ibid)*.

Familial power was a common feature of medieval life; Stafford and Mulder-Bakker tell us that a woman's

> fertility was politically crucial, and along with its expression in motherhood, furnished potent imagery to be deployed in the struggles over inheritance and succession which were such a feature of politics (2001: 3).

Through out all strata of society, beneficial alliances between families were often achieved through marriage and cemented by the couple's issue.

During the central and late Middle Ages, patrilineage became the dominant form of kin organisation (Herlihy, 1985: 79), although the church doctrine of marital consent by both parties limited the development of a truly patriarchal medieval family (*ibid.:* 81). This underpinned the segregation of gender roles, particularly in the work sphere, throughout the lifetime of an individual.

Women were the principal carers for female children in medieval society; theirs was the domestic sphere and they rarely travelled away from home for work (Hanawalt, 1986a: viii). While children did enjoy the affection of both parents, fathers were far more likely to be concerned with the upbringing of their male children than their female (Hanawalt, 1998: 165). Daughters learned the work of the household from their mother's knee and were socialized to different economic activities to those of sons. This ensured that the family unit of husband, wife and children would contain the core skills of the basic medieval economic unit.

While it was advocated that mothers should be the principal carers of their infants and young children, children could be given over to the care of wet nurses and nurses when this was financially possible. Cases of wet nursing in medieval England were chiefly restricted to the upper classes. This was not true in other areas of Europe. In 14th- century urban Italy, middle class children were often sent to a wet nurse in the country soon after their birth and baptism, where they would remain for about two years, or until weaning was completed (Ross J.B., 1974). Despite the recommendations of contemporary writers, there was much social pressure against maternal feeding. After recommending mother's milk, most treatises of the time devote themselves to the problems of identifying and retaining a suitable wet nurse (*ibid.*). Other advice given in these treatises included separating male from female children, not allowing parents to touch their child, preparing children for starvation by sometimes giving them bitter foods and for sickness by administering purgatives. However such prescriptions reflected religious attitudes and sexual fears more than secular reality.

In Europe, urban, and to a lesser extent, rural boys often went into service or an apprenticeship in their teenage years. Parents would take great care in placing their offspring in this manner, the training and placement of their children was important to ensure their well-being and therefore their survival and perhaps happiness (Hanawalt, 1998: 172). Servants would be hired on a yearly basis, although an adolescent was likely to spend a number of years in service often with a master who was related to him or her in some way (Flemming, 2001). Apprenticeship lasted for a far longer period than the tenure of a servant and the apprentices parents would pay the master a fee in return for which both board and lodging, and training in a craft would be provided. Apprenticeships would start between twelve and sixteen and the more prestigious the craft, the longer the apprenticeship would be (*ibid.*). Less commonly, girls could be put out to an apprenticeship, in an accepted 'woman's craft' (Reyerson, 1986: 121). Most women would work in occupations requiring skills learned within the domestic environment: servantry, food retailing, brewing, cloth manufacture; nursing of children and prostitution were also traditional womens occupations that did not usually require an apprenticeship (Kowaleski, 1986: 155).

Upper class children were also often sent away from home and into fosterage and/or service in this period. The explanation given for this was so that they might learn better manners. Parents were also aware of the career opportunities available for their children, they were often remembered for offices and annuities after serving powerfully-placed strangers (Attreed, 1983: 47). It has been suggested that fosterage was detrimental to the well being of the child, depriving them of the caring environment of their natal families. While this may have been true in some cases, there is also evidence to the contrary. In her discussion of the female fostering used by Lady Lisle for her daughters, Hanawalt (1996) demonstrates that parents would spend time and money searching for suitable households in which to place their children. In addition to being of higher social status, a family where the skills required by the child could be taught, and a congenial environment was preferred. The letters of Lady Lisle and her family indicate

that strong attachments were maintained between those remaining at home and those living away throughout the period of fosterage or service. Strong bonds were also formed and maintained with the families the children were placed with; one daughter, Mary, writes that if she could see her mother on a regular basis, she would be very happy always to stay with her foster family (*ibid.*:245).

Early medieval children

Anglo-Saxon childhood

Family ties were important throughout all levels of society in early medieval England. Family and kin determined how a member might participate in daily life and emphasised the divisions between man and woman, adult and child (Stafford, 1985: 147). It is necessary to emphasise that political and economic life was documented chiefly by males. The use of the scarce documentary sources must therefore always be carried out with the awareness of potential biases and omissions in the record. Children in this period, as in the later medieval period are written about; however childhood is seen principally through the eyes of monks, who had been children themselves, but not, usually, parents. Parental roles are therefore rarely articulated (McLaughlin, 1974).

It is not possible to discuss childhood in this period without critiquing Crawford's *Childhood in Anglo-Saxon England* (1999). This is the only work devoted solely to early medieval English childhood and any subsequent research must be influenced by Crawford to some extent. The book draws on documentary and archaeological evidence to discuss the progression of children's lives from infancy to adolescence, exploring aspects of health and childcare, education and play, the family, fosterage, God-parents and adoption. Aiming to reconstruct the 'shape' of the Anglo-Saxon family and the place of the child in that family, Crawford posits that the Anglo-Saxons not only had a concept of childhood, but that children were cared for and brought up to the best of the society's ability. As with any early comprehensive work in an area, Crawford's thesis is interesting, but not without flaws. The importance of kin groups and thus familial structures to

Anglo-Saxon society is repeatedly emphasised. An individual would be dependent on his kindred for protection of his person through the structures of the feud and payment of wergild (John, 1996). In early Anglo-Saxon society, the kin group would undertake responsibility for children in the event of the death of the father (Hadley, 2000), but it has been suggested that the nuclear family and therefore children increased in importance in the Christian era due perhaps to an alteration from smaller kin-based geopolitical units to larger regional and even national identities. If this is the case, responsibility for children where a parent was deceased may have been divided between the immediate family and political and religious authorities, rather than within an extended kinship network.

Such identities might be focused both on Christianity and on an urge towards an English identity, formed in opposition to the common threat from the Danes (Foot, 1995), although work by Hadley (2000) indicates that the Scandinavian influence may not have been as all encompassing as previously thought. While such factors would inevitably affect both individual senses of identity, and the identity of kin groups, these identities are storied[3] and formed through reflexive processes of group and individual interactions (Frazer, 2000). There was a shift from bilateral (descent traced through both parents) to agnatic (traced through the male line) kinship strategies, particularly from the tenth century onwards as aristocratic energy and resources were increasingly invested in monastic programmes (Wareham, 2001). Crawford believes that this alteration in focus had reconstructable effects on attitudes towards children. In particular, she cites a lack of specific terms in Old English for more distant relatives, the normal pattern of inheritance by widows and children and the statistic that less than 10% of the earlier Anglo-Saxon populations were aged over forty five to reconstruct a nuclear family grouping of parents and children, with few grandparents.

[3] Frazer posits that people form multiple, changing biographical identities that reflect the situations they find themselves in and the people they interact with. These identities are essentially narrative in form (hence 'storied') and change over an individual's lifetime.

Aside from the problem of using evidence from both the pre- and post-Christian periods to construct a general family pattern, for example the (13th to 14th century) Halesowen records which indicate that girls tended to marry at 18 years of age or later when they had sufficient dowry (Razi, 1980), Crawford's contention that families lacked grandparents or kin groups beyond the nuclear centre is unlikely to be universally correct. There are old English terms for nieces and nephews, and kinsman or woman is often used to imply a familial relationship less close than sibling or offspring (Fell, 1984), indicating that these groups did not simply disappear with the advent of Christianity. Crawford's hypothesis of small nuclear family groupings is partly based on the age of women buried with infants in cemeteries and the estimated impact of a low average life expectancy.

Crawford uses the late age of three of the four women buried with infants at Abingdon (two were in their twenties, one was over forty-five) to imply that, as the highest risk of maternal and infant death during parturition is with the first or second child, women were not having children until they were in their twenties, or later. This would enable children to be born who had the greatest chance of survival but would reduce the number of children women were able to bear and mean that if the life expectancy data is correct, they were unlikely to survive to become grandmothers. In reality, in a situation where skilled medical help is unavailable, maternal death during and post-partum can have a number of causative factors. These may or may not include primiparity, multiparity, age (both young and old), and levels of nutrition and health status (see for examples Andersson, *et al.*, 2000; Alexander, *et al.*, 2003; Mahbouli, *et al.*, 2003). Infants are at risk of death both through maternal factors and through factors that come into play after birth (Caldwell, 1996). It should also be remembered that maternal death related to parturition does not necessarily include the death of the infant, and may not occur on the day of parturition (Li, et al., 1996). It is therefore unlikely that the four women buried with infants, even if they are mothers and first born children, are representative of all maternal deaths in Anglo-Saxon England and any interpretations drawn from them on age at first birth are unlikely to be correct.

Her contention that low average life expectancy would have led to high rates of orphancy and a lack of grandparents is based on Goody's (1972) post-medieval data for English communities. During this period 42% of the registered population were children, of which 20% were orphaned and only 2.3% of children had a living grandparent. However this final figure is a misinterpretation, including only those households in which both the grandchild and the grandparent were resident and ignoring those grandparents who were not living under the same roof. As Crawford points out that newly married couples would often have the opportunity to set up house on new land, there is likely to be a large number of grandparents living in separate households. In addition there is a tendency to systematically underestimate the age of older members of any cemetery population (Buckberry and Chamberlain, 2002), leading to the older members of society being effectively hidden from the demographer's eye.

As a social category, childhood is unique in being at least partially biologically determined. Crawford ascribes some of the differences seen in the daily and yearly routine of the child to their society's reaction to this biological difference. This social difference is also seen to be reflected in the grave goods in the Anglo-Saxon pagan period. Crawford believes that there is a watershed at 10-12 years old where juveniles begin to be accorded adult burial rites (1999: 48). That childhood was a recognized social category is also evident in the manuscript illuminations for the later period, children are depicted as consistently smaller than adults, often with scaled artefacts (*ibid.*). Anglo-Saxon sources indicate that boys at least went through several distinct stages before achieving full adulthood. This is given the clearest definition by the 10th-century homilies of Ælfric, where the stages a child must pass through from birth to adulthood are contrasted with the spiritual rebirth of baptism. There were also a number of rituals that marked the transition from childhood to adult status. For free male children this would be the possession of weapons, in the 6th and 7th centuries, these would be handed over to the child at the age of maturity (Stafford, 1985: 147). Stafford (*ibid.*) believes that there were no female objects with the same significance. For

girls, the most distinctive rite of passage was marriage, any stages she passed through before this were subsumed in this life-altering event.

Before the transition from child to adult, an individual would go through at least two stages: infant and child. Crawford debates length and definition of infancy, drawing again on documentary sources to indicate that this period was defined by an utter dependence of the child on others and also a lack of communication, extending to about eighteen months to two years after birth (1999: 53).

In the network of interdependence and ties between family, community, noble and common born, one tradition seems to have remained an upper class phenomenon: that of fosterage. In the 6th to 8th centuries, it was common for the sons of the noble born to be fostered. This would forge close emotional ties with the surrogate kin, such a son would often take his foster father for his lord, ensuring a close bond of loyalty between a lord and his pledged men (Stafford, 1985: 163). There seems to have been a gendered division in the practice of fosterage, female children were kept and trained at home. The word 'foster' covered a wide spread of nurturing patterns, ranging from help for the parents within the household to the equivalent of full scale adoption. This mechanism for providing childcare relief for parents often has a greater value in traditional populations than in modern populations where there childcare is to some extent made available by society at large (Hewlett, 1991). There is no record of any of these practices being condemned by contemporary sources (Crawford, 1999: 122). Crawford believes that the most common type of fosterages was the importation of a nurse brought into an elite household, charged with raising the noble child. Again this would encourage the formation of warm ties between the nurse and her charge. Sending a child away to fosterage could be done for a number of reasons, particularly in troubled times this practice would not only form ties between different families, but also reduce the risk of having all ones offspring in one place. Not all cases of fostering were happy, abuse of the relationship could and did occur and laws designed to address this problem were formulated (*ibid.*:127).

Was childhood the same throughout Europe?

Evidence on childhood from Anglo-Saxon England can be enhanced by drawing parallels with early medieval Europe as a whole. Was childhood essentially the same in the countries England would have perhaps had contact with during this period and can this evidence tell us something about the general experience of the early medieval child?

The concept of family as the environment in which most children lived and grew up still did not exist in a definite and isolated form in early medieval Europe: *familia* could still mean a much larger household and its property, including slaves (Herlihy, 1991). During the early medieval period, the idea of a family farm which is inheritable becomes commensurate across Europe; peasant families became viewed as moral and fiscal units (Herlihy, 1985: 57). The teachings of the church imposed some uniformity on the peasant class across Europe, particularly through their insistence on monogamous marriages outside the seven degrees of kinship (by blood and marriage). This dictum also ensured a more even distribution of women throughout the levels of society than had previously been the case.

This changing set of ideals was also expressed through a system of patrilineage that was particularly prevalent in aristocratic societies. Beitscher (1976) has used the chartularies of six monasteries from the Limousin, France in the post-Carolingian era (specifically 814-1096) to show how the system of patrilineage often affected the relationships between male members of families. The charters concern the transfer of land from noble families to the Church; these might be whole properties, or portions thereof, with the remainder being retained for offspring. Problems particular to the area, for example the local geography that limited the amount of land available for cultivation, partible inheritance, gifts to the Church, dowries and 'morning-gifts' for wives led to the breakup of large estates and fierce intra-familial struggles for property, often reflected in the charters. Until the 10th century the charters, drawn up by adult monks generally ignored all offspring other than the dominant son. From the eleventh century, usurpations of land increased as more sons and daughters reneged on promises made by their

parent and so monastic officials insisted that children, usually the male offspring, signed the witness list (*ibid*.). Most children were born into vertical three-generation families, and the strongest family bond would often be between the grandfather and grandson. This was due to the competition between a son and the often large number of other siblings for parental bequests, the provisions of a grandfather would therefore be particularly welcome. On the other hand, relationships between sons and fathers often lacked affection and regard. Bequests by fathers to the church restricted the amount of land available for their sons, causing much bitterness and resentment. This was often expressed by the usurpation of the land by sons both following the death of their father and during his life, since by custom a *manse* was indivisible and its transfer required assent from all shareholders, including offspring (*ibid*.:188). This picture was often complicated by the infighting amongst siblings, all competing for a larger share of the familial holdings.

Nonetheless, children occupied a primary place in the lives of medieval adults, they were relied upon to maintain aristocratic bloodlines and make marriage alliances and for the less wealthy, to provide a workforce. There is, for example, evidence that prospective parents in early medieval southern Italy promised donations to the church on the safe birth of their child (Skinner, 1997).

There are European parallels of an early maturity amongst adolescent males, in particular the tendency to go to war before they are fully grown. For example the Limousin viscount of Comborn, Ebles II was around fourteen when he tried to reclaim his inheritance from his uncle. The local chronicler records that he besieged castles, raided the countryside and at one point, raped his aunt in front of witnesses (Beitscher, 1976: 184). The Limousin chartularies provide numerous examples of the early and abrupt onset of adult life, which resulted in a hybrid 'child-adult' whose identity began early and ended late in life (*ibid*.:185). The early medieval child in the Limousin must therefore have occupied a difficult place in society, having to transform

from child to adult without warning yet maintaining the attributes of a child until called to fill their adult role.

This then is a brief overview of the general picture of early medieval childhood. That this relies heavily on Crawford for England, is unsurprising, this is the first general work specifically on Anglo-Saxon childhood and targeted research on specific aspects of the childhood experience in early medieval England has yet to be undertaken. Children in England in this period appear to have been members of communities that cared about them and were concerned about their welfare and were concentrated for the most part in family groupings (their own or that of their foster families). This is not unique to the region, but the experience across the continent as a whole illustrates the variety of childhood experience at this time. This was not a novel situation, what little research that has been done on earlier historical periods indicates that, although the experience of childhood varied there was an underlying constant of parental concern and affection for their children. The far richer variety of evidence for the later medieval period indicates that this did not change. While there would have been many concerns and interests for the family group as a whole, children were seen as members of this group and contributed to it in numerous ways. Children may have been sent away into fosterage, service and apprenticeships or kept at home to work with the family, but this was generally done in a context where parents were concerned for the welfare of their offspring and wanted their children to have best opportunities they could provide.

It is within this context that children were eating and, while food production and consumption is one of the most important aspects of any society, this is one of the most neglected areas of research. Other than Crawford's (1999: 71-4) tentative suggestion, based on grave good evidence, medical remedies and dental wear rates that weaning occurred when the child was at least two to three years old is no research specifically on early medieval children's eating habits, or what they ate. The evidence there is, is discussed below, but in order to make any reasonable interpretations it will be necessary to draw upon anthropological parallels of eating habits in the modern world.

Looking at diet

The timing of maintenance activities: day to day routine, processes of food preparation, and child care and socialisation are the fabric of societies in the past and present and around the world. As Picazo states

> Maintenance activities, therefore, can be said to imply not only the creation or 'production' of social persons, but their constant re-creation by a continuous and interactive process of sustenance and socialization (1997: 60).

Studying diet fits into this context of maintenance activities and enables the elucidation of past societies though determining altering patterns of food consumption throughout the lifetime of an individual.

Diet, and thus levels of nutrition, affect the ability of an individual to perform in society. Undernourished children are characterised by excessive thinness and/or low stature for age, the most prevalent form being low height-for-age, or stunting (Dufour D.L., 1997). Severely undernourished children tend to be tired and lethargic and less inclined to physical activity, although they will respond quickly to an increased nutrient intake (*ibid*.). Therefore in societies where children are expected to make some contribution to household or community economics, ensuring adequate nutrient intake to support both their growth and their role is suggested to be important.

The majority of infants both past and present are initially breastfed. Again the extent and duration of this is not only physiologically determined but is also a social and there cultural process. Breastfeeding can have many different meanings and there can be little parity in the phraseology used (Armstrong, 1991), claiming a child is breastfed can mean anything from a toddler who receives the breast for a few minutes before bed to a child whose only source of nutrition is breast milk.

The Interagency Group for Action on Breastfeeding (IGAB) has proposed a set of clear definitions for breastfeeding patterns, which can be summarised as full, partial and token (figure 2.1). Clarity in the definition of breastfeeding is important as not only does the level of breastfeeding affect its nutritional

impact, but it is also necessary to clarify the weaning process. Weaning is normally discussed in two different ways: the gradual process of introducing beikost[4] to accustom the infant to eating foods other than breast milk (or its substitutes); and the final cessation of breastfeeding (Dettwyler and Fishman, 1992). Duration and exclusivity of breastfeeding in non-western and past societies could have a strong impact on the health and life expectancy of the infant (Knodel and Kintner, 1977). In their review of infant feeding practices and growth, Dettwyler and Fishman (1992: 176) report that researchers often suggest that many deaths associated with various forms of infant feeding could be averted if children were exclusively breastfed until 4-6 months of age and then continued to be breastfed whilst also receiving appropriate and adequate uncontaminated complementary foods until 2 years of age or beyond. This results from:

> the immunological content of maternal milk, the avoidance of contaminated water and foods, and an increase in child spacing via the suppressive effects of lactation on ovarian function. (Vitzthum, 1994: 308).

Breast milk can be synthesized efficiently from the mother's primary energy reserves, and provides a cocktail of nutrients specifically tailored to the individual child's needs (Ellison P., 2001). Indeed as the size of fat stores is related to breast milk intake (Forsum and Sadurskis, 1986), breastfeeding could have a prolonged influence beyond weaning. As parents and carers in the early medieval period would not have had access to sterile infant foods, it is reasonable to assume that most of those who survived to adulthood would have been breastfed, although the nature of the weaning process is less clear.

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[4] *Beikost* is "any non-milk food (neither breast milk, formula, nor any other milk-based product) given to the infant for nutritive purposes." (Dettwyler and Fishman, 1992: 174).

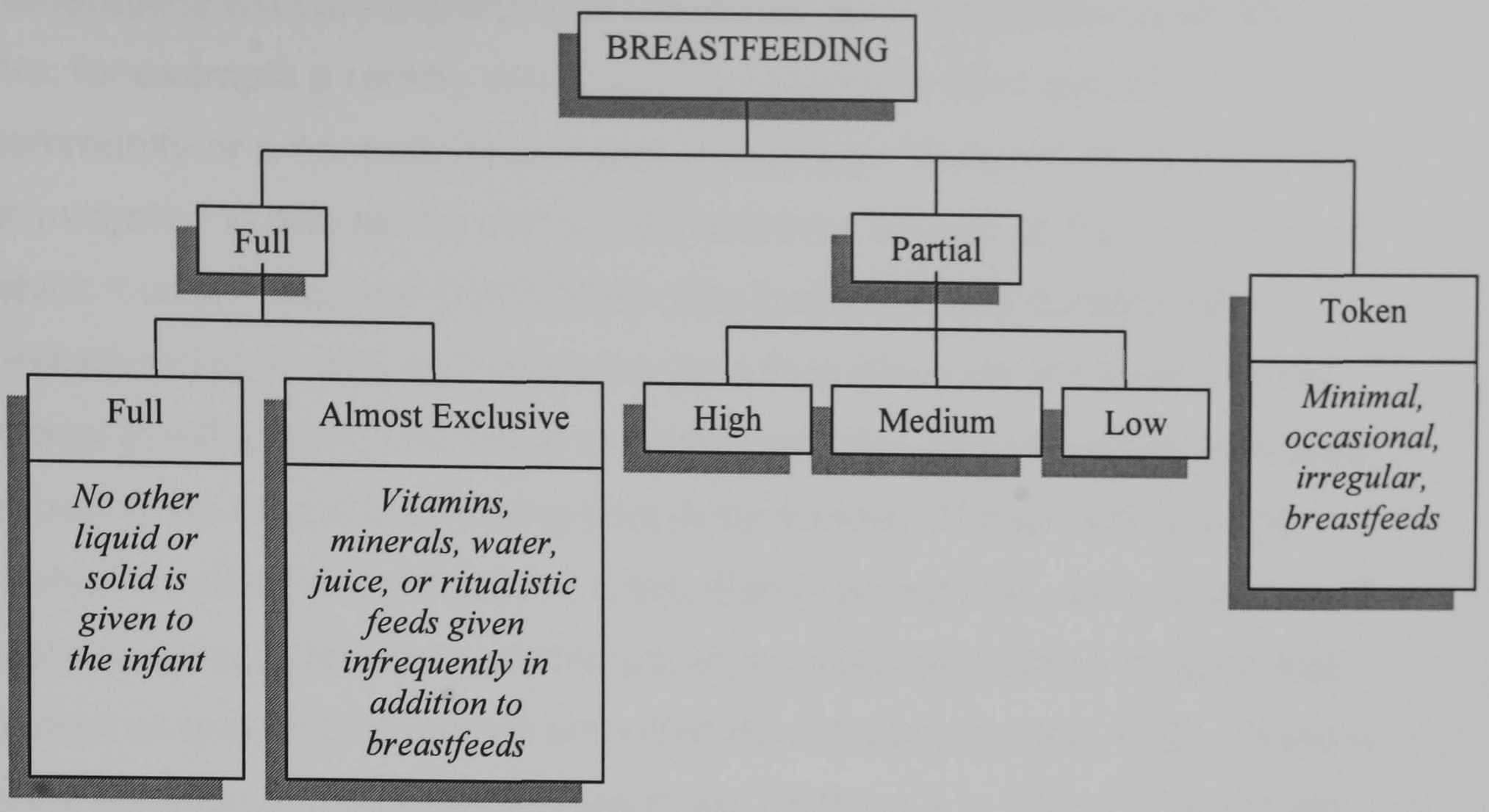

Figure 2.1: Schema for breastfeeding definition.

<u>Anthropological studies of children's eating patterns</u>

Early modern western societies

Demographic studies have been carried out on breastfeeding, fertility and infant mortality using early French, Canadian and German data (Knodel and Van de Walle, 1967). Data indicate that breastfeeding, as well as being beneficial to the child may have been used to affect birth spacing, as full breastfeeding often causes amenorrhoea. While the early studies discussed by Knodel and Van de Walle assumed universal breastfeeding in rural peasant societies, the German data used by the authors indicates that this was not the case. The percentage of infants never breastfed varied greatly between provinces and even in those areas where breastfeeding was common, the average duration was only seven months. In provinces, such as Bavaria, where it was not customary to breastfeed children, this practice could be traced back to before the sixteenth century and was often so ingrained that exceptions were met with social condemnation, this was despite breastfeeding being correlated with infant mortality (*ibid.:* 123).

Less developed societies

That children in the contemporary third word, as well as the European past are highly physically vulnerable, is undisputed. The nature of this

vulnerability will vary according to the structure of the society in which they live: for example a rapidly industrialising country, a rural agricultural community or a nomadic hunter-gatherer group. Vulnerability is exacerbated or mitigated in part by the diet a child receives, as well as the conditions in which it eats. Caldwell (1996: 612) cites incidence and duration of breastfeeding as well as family size (and thus strain on resources) to be critical in influencing childhood mortality patterns. Breastfeeding has been shown to be critical in ensuring post-natal survival of infants due to the protection afforded by maternal antibodies in breast milk; indeed studies of agricultural populations in contemporary sub-Saharan Africa indicate that almost all babies that are not breastfed do not survive (*ibid.*: 616). There is wide variance in infant feeding practices, as there is in all aspects of food consumption. Even when breastfeeding is the norm, supplemental feeding with other foodstuffs often occurs before full weaning takes place; for example the Melanu feed their infants a selection of soft starchy foods from when the baby is a few weeks old (Samuh, 1956).

Little work has been carried out on childhood diet or eating patterns post-weaning, however gender based nutritional differences have been researched in pre-industrial societies, particularly where there are high male-biased juvenile sex ratios (Hewlett, 1991). Those studies that do have an explicit focus on children demonstrate a wide variety of diet and eating patterns ranging from the Bapedi, whose basic subsistence food of porridges is eaten by everyone from weanlings through adults to the elderly (Waldmann, 1980); to the Kami of Nepal, whose women often cook special meals for their offspring and nurse them for a prolonged period (Panter-Brick, 1996). Data suggest that in societies where males contribute substantially more calories to the diet than females, or where warfare, or risky male tasks, result in high adult male mortality, sons will be preferentially cared for over daughters, gaining access to more calories and higher quality foods (Hewlett, 1991). Conversely some Sub-Saharan pastoralist communities buffer women and children of both genders from under-nutrition (Sellen, 1996), although no explanation has been offered as to why this might be the case. There are undoubtedly many cultures where diet is restricted for various

members of society through taboos or other mechanisms. Ross states that this can apply to both extant children and to pregnant and lactating women, thus prioritising the well-being of older children over new and future offspring (1987). Wheeler and Abdullah (1988) suggest that a characteristic of human groups is to develop some system of differential rights and access to food to cope with uncertainties in supply. This can often relate to children as well as sex based differences, indeed they claim that there can be differences in energy intakes in the order of 30 to 50% between adults and children despite children over five requiring the same amount of energy as a moderately active 'smallish adult' (*ibid.*: 437). Finally the actions of children in food procurement should not be under estimated, children may gather different resources to adults and in a different manner (Bird and Bliege Bird, 2000), and would therefore have the opportunity to consume resources at different rates.

Food and eating in the early- and later medieval periods.

Pearson discussed nutrition and the early–medieval diet (1997), giving a précis of research done by Hagen, Hodges and others. She notes that the cultivation of diverse grains, such as wheat, barley, oats and rye by various communities and suggests that this was a form of risk buffering to prevent grain shortages if one crop failed. Diversity of cultivars also ensured that the fields were used efficiently, as planting could be carried out in different seasons. Cereals would have been supplemented by legumes in many communities, providing both extra protein in the diet and a method of enriching fields that had been in cultivation for a number of years. Pearson emphasises the importance of meat to Anglo-Saxon households but gives no indication of the proportions in the day to day diet. Fish, fruit and vegetables and nuts would also have been available to early medieval populations at certain times of the year. Pearson (1997: 14) states that with the foodstuffs theoretically available, the Anglo-Saxon diet would have been

> marginally adequate by the standard United States Department of Agriculture food pyramid…It contained sufficient carbohydrates, proteins, and fats and minimally acceptable levels of the necessary vitamins and minerals."

Diet and the timing of sustenance activities in this period would have varied with social class, personal preference and the calendar (Hagen, 1992). Monastic rules such as the *Regularis Concordia* prescribes the times of day for meals, and the number of meals allowed, this would often be less in the winter.[5] Hagen suggests that in secular households, the main meals were possibly at the third hour and again at suppertime, allowing a full day's activity between the two (*ibid*.: 70). Both secular and religious communities would fast and feast at prescribed times of the year. Fasting was carried out both to expiate sin and in order to obtain God's mercy and compassion; it was therefore almost entirely a religious phenomenon. Feasting on the other hand had religious, aesthetic, legal and societal ramifications (Hagen, 1992: 80). Underlings provided food as tribute to their lord, which also brought to the lord honour and demonstrated the ability to dominate. Feasts would thus be held to consume food rents, as well as to mark religious or personal (for example the arrival of a guest or the marking of a rite of passage) festivals, demonstrate the power of the lord and reinforce obligations. Most feasts would be shared by the higher ranks of society, but those connected with the seasons and the completion of agricultural tasks such as the harvest may have been attended by the lower classes and slaves (Hagen, 1992). Hagen lists suitable food to be consumed at feasts as roast poultry, pork and fattened bullocks, game, fish, broth and cheese. Bread would be of a finer kind than on ordinary days, and there would also be festival cakes based on enriched dough mixtures (*ibid*: 86-7).

A systematic study of infant feeding in history was carried out by Fildes (1986). Focusing principally on the fifteenth to the eighteenth centuries, Fildes does survey some of the evidence available for earlier periods. While some information can be gathered from hagiographies, and other sources mentioning children in passing, as discussed above, most information is available from medical texts. Yet even here Fildes states that information on childcare and feeding is scant and in many treatises advice on infant feeding practices is omitted or barely touched upon. From Trotula of Salerno, in the

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[5] See Hagen (Hagen, 1992: 69-70) for examples of meal times in monastic rules.

eleventh century to Bernard of Gordon in the fourteenth most medical manuscripts recommend the feeding of infants by their mothers, although all provide recommendations on the selection of wet nurses where maternal feeding is either not desirable, or not possible. Physicians recommended extended feeding of infants beyond 1 year, longer for boys than for girls coupled with the gradual introduction of gruel, and then other foods as the child cut his teeth (*ibid.*: 57). There was some feeling amongst the clergy that women should nurse their own children, indeed a letter purportedly from Pope Gregory the Great to Augustine of Canterbury in 731 specifically warns against wet nursing:

> Her husband should not approach her until the infant is weaned. A bad custom has sprung up in the behaviour of married people, that is, the women disdain to nurse the children to whom they give birth, and give them to other women to nurse. This practice seems to have been devised solely because of incontinence because, as they will not be continent, they will not nurse the children which they bear. (Murray, 2001: 397)

Documentary evidence indicates that whether fed by their mother or by a nurse, infants received human milk in the first year of their life. This was only supplemented by animal milk when breastfeeding was not possible.

How do we investigate diet amongst Anglo-Saxon children?

There are some indications that children did not always have the same diet as their elders, for example they were not made to fast and, in a monastic context, the Benedictine rule was relaxed for children on account of their 'feebleness'. The basic diet for both adults and children would have been bread, supplemented by meat and other foodstuffs discussed above. Most children would have been breastfed either by their own mother, or by a wet nurse. Crawford's suggestion of an age of weaning at two years is unlikely to be fully correct: evidence from anthropological studies indicates that weaning was an extensive process involving supplemental foods before the final cessation of breastfeeding. This is particularly necessary when women are active economic producers, for example in rural communities where women must go out to work in the fields, meaning that on demand breastfeeding is not always possible (e.g. Panter-Brick, 1996). Diet post-infancy was also

varied in the anthropological record and extremely dependent on the structure of the society in which children live. As we have seen, early medieval children were active members of their community and would probably have been involved in the economic production of their households to some degree. They may have had some scope for opportunistic foraging, but I would hypothesise that the bulk of their nutrient intake would have come from the main meals of the household. Whether children had the same bulk diet as adults can be tested through isotopic analysis of tooth and bone, as discussed in the following chapter. This could reveal further information as to the position of children in early medieval society

Chapter 3: Stable Isotope Analysis of Human Hard Tissues

This chapter introduces the principles and methods of stable isotope analysis of human hard tissues. The use of stable isotopes for the reconstruction of human diet is "predicated on the assumption that the isotopic composition of an animal tissue is a direct and constant function of that of the diet" (Ambrose, 1993: 60). The inorganic and chemical tissues of tooth and bone provide a long-term record of the relative consumption of general food groups (Pate, 1994). What carbon, nitrogen, oxygen and sulphur stable isotopes can tell us about human behaviour is discussed first. This is followed by a discussion of how these isotopes are incorporated into human hard tissues. This section also includes an introduction to the methods currently in use to extract these isotopes from hard tissues. An overview of previous isotopic studies on humans; firstly, by period and continent, and, secondly with a specific focus on the early and later medieval period is then given. The final section places the current research into the context of the broader research framework.

What is a stable isotope? Isotopes of elements differ in the number of neutrons in their nucleus, leading to differences in the mass of atoms and molecules (Ambrose, 1993). Stable isotopes are not radioactive, and do not decay over time unless diagenesis (the physical and chemical degradation of material) occurs. All the biochemically important elements except fluorine have more than one stable isotope (Schwarcz and Schoeninger, 1991). Isotopic mass is represented by superscript numbers to the left of the element symbol, for example ^{12}C, ^{14}N and ^{16}O are the common, lighter forms of carbon, nitrogen and oxygen respectively. The uncommon forms, ^{13}C, ^{15}N and ^{18}O have extra neutrons, adding mass. This added weight slows their rates of movement and diffusion relative to the lighter isotopes and changes their rates and temperatures of melting, freezing, crystallization, condensation and evaporation. Differences in rates of movement, chemical reaction and state transition cause discrimination or fractionation, usually against the slower, heavy isotope.

Each element has only a small proportion of the heavy stable isotope and differences in the natural abundances of these isotopes are usually very small. Because of this the ratio of the heavier to the lighter isotope is measured with reference to the ratio of a standard reference material (Ambrose, 1993). Isotope ratios are expressed using the delta (δ) notation in parts per thousand (permil: ‰) relative to a standard:

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

where R is the ratio of the heavier to the lighter isotope. The Peedee Formation *Belemnitella americana* marine fossil limestone (PDB) is the standard reference material for carbon and oxygen isotope ratios in carbonates and organic matter. For oxygen in phosphates Standard Mean Ocean Water (SMOW) is used. Atmospheric N_2 (AIR) is the standard used for nitrogen and the Vienna Canyon Diablo Troilite (VCDT) is the standard for sulphur.

What can stable isotope analysis of biological samples tell us?

Carbon

The stable isotopes of carbon can be used to assess the source of carbon in either the protein component of the diet (as seen for example in bone collagen) or in the whole diet (for example in bone cholesterol and apatite carbonate (Ambrose and Norr, 1993; Jim, *et al.*, 2004)). Analysis of the protein component of the diet is more common as collagen is seen as being resistant to change, and in good conditions can survive many thousands of years. The use of carbonate to analyse carbon input in the whole diet is associated with problems of diagenesis. Most fossil bones contain significant amounts of calcium carbonate deposited in the burial environment that contribute to the CO_2 evolved from the bone during extraction procedures (Schoeninger and DeNiro, 1982). However it has been suggested that with proper cleansing and extraction protocols, the carbonate phase of biological apatite is an appropriate analysical phase for dietary studies on bone or teeth as old as 10 000 years (Krueger, 1991). Experiments testing the reliability of

acetic acid removal of diagenetic contamination indicate that in histologically well preserved bone, this treatment is successful, but in samples with poor histology the remaining fraction is hypermineralised bioapatite which cannot be reliably used to obtain accurate biological signals (Nielsen-Marsh and Hedges, 2000b). Schoeninger *et al.* (2003) showed that carbonates extracted from the interior surface of tooth enamel were less susceptible for diagenetic alteration than that sampled from the exterior, but in some cases alteration had occurred throughout the enamel crystalline matrix, as indicated by cathodoluminescence screening. In such cases interpretation of such signals may erroneously ascribe a different feeding pattern to that of the animal in its lifetime.

Carbon in human tissues has two major dietary sources: plants and both terrestrial and marine faunal protein. In populations with a high protein diet, isotopic analysis will under-represent protein from dietary carbohydrates (i.e. plants) in bone collagen, whereas in populations with low protein diets, carbohydrate consumption is more accurately reflected in bone collagen (Ambrose, 1993). In temperate areas plants have only one photosynthetic pathway, known as the Calvin or C_3 (Katzenberg and Krouse, 1989). In these plants, atmospheric CO_2 diffuses through the boundary layer with an apparent fractionation of ~4‰. The carboxylating enzyme discriminates further against the heavier isotope, with a $\Delta\delta$ of about 29‰. As CO_2 uptake is mediated by both atmospheric diffusion and enzyme action, median $\delta^{13}C$ values lie around -27‰ (Lajtha and Marshall, 1994). Heaton (1999) warns that environmental changes with space and time may affect this value, potentially leading to uncertainties of at least 2‰. In non-temperate regions plants may follow the C_3 photosynthetic pathway, or they may follow C_4 (Hatch-Slack) or CAM (Crassulacean Acid Metabolism) pathways. These photosynthetic pathways affect the end values of the carbon isotopes in the plants and therefore their consumers. The initial carboxylating enzyme in C_4 plants is different to that of C_3 plants, and has a $\Delta\delta$ of -6‰ for the fixation of CO_2. $\delta^{13}C$ values for C_4 plants generally cluster around -14‰ (Lajtha and Marshall, 1994). Plants using the CAM pathway have the same carboxylating enzymes as C_4 plants, but segregate the activities of the

enzymes between night and day rather than between tissues. CO_2 is initially fixed at night then released and refixed during the day. Some CAM plants may switch to daytime C_3 photosynthesis when conditions are favourable and may therefore have $\delta^{13}C$ values that span the range of C_3 and C_4 values (*ibid.*).

Carbon stable isotope analysis can therefore determine the proportions of C_3 and C_4 plants in the diet (DeNiro and Epstein, 1978a). The $\delta^{13}C$ values of most C_3 plants range from -24‰ to -34‰, while most C_4 plants have values between -6‰ and -19‰ (Smith B.N. and Epstein, 1971). The $\delta^{13}C$ value of consumers is enriched on average by about 1-2‰ relative to the diet (DeNiro and Epstein, 1978b; van der Merwe N. J., 1989). However the difference between herbivore meat and carnivore collagen can be as much as +5‰ due to the differences in ^{13}C values in various body tissues (van der Merwe N. J., 1989). In closed woodlands containing only or dominantly C_3 plants some variation in $\delta^{13}C$ values may still be seen in the leaves of the plants (Koch, *et al.*, 1994). Leaves collected near the forest floor may have $\delta^{13}C$ values depleted by as much as 4 to 6‰ compared with typical terrestrial values, or leaves from the canopy roof (*ibid.*).

Carbon stable isotope values also become enriched in marine environments as carbon is ultimately derived from dissolved bicarbonate (HCO_3) which has a $\delta^{13}C$ value of 0‰ (Smith B.N. and Epstein, 1971; Ambrose, 1993). The marine carbon cycle is also more complex and forms a longer food chain; from plankton, then molluscs, zooplankton and so on through to large carnivores. Mollusc meat has a $\delta^{13}C$ value of about -18‰, while predatory ocean fish and seals have a value of about -12‰ (Lambert, 1997). In temperate regions it is therefore possible to distinguish those individuals whose diet contains a significant marine component as their ^{13}C will be enriched over the C_3 values (DeNiro and Epstein, 1978b; Chisholm, *et al.*, 1982). This is more difficult in regions where C_4 foods are consumed as C_4 plant consumption can mask a marine isotopic signal. Consumption of marine resources may still be detected by also analysing nitrogen isotopes and, latterly, sulphur isotopes. Although freshwater aquatic food webs have

not been intensively studied, non-tropical systems appear to have C_3-like carbon isotopic compositions, meaning that stable isotopes of carbon are not the best mechanism for assessing consumption of freshwater resources. Freshwater fish from Lake Baikal (Russia) are highly variable, ranging from -24.6‰ for the pelagic omul to -12.9‰ for littoral species such as ide (Katzenberg and Weber, 1999).

In addition both carbon and nitrogen isotope ratios may differ due to local and regional environmental factors such as temperature and the availability of water. It is therefore necessary to analyse foods consumed from the same food web as the human population under study in order to determine accurately the amounts of plants, animal and marine resources in the diet.

Nitrogen

Nitrogen represents the protein component of the diet and is used in the synthesis of all body tissues. The stable isotopes of nitrogen can be used to study the location of an individual in the food web, and the source of its body protein, as body tissues become enriched in ^{15}N relative to the diet (DeNiro and Epstein, 1981). Once food is consumed by an individual, the metabolic process causes nitrogen to fractionate and the lighter ^{14}N isotope is preferentially excreted over the heavier ^{15}N, which is incorporated in relatively greater proportions in the body's tissues. If this individual is then eaten, the consumer will incorporate the nitrogen from the individual's flesh into the consumer's own body's tissues and the preferential fractionation will occur again. This means that the consumer will have a greater proportion of ^{15}N in their body relative to the consumed. This trophic shift is said to be 3 to 4‰ between plants and herbivores, herbivores and carnivores (DeNiro and Epstein, 1981; Minagawa and Wada, 1984; Schoeninger and DeNiro, 1984); although the range can be lesser or greater for some predator-prey pairs (Bocherens and Drucker, 2003). Values for omnivores fall between those of herbivores and carnivores, depending on the proportion of animal to vegetable protein in their diet. However, research has suggested that this fractionation pattern may not be constant, rather it fluctuates within trophic levels and within and between habitats, particularly in tropical ecosystems

(Ambrose, 1993). Food webs in hot and arid environments tend to have higher nitrogen isotope ratios than cool wet ones, with a greater stepwise enrichment between trophic levels (Ambrose, 1991). There are also physiological adaptations for water conservation in such environments where animals may reduce the content of water in their urine when under water and heat stress, while the total amount of urea, depleted in ^{15}N, increases and the total food intake decreases. This leads to the pool of nitrogen not excreted and available for tissue synthesis having significantly more ^{15}N available than the diet, reflected in the nitrogen isotope values in body tissues (*ibid.*). Differing metabolic processes can also lead to isotopic differences of the same magnitude as a trophic shift in herbivores consuming the same diet when not under heat or water stress. Sponheimer et. al. (2003a) noted a difference of 3.6‰ between rabbits and alpacas in a controlled feeding experiment, which they attributed to foregut fermenting species (such as cattle and alpacas) digesting symbiotic gut microflora, resulting in an enrichment in $\delta^{15}N$. However this difference was also noted between rabbits and horses, both hindgut fermenters (*ibid.*). This means that the digestive strategies of different species should be taken into account when assessing their nitrogen isotopes.

The trophic shift can also be used to determine patterns of breastfeeding and weaning in a population since infants are, in effect, higher level carnivores of their mother's body tissues during breastfeeding. This leads to increased levels of ^{15}N in their body tissues, which then begin to equilibrate with the adult population during and after the weaning process (Fogel M., *et al.*, 1989). This process is less susceptible to the fluctuations discussed above as analyses are carried out on variations within a single species and habitat.

Marine food chains are often longer than those on land, leading to a far greater increase in ^{15}N in end consumers. This means that it is possible to identify any input into the diet from marine protein as the $\delta^{15}N$ values of an individual consuming a marine diet is enriched by an average of 9‰ over that of an individual consuming a terrestrial diet (Schoeninger and DeNiro, 1984). When combined with carbon stable isotope analysis, this can produce a

picture that is very distinctive (figure 3.1). As discussed above, this is not the case in dry coastal regions where consumers may be recycling urea due to water deficits causing increased fractionation, making differentiation between marine and terrestrial foodstuffs impossible. In a study of marine and terrestrial animals from the south western Cape (an area of low rainfall) it was found that there was an almost complete overlap in $\delta^{15}N$ values (Sealy, *et al.*, 1987). It is also possible to identify the consumption of freshwater protein, although this can be more difficult as the length of freshwater food chains are far more variable than those of marine or terrestrial ecosystems and the level of enrichment can be confused with consumers of omnivore protein, particularly if the carbon values are not also enriched. Dufour *et al.* (1999) analysed a number of samples of lacustrine fish from three European lakes and from Lake Baikal (Russia). They determined that there is a great deal of isotopic variability in both carbon and nitrogen values both within and between lakes. They suggest that where the question of freshwater food consumption is to be addressed, stable isotopes from fish from the archaeological site should be examined. Where this is not possible an investigation of the isotopic composition of recent species from local environments is recommended.

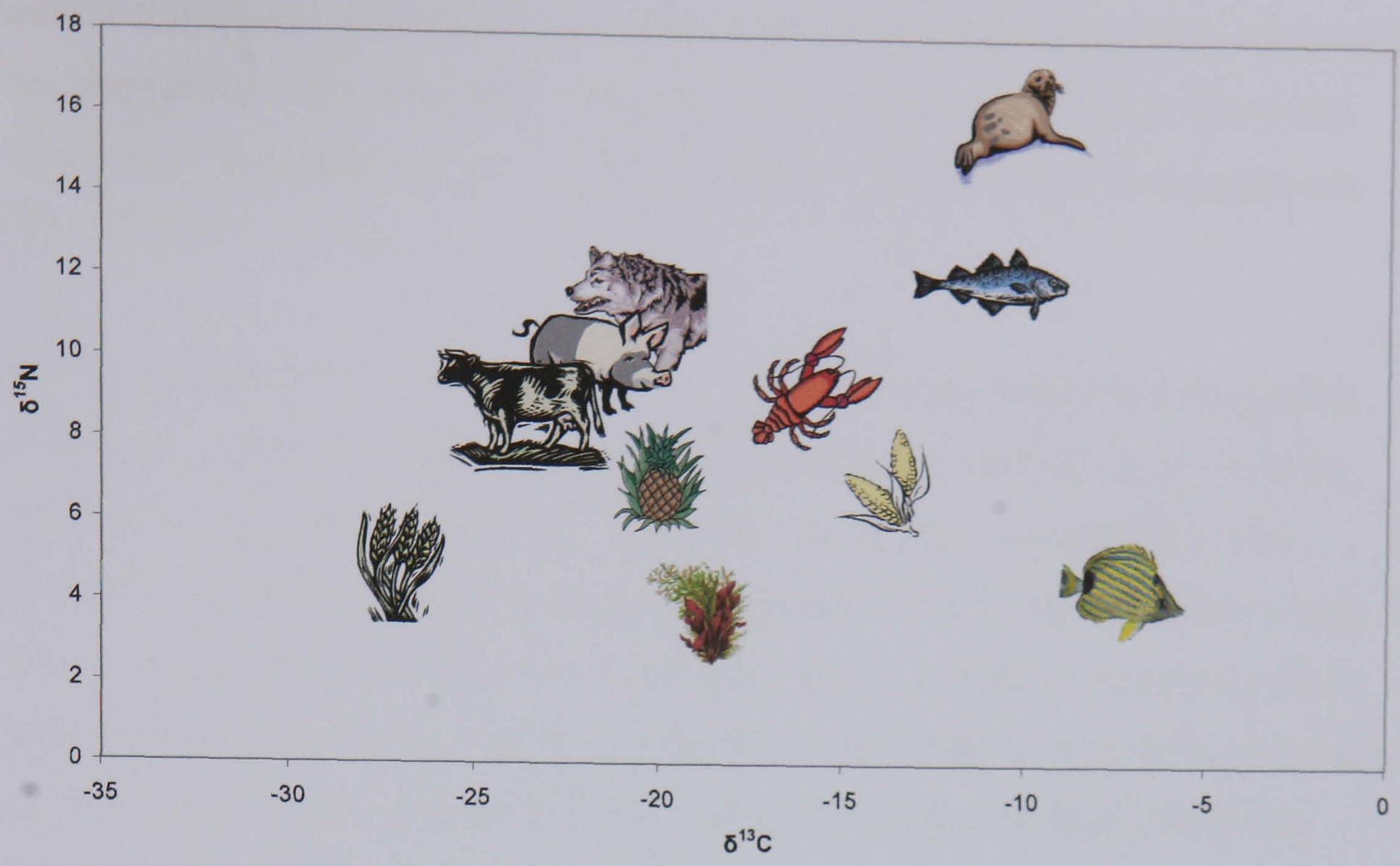

Figure 3.1: Pictogram indicating the average values for simple marine and terrestrial ecosystems, after Ambrose, 1993. Note that large variations surround each point.

<u>Oxygen</u>

Oxygen is analysed in either the phosphate or the carbonate component of apatite in tooth and bone. In mammals oxygen is principally derived from ingested water (in drinks and plant and animal tissues), inspired O_2 and dietary solids (Koch, *et al.*, 1994). Oxygen is lost from the body as liquid water in urine, sweat and faeces, and as water vapour and CO_2 in respiratory gases (*ibid.*). Isotopic mass balance calculations indicate a predictable, linear relationship between the $\delta^{18}O$ of ingested water and that of body water for an animal at steady state (Luz, *et al.*, 1984). Longinelli (1983) found that these oxygen isotopic fractionation effects were the same in all specimens of the same species. This linear relationship also exists between the oxygen isotopic composition of phosphate and structural carbonate in mammalian biogenic apatite and body water, thus these tissues also reflect fluid intake (Iacumin, *et al.*, 1996). Any mammal that grows apatite at a constant body temperature will have $\delta^{18}O$ values that dominantly reflect the changes in ingested water, and thus the local environment (Koch, *et al.*, 1994), although body mass, ambient relative humidity and temperature are also controlling

factors (Langlois, *et al.*, 2003). Fractionation factors between body water and the phosphate and carbonate components of biogenic apatite in mammals have been quantified as 1.0176 ± 0.0005 and 1.0263 ± 0.0014 respectively (Bryant, *et al.*, 1996).

As discussed above, apatite carbonate appears to be subject to diagenetic processes. Nelson et al (1986) noted that carbonate in prehistoric (610 to 5470 years old) bone from Greenland failed to preserve the differences observed between marine and terrestrial feeders observed in modern bone. It has been noted that fossil bone and dentine have better crystallinity than recent specimens while enamel is identical in crystallinity in fossil and recent specimens indicating diagenesis and lack thereof respectively (Shahack-Gross, *et al.*, 1999). Others believe that oxygen isotope signatures can be preserved in enamel carbonate without alteration by diagenesis (Sponheimer and Lee-Thorp, 1999). Microbially-induced oxygen isotopic exchange for phosphate has been observed in fossil enamel from Chad, in association with extensive recrystallization (Zazzo, *et al.*, 2004), indicating that where enamel carbonate is severely compromised, there is the possibility that the phosphate component may also be. In general, however, the oxygen in the phosphate component of bone and tooth mineral is very resistant to exchange during bone diagenesis and is therefore one of the best preserved records of the original composition of the organism (Schwarcz and Schoeninger, 1991).

Oxygen stable isotope analysis is principally used to research palaeoclimate and environmental change (e.g. Wang, *et al.*, 1993; Sharma, *et al.*, 2004). They have also been used to investigate seasonal change within regions using sequential sampling of mammalian hypsodont[6] teeth (Fricke and O'Neil, 1996; Fricke, *et al.*, 1998; Balasse, 2002). Because oxygen fractionates according to latitude, altitude, rates of precipitation and levels of humidity, it can also be used to track mobility patterns by studying biological materials formed at different times in an individual's life. Studies have been

[6]high-crowned and, in some species continually erupting teeth that form over a period of months.

carried out in Britain, and to a lesser extent Europe, to determine the variability of oxygen isotopes (Lécolle, 1985; Darling and Talbot, 2003a, b). These have indicated that European $\delta^{18}O$ becomes more depleted on an east-west, and to a lesser extent south-north gradient (figure 3.2).

When oxygen isotopes are incorporated into dental material they are effectively 'locked in' and will undergo no change during the lifetime of that individual. This means that it is possible to determine whether the area where an individual grew up is also the area where he died. In addition, because oxygen is fractionated during metabolic processes where the heavier ^{18}O is preferentially retained over the lighter ^{16}O, it can be used to track breastfeeding and weaning (Roberts S.B., *et al.*, 1988). A breastfed infant is drinking his mother's milk, which is enriched in ^{18}O compared to the local drinking water; he will therefore display a more enriched $\delta^{18}O$ value than his mother. When breastfeeding ceases the level of enrichment will decrease until the infant reflects local oxygen values.

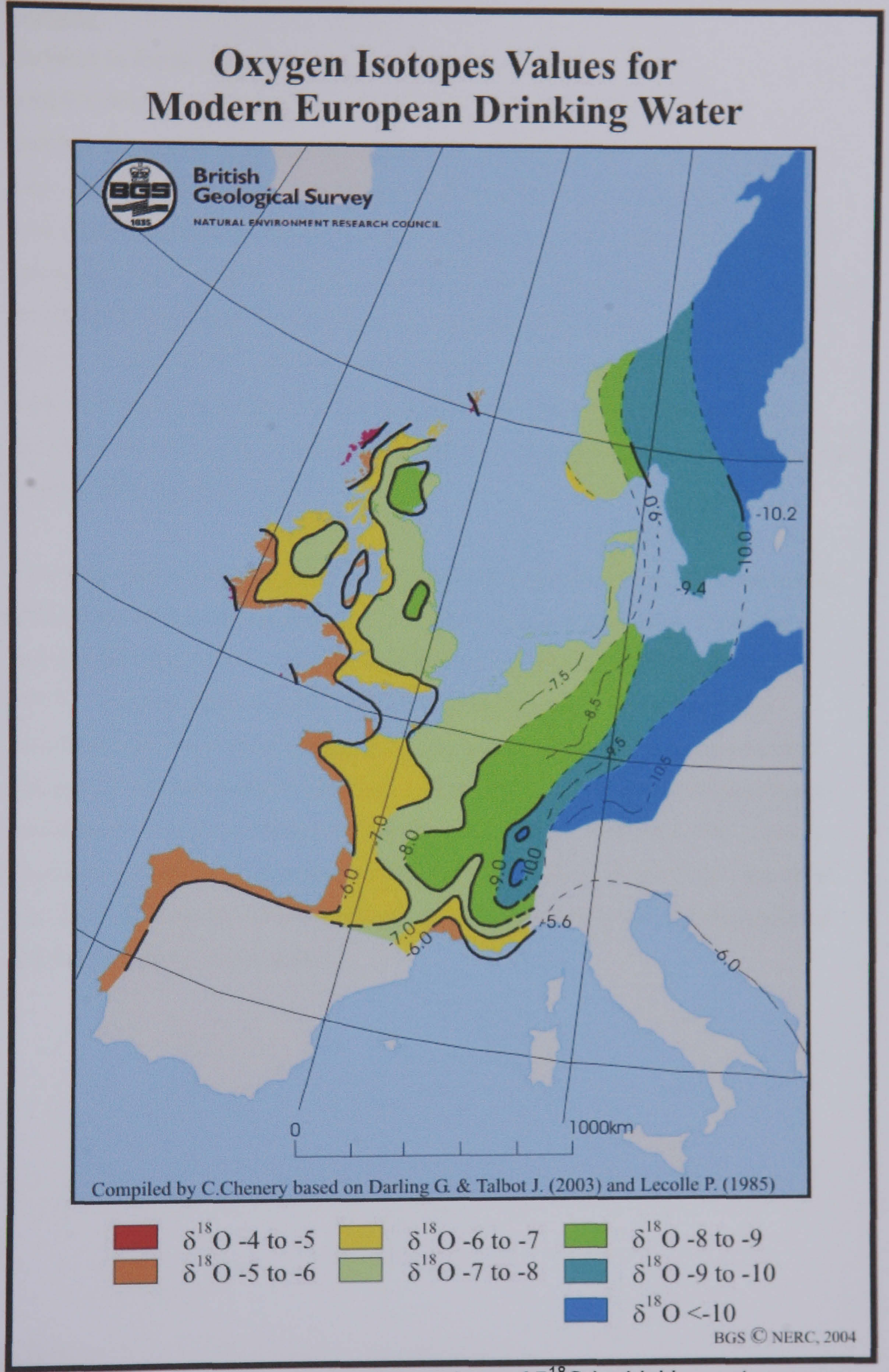

Figure 3.2: Map showing the average values of $\delta^{18}O$ in drinking water across Europe, courtesy of C. Chenery, NIGL, BGS.

Sulphur

Sulphur in foods reflects environmental sulphur, derived from the atmosphere and the lithosphere (Katzenberg and Krouse, 1989). Plants can incorporate sulphur from both sources, reflecting a $\delta^{34}S$ value intermediate between the two. In animals, sulphur is an essential component of growth and survival, and must be obtained from the diet (Richards, *et al.*, 2003a). As sulphur is geographically variable, it can be used to determine area of normal residence and therefore detect to any migrants into a population (Richards, *et al.*, 2001). There is little fractionation in sulphur with increasing trophic level, however Katzenberg and Krouse (1989) were able to use the isotope in combination with carbon nitrogen isotopes to narrow down possible places of residence in forensic cases.

The well-mixed sulphur reservoir in the ocean and in marine plankton and is 21‰ heavier than primordial sulphur in the meteoric standard, whereas continental vegetation average between +2 to +7‰ (Peterson and Fry, 1987). It is therefore thought that $\delta^{34}S$ in marine organisms should be enriched relative to terrestrial organisms, making it possible to use sulphur isotopes to supplement information gained from carbon and nitrogen stable isotopes on marine consumption (Schwarcz, 1991). Richards et al. (2001) found that in areas with well differentiated $\delta^{34}S$ values in marine, freshwater and terrestrial ecosystems, sulphur can be used to infer the consumption of foods from these ecosystems.

How are these isotopes incorporated in human hard tissues?

The stable isotopes discussed are incorporated into the mineral (carbon and oxygen) and organic (carbon, nitrogen and sulphur) phases of tooth and bone; the major element contents of which do not vary as a function of diet (Schwarcz and Schoeninger, 1991). In addition to the food and water sources outlined, nitrogen in collagen may also be derived from recycled tissues in the body (Katzenberg and Lovell, 1999). Some carbon in non-essential amino acids may also come from the breakdown and recycling of tissues in the body (*ibid*.). Tooth and bone are composite materials consisting of an organic and a mineral phase. Protein, principally in the form of collagen constitutes approximately 90% of the organic content of living bone (White T.D., 2000). Collagen molecules intertwine to form flexible, slightly elastic fibres with great tensile strength and relative insolubility due to extensive linkages between each of its three equal-sized chains (Schwarcz and Schoeninger, 1991). Each chain has approximately 1000 amino acids, comprising one-third glycine with proline and hydroxyproline together constituting one-fifth to one-fourth of the total. Crystals of hydroxyapatite, a form of calcium phosphate, impregnate the collagen matrix giving the bone its hardness and rigidity. Collagen comprises approximately 20% of bone by weight; however, compared to bone, whole teeth have significantly lower collagen concentrations (Ambrose, 1990, 1993).

Composition of hydroxyapatites varies widely through substitutions and vacancies within the crystal lattice, the commonest variations are carbonate, fluorine and magnesium; although other calcium phosphate minerals may be found in association with dental caries, calculus or burial in the ground (table 3.1). Minerals deriving from the groundwater of the burial matrix may also be deposited on or within the crystalline lattice, although little is known about these processes (Hillson, 1996).

Apatites	
Hydroxyapatite – $Ca_{10}(PO_4)_6(OH)_2$	
Substitutions of ions into hydroxyapatite lattice, and vacant sites	
Ca^{2+} sites:	Sr^{2+}, Ba^{2+}, Pb^{2+}, Ra^{2+}
	Na^{+}, water, vacancy (less commonly)
	K^{+}, Mg^{2+} (uncommon)
PO^{3-}_4:	AsO_4^{3-}
	HPO_4^{2-}, CO_3^{2-}, HCO_3^{-} (less commonly)
OH^{-} sites:	Cl^{-}, F^{-}, Br^{-}, I^{-}, CO_3^{2-}, O^{2-}
	Water, vacancy (less commonly)
Fluorapatite – $Ca_{10}(PO_4)_6F_2$	
Fluorhydroxyapatite – $Ca_{10}(PO_4)_6(OH,F)_2$	
Carbonate-containing apatite – $Ca_{10}(PO_4)_6CO_3$	
Surface bound ions	
Ca^{2+}, PO_4^{3-}, HPO_4^{2-}, CO_3^{2-}, HCO_3^{-}, Mg^{2+}, K^{+}, citrate, water	
Other calcium phosphate minerals	
Whitlockite - related to β-tricalcium phosphate, β-$Ca_3(PO_4)_2$, with impurities Mg^{2+}, Mn^{2+} or Fe^{2+}	
Monetite – $CaHPO_4$	
Brushite – $CaHPO_4 2H_2o$	
Octacalcium phosphate – $Ca_8(HPO_4)_2(PO_4)_4.5H_2O$	
Possible secondary minerals	
Calcite – $CaCO_3$	
Goethite, lepidocrocite, limonite – FeO.OH	
Pyrite – FeS	
Vivianite – $Fe_3P_2O_8.8H_2O$	

Table 3.1: Minerals in hard tissues, adapted from Hillson, 1996: 219.

Collagen turnover

Collagen turnover is part of bone remodelling: mineralized bone is removed by osteoclasts and replaced by a collagenous bone matrix that subsequently becomes mineralized (Compston, 2002). Harkness and Walton (1972) noted a lower concentration of ^{14}C in the bone tissues of a 37 year old woman than in her soft tissues and suggested that the carbon in bone was several years older than the remainder of the body (Harkness and Walton, 1972). There has been little research into long-term collagen turnover. Those few studies that have been conducted conclude that the total turnover time in bone collagen is between 10 and 30 years (Libby, *et al.*, 1964; Stenhouse and Baxter, 1979). However these studies were based on a small number of elderly individuals suffering from illnesses or other physiological stresses that may affect metabolism (Okazaki, *et al.*, 1997). In addition, a study by Bailey et al. (1999) indicated that bone density and collagen content decline with age, coupled with an increase in mineralization probably due to decreased collagen turnover. Katzenberg and Lovell (1999) also found that three out of four samples of pathological bone exceeded normal variation for $\delta^{13}C$ and $\delta^{15}N$ reinforcing the hypothesis that differing health status may affect the tissue synthesis rates of individuals. Different skeletal elements may also have varying rates of bone turnover, those with a high proportion of cancellous bone, well fed by blood vessels, are likely to turn over faster than dense compact bone such as the shafts of long bones (Stenhouse and Baxter, 1979; Sealy, *et al.*, 1995; Vajda, *et al.*, 1999). Indeed, a study by Babraj et al. (2002) indicates that different collagen fractions turn over at different rates, some markedly more rapidly than had been previously considered. The synthesis of bone collagen on the iliac crest is faster than generally assumed, and of the same order as muscle protein turnover (Babraj, *et al.*, 2005). Lactation in also associated with increased intracortical bone remodelling, possibly providing a mechanism for the skeleton to be responsive to the calcium requirements of lactating (Vajda, *et al.*, 1999). Therefore, the studies of Libby and Stenhouse and Baxter may not be an accurate estimation for younger subjects, particularly growing children. Studies on cave bears have indicated that isotopic signatures may be affected by growth rates (Liddén and Angerbjdörn, 1999), in particular

periods of rapid growth may smooth out any increases or decreases in isotopic values. The study by Lidén and Angerbjdörns also indicates that the rate of collagen turnover is not a constant over the period of growth, rather they suggest that turnover time increases with age during the juvenile stage, probably due to changes in metabolism. It has been noted that collagen metabolism increases in pubertal boys (Sorva, *et al.*, 1997), and during exercise in young women (Thorsen, *et al.*, 1997).

Nitrogen in bone collagen can be affected by factors other than diet, principally relating to the rate of protein synthesis and turnover. There are three possible conditions for nitrogen balance in collagen (Katzenberg and Lovell, 1999):

1. Tissue gain during growth – new tissues are being produced and more nitrogen is being ingested than is excreted. The individual is in positive nitrogen balance and it is expected that the diet will be reflected by newly forming tissues.
2. Tissue maintenance in healthy adults – the same amount of nitrogen is being ingested as excreted. The individual is in nitrogen equilibrium and bone collagen will reflect ingested protein from the diet averaging over several years.
3. Tissue loss during stress – less nitrogen is being ingested than is needed to maintain and replace proteins in the body. The individual is in negative nitrogen balance resulting in a catabolism of existing proteins in the body. There should be a preferential loss of ^{14}N relative to ^{15}N as amino acids with ^{14}N are broken down more readily and ^{14}N is preferentially excreted. The remaining tissues should be enriched in the heavier isotope relative to what those same tissues would have been in nitrogen equilibrium.

Extraction of collagen from tooth and bone

Extraction methods

Several methods have been developed for extracting the collagenous fraction of tooth and bone; all have their advantages and drawbacks.

Longin (1971) developed the first commonly used method of extracting the organic remnants in fossil bone. Crushed bone is soaked in an 8% HCl solution for 20 minutes, intended to remove most mineral substances and some organic pollutants. Collagen is extracted from the residue by heating with pH3 water at about 90°C and stirring for 10 hours. Any remaining impurities are eliminated by centrifugation and the resulting gelatine oven dried. This aimed to convert the protein-remnants to gelatine, eliminating humic substances and any other contaminants in the process. However this method was not always successful at eliminating contaminants (Brown, *et al.*, 1988) and additional steps were later added by other researchers. Brown et al. (*ibid.*) re-evaluated the method of collagen extraction developed by Longin and showed that a lower reflux temperature (58°C) reduced the degradation of protein ('collagen') remnants allowing an additional purification step through ultrafiltration. As contaminants such as fulvic acid are likely to be of low molecular weight, ultrafiltration isolates the >30kDalton fraction of the reflux product comprising only of the larger peptides such as collagen. In addition maintaining an acid environment throughout the process also increased the collagen yield and decreased the risk of contamination by humic and fulvic acids.

Further modifications include the addition of NaOH treatment step to eliminate contamination by humic and fulvic acids (DeNiro and Epstein, 1981), although this has been shown to alter isotopic character of the collagen by preferentially affecting specific amino acids, decrease collagen yields and may not remove lipids (Lidén, *et al.*, 1995). Liden et al. (*ibid.*) recommended lipid-extraction with methanol-chloroform added to the Brown et al. (1988) protocol to remove lipids as the $\delta^{13}C$ of non-lipid extracted collagen can be up to 1.8‰ more negative than the same lipid extracted sample.

Chisholm (1989) describes a method based on that of Grootes (c.f. *ibid.*), another variation on the classic Longin method. After mechanical cleaning, bone samples are ground to pass through a 1mm screen. Demineralization is achieved by repeated extractions at room temperature in 0.25M HCl until

the solution pH stabilises at pH1 or below. Chisholm feels that this treatment is gentler than the Longin method with its use of more concentrated HCl for 20 minutes. The procedure is intended to remove all acid and water soluble materials including free amino acids and soluble peptides whilst minimising loss of collagen. Treatment of residues from the Longin process revealed that removal of minerals and other contaminants was not complete after the 20 minutes. Because of problems with the NaOH soak, Chisholm omits this stage, preferring instead to maintain an acid pH at all stages to prevent any acid insoluble materials (such as humic and fulvic acids) entering the solution. The collagen remnant is then solubilized for 10 hours in pH3 water, leaving any non-acid soluble products in the residue. Amino acid analysis on the products of this extraction protocol have shown no signs of contamination, and have yielded proportions of 1/3 glycine, and 1/5 hydroxyproline and proline characteristic of human collagen. Semal and Orban (1995) attempted to shorten solubilization times in order to improve the yield of large peptides (> 10 kDa). This was principally carried out by strengthening the solubilization solution to 0.2 M HCl, which gave higher yields than a simple Longin method. Most researchers now will use a modified Longin method, with or without the ultrafiltration and NaOH stages, depending on laboratory protocols and the level of preservation of bone samples.

Other methods have been developed in order to extract collagen from poorly preserved fossil bone. DeNiro and Weiner (1988) used the enzyme collagenase, which is highly specific for native or denatured collagen and produces peptides of molecular weight 500-700 daltons which can then be separated out from the enzyme, unhydrolyszed collagen and other organic components left in the bone. The method is suitable for poorly preserved prehistoric bones that do not yield collagen with isotope ratios that reflect *in vivo* values by the solubility methods discussed above. Tuross et al. (1988) compared the $\delta^{13}C$ and $\delta^{15}N$ values of collagen replicas obtained after HCl and EDTA demineralization to those obtained with a gelatinization procedure and found that with modern bone the values were similar. However in poorly

preserved fossil bone the yield of collagen was consistently higher than extraction procedures that used HCl.

Sample quality

Finally it is essential to assess whether or not the extracted material represents the *in vivo* collagen, or has been substantially altered by diagenesis. Archaeological bone has been subject to a complex post-burial history which may result in the addition of contaminants such as humic acids or nitrogen-containing compounds, both organic and inorganic. These processes may be mediated by fungi and bacteria, which are in themselves contaminants, causing differential degradation of the collagen cross-linked chains. In bones with poor collagen preservation, other components such as peptide fragments may adversely affect stable isotope ratios as there can be significant isotopic fractionations between individual amino acids (Schwarcz and Schoeninger, 1991). Criteria for acceptance of samples are therefore based on determining whether intact proteins, or ones with amino acid compositions similar to intact proteins, are present. Ambrose (1990) published measurements of collagen concentrations in tooth and bone, atomic C:N ratios, and carbon and nitrogen concentrations in the collagen of 359 historic and prehistoric African humans, and modern and prehistoric East African non-human mammals. He found that compared to bone, whole teeth have significantly lower collagen concentrations, lower carbon and nitrogen concentration in collagen, and similar C:N ratios. In well preserved bone, carbon and nitrogen concentrations and C:N ratios are relatively constant over a wide range of collagen concentrations. The C:N ratio of collagen, estimated from amino acid composition is 3.21, ratios from samples typically considered acceptable for isotope analysis range between 2.9 and 3.6 (Ambrose, 1993). Poorly preserved prehistoric specimens with very low collagen concentrations have highly variable C:N ratios, very low carbon and nitrogen concentrations in collagen, and stable carbon and nitrogen isotope ratios unlike collagen. At the transition from well-preserved to poorly preserved collagen, Ambrose found that the most reliable indicator of collagen preservation is the concentration of carbon and nitrogen in collagen.

Extraction of phosphate from bioapatite

Crowson et al. (1991) developed a method of determining the oxygen isotope composition of phosphate in bioapatite by BrF_5 fluorination of silver phosphate prepared from apatite by an ion-exchange method.

A precise and simple method was subsequently developed by O'Neil et al. (1994) requiring only a vacuum extraction line and a high-temperature furnace. This method was quicker, safer, and less expensive than the conventional fluorination method. Organic rich samples such as tooth or bone are treated with H_2O_2, and then dissolved in HNO_3. The resulting solution is neutralized with KOH and reacted with HF to remove calcium. After dissolution Ag_3PO_4 is precipitated, the resulting crystals are filtered, rinsed and gently dried. Thermal decomposition of Ag_3PO_4 in the presence of graphite produces CO_2 for isotopic analysis.

Previous studies on humans

Stable isotope analysis of humans is increasingly frequent in archaeological science and studies have been published in many countries. This section discusses a selection of those studies published that are of relevance to this research. Broad chronological and geographical areas are first summarised, highlighting studies that have the most relevance to the current project. Research on the isotopic shifts associated with breastfeeding and weaning are discussed separately. This is followed by a discussion of published data for the early (Anglo-Saxon) and later medieval periods, likely to be of most relevance.

Overview by period/continent

Isotope studies on individuals from the UK span the Palaeolithic through to the medieval period (Bocherens and Fogel, 1995; Mays S.A., 1997; Richards and Hedges, 1998; Richards and Hedges, 2000; Mays S.A., *et al.*, 2002; Privat, *et al.*, 2002; Richards, *et al.*, 2002; Fuller, *et al.*, 2003; Mays S., 2003; Müldner and Richards, 2005). A single study has been published on the Poundbury Camp Cemetery site (48 Iron Age, Roman and Post-Roman individuals were analysed) where analysis of stable carbon and nitrogen isotopes reflected a pattern of changing diet over time from terrestrial based in the Iron Age/Early Roman individuals to diets with some contribution from marine protein in the late Roman burials (Richards and Hedges, 1998). In the late Roman period, differences in diet could also be related to burial type, where those individuals in graves defined as elite were more likely to have consumed some marine protein than those in plain graves. In Italy itself, individuals from the middle class cemetery site of Isola Sacra consumed a diet with a significant marine component, this contrasts with a, lower class, nearby inland site (ANAS) where individuals display a terrestrial-based diet (Prowse, *et al.*, 2004).

Studies outside Britain also span a broad chronological framework. Neanderthals have been studied from a number of sites including ones in Belgium and France (Bocherens, *et al.*, 1991; Bocherens, *et al.*, 1999). These studies have shown that Neanderthals from the Scladina cave

(Belgium) and Marillac (France) obtained much of their protein from open country herbivores. Examination of further Neandertal specimens from Belgium illustrated the variability of diet within this broad range. A specimen from Spy, had isotopic compositions similar to those of Marillac, and was likely to be consuming large herbivores, including sucklings with elevated $\delta^{15}N$, and possibly omnivores such as bears. An additional specimen from Scladina may also have had a diet based on large herbivore meat, but with more mammoth meat or possibly freshwater fish (Bocherens, *et al.*, 2001). A sample of cranial bone from a young child from Engis indicates that this individual may not have been fully weaned, despite an age estimate of 5-6 years old for the specimen (*ibid.*).

Much of the stable isotope research carried out on the European Mesolithic and Neolithic has focused on the transition phase (Schulting, 1988; Bonsall, *et al.*, 1997; Richards and Hedges, 1999; Lillie and Richards, 2000; Richards, *et al.*, 2003c). Specifically researchers have theorised that consumption of fish was high in the Mesolithic and decreased in the Neolithic, a shift that should be detectable isotopically. Analysis of sites in the Iron Gates (a section of the Danube valley) indicated that Mesolithic populations shared the same basic subsistence pattern based on aquatic/riverine protein sources, supplemented by terrestrial foods over a period of several millennia (Bonsall, *et al.*, 1997). However a shift in subsistence pattern from the exploitation of aquatic/riverine resources to one in which the consumption of meat from terrestrial herbivores increased in importance was detected at Lepinski Vir (Serbia, *ibid.*). The authors suggest that this is part of a transition from a Mesolithic to a Neolithic economy, with increasing emphasis on food resources gained by farming. In some areas, such as the Ukraine, there is a dietary equivalence between the Mesolithic and the early Neolithic (Lillie and Richards, 2000), perhaps indicating that a move away from fishing as part of the subsistence package came later into the Neolithic period.

The Middle Neolithic Pitted-Ware site of Västerbjers on Gotland presents a different case. This population had not moved to a subsistence pattern based on agriculture, despite the possibility that they were in contact with

Corded-Ware populations who did practice farming. Rather they maintained their practice of sealing and consumed a diet predominantly based on this marine mammal (Eriksson, 2004). Eriksson is one of the few researchers to have published longitudinal studies on individuals. Samples were taken from the CEJ[7] of sequentially forming teeth (M1's, M2's or P2's and M3's, or deciduous teeth) and from a skull bone to plot dietary changes over an individual's lifetime. Eriksson found:

> systematic changes during life after infancy in many individuals, who display their lowest $\delta^{15}N$ values as young children, reaching a maximum in early adolescence, and lower values as adults – although higher than in childhood (2004: 149).

Recent work has attempted to problematise the use of stable isotope analysis to study dietary change in the Mesolithic-Neolithic transition. Milner *et al.* (2004) suggest that there have not been enough samples analysed to convincingly demonstrate a sharp and dramatic change of diet associated with the onset of agriculture. Furthermore they posit that the presence of Neolithic shell middens indicates a continued consumption of marine food resources into the Neolithic period (*ibid.*). Lidén *et al.* further suggest that the consumption of marine or terrestrial protein may be largely based on geographic location rather than time period. In his reply to these two articles, Hedges (2004) emphasises the weight of evidence in favour of a shift in subsistence pattern in the Neolithic, pointing out the wealth of coastal Neolithic individuals with terrestrial isotope signals.

A study of diet during the La Tène period in Bohemia indicated that, as in much of inland Europe, food consumption was based around animal protein and C_3 plant foods (Le Huray). Males buried with items of iron weaponry, implying a higher social status in life, had more positive $\delta^{15}N$ values indicating a higher consumption of meat. Two individuals had $\delta^{13}C$ values indicating at least some contribution from C_4 plant foods, most likely millet. A mixed regime of C_3 and C_4 consumption is seen in ancient Nubian populations (White C. and Schwarcz, 1994; Iacumin, *et al.*, 1998; Schwarcz and White, 2004). This trend fluctuates over time, but serial analysis of

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[7] CEJ: cemento-enamel junction

mummy hair sections indicates that most fluctuations occurred on a seasonal basis, with some shifts towards stored food in times of famine (Schwarcz and White, 2004).

Sealy *et al.* (1995) were amongst the first researchers to analyse the stable isotopes of different skeletal elements in order to detect dietary change. Five skeletons, two prehistoric from the Cape, South Africa and three historical, from archaeological sites at or near the Cape were analysed for $^{12}C/^{13}C$, $^{14}N/^{15}N$ and $^{87}Sr/^{86}Sr$ ratios in a tooth forming in early childhood, a third molar, a rib and the shaft of a long bone. Results showed that the different skeletal elements reflected diet and place of residence at different times in an individual's life.

Continental America has been the subject of much isotopic research, focusing particularly on the use of C_3 and C_4 plants and the assessment of marine protein input into the diet of coastal dwellers; three examples are given here. Researchers have also done much research on weaning behaviour, discussed below. One of the earliest uses of stable isotopes in North America was to document the introduction of maize horticulture, a C_4 food source in regions where previously C_3 food sources were predominant. Hunter-gatherers who lived in a C_3 environment, such as the North American woodlands exhibited classic isotopic signals for a C_3 diet (van der Merwe N.J. and Vogel, 1978). It was not until the end of the Late Woodland period that evidence for maize cultivation was seen in the stable isotopes, characterised by a shift in signal to a C_4 diet [ibid]. Research carried out on samples from the Pecos Pueblo, New Mexico indicated that the people ate no more than about 10% of their calories as meat, and that the C_4 component of the diet (from maize and bison meat) was approximately 80% of dietary calories (Schoeninger, 1989). Stable isotope analysis for the Modified Thule indicate that whaling accounted for approximately 12% of dietary intake (Coltrain, *et al.*, 2004). However, there is significant variation in this data set, which the authors suggest may be attributed to status differences based on whaling success in some communities.

Research on Weaning

Infant feeding and weaning practices have been carried out for a number of time periods and regions, most often in continental America, but also in Roman Italy and Egypt, Neolithic Turkey and ancient Nubia (Fogel, *et al.*, 1989; Katzenberg, 1993; Katzenberg, *et al.*, 1993; Katzenberg and Pfeiffer, 1995; Fogel, *et al.*, 1997; Herring, *et al.*, 1998; Schurr, 1998; Wright and Schwarcz, 1998, 1999; Dupras, *et al.*, 2001; Richards, *et al.*, 2003b; White, *et al.*, 2004; Schurr and Powell, 2005). Studies on infants and children from the Roman cemetery at Kellis 2 in the Dakhleh Oasis, Egypt indicated that breastfeeding was supplemented by other, C_4, foods from 6 months old, and that weaning was complete by 3 years (Dupras, *et al.*, 2001). Rib bone from a small sample of juveniles from Çatalhöjük indicated that weaning occurred before 1.5 years of age (Richards, *et al.*, 2003b). Weaning in ancient Nubia has been studied using stable isotopes of carbon, nitrogen and oxygen (White and Schwarcz, 1994; Schwarcz and White, 2004; White, *et al.*, 2004). There is variability in how the weaning process is expressed in this population: analyses of stable nitrogen isotopes indicated that the weaning transition occurred at around 3 years of age. When compared to oxygen in bone, the $\delta^{18}O$ in tooth enamel showed the expected enrichment associated with breast feeding. However when compared to later forming teeth such as permanent 2nd and 3rd molars, the pre-weaning teeth had lower $\delta^{18}O$ values. The authors suggest that many children may have been nursing from mothers who were depleted of ^{18}O because of high water flux and point out that the values of pre-weaning teeth are still significantly higher than those of female bone samples.

Several studies have been carried out on weaning behaviour in continental America. Fogel *et al.* (1997) carried out studies on two archaeological populations, one pre- and one post-agricultural and found that both populations weaned their infants at around the same time, contrary to the proposed hypothesis that post-agricultural populations would wean their offspring more rapidly in order to shorten birth spacing and increase family size. Isotopic analyses of a population of prehistoric maize horticulturalists from the MacPherson site, Ontario indicated that infants were weaned onto a

diet high in maize, $\delta^{15}N$ values were highest in children under 2 years implying that weaning was underway by this age (Katzenberg, *et al.*, 1993). Subsequently two historic European sites from the same area of southern Ontario were studied: the Harvie and Prospect Hill cemeteries, infants from these sites were also weaned by approximately 2 years, but onto a C_3 rather than C_4 based diet (Katzenberg, 1993). A re-examination of the Prospect Hill data subsequently suggested that infants in this cemetery were weaned a few months before they were 1 year old (Katzenberg and Pfeiffer, 1995). Conversely a 19th-century population buried in Belleville, Ontario indicated an extended pattern of nursing until 14 months of age, although foods other than breast milk were introduced from around 5 months of age (Herring, *et al.*, 1998).

The site of Kaminaljuyú, Guatemala has also been studied to determine weaning behaviour in prehistoric central America (Wright and Schwarcz, 1998, 1999). These are two of the few published studies that utilise stable oxygen isotopes in enamel carbonate to study weaning behaviour: permanent 1st molars, premolars and 3rd molars were analysed for stable isotopes of oxygen and carbon in enamel carbonate, and stable isotopes of carbon and nitrogen in dentine collagen. Kaminaljuyú children began to eat solid maize foods before the age of 2 years, shown in the $\delta^{13}C$ values of enamel carbonate and dentine collagen but continued to drink breast milk until much later, shown in the $\delta^{18}O$ values of carbonate. $\delta^{15}N$ values also show decline in values in late forming teeth compared with permanent first molars, indicating that solid protein was introduced before 2 years of age.

Schurr and Powell (2005) have recently completed a suite of new analyses and added them to the data already published on weaning behaviour from four sites (two pre-agricultural, two highly agricultural) in eastern North America (Schurr, 1997, 1998). Results from the total sample of 196 burials of adults and children indicated that weaning began at around 2 years of age and was completed by age 5. Furthermore there was no difference in weaning behaviour between the pre- and highly agricultural sites indicating that population growth after the appearance of food production cannot be

attributed to earlier weaning. Sex based differences $\delta^{15}N$ values in adults were also observed in these populations, with females being on average 0.5-1‰ more depleted in ^{15}N than males. The authors suggest that this is most likely to be a metabolic effect associated with multiple pregnancy and lactation events, rather than dietary differences between males and females. In this context it is also interesting to note that the authors state that post-weaning juvenile $\delta^{15}N$ values equilibrate with *female* values, and not male and that children were therefore consuming the same diet as women. If this is indeed the case, then these juveniles must also be exhibiting a metabolically induced depletion in ^{15}N.

Focus on medieval

There has so far been only one published study exclusively on Anglo-Saxon dietary analysis for the UK. Privat et al. (2002) analysed remains from the early[8] Anglo-Saxon cemetery at Berinsfield, Oxfordshire and found an apparent distinction between the average diets of individuals classified as 'wealthy', 'intermediately wealthy' and poor through grave goods. A single post-Roman (5th- to 7th-century) individual from Poundbury has also been analysed (Richards and Hedges, 1998); this male had isotope values consistent with a terrestrial diet including only a small amount of animal protein. Research has been published on isotope analyses on skeletal material from the early medieval (6th- to 8th-century A.D.) site at Weingarten, Germany (Schutkowski and Herrmann, 1999). Carbon and nitrogen stable isotope values indicate a C_3 terrestrial diet and consumption of animal protein. Evidence for Viking diet comes from a study on the Greenland Norse colony (Arneborg, *et al.*, 1999). Diet changed from predominantly terrestrial food around 1000 to predominantly marine food toward the end of the settlement period, around 1450. This is ascribed to a deteriorating climate resulting in a change in subsistence pattern.

A number of stable isotope studies have been carried out on the medieval site of Wharram Percy, $\delta^{13}C$ values indicate no measurable contribution to

[8] The cemetery was dated to the mid-5th- to late 6th-/early 7th-century AD by the artefact chronology of grave goods (Privat, *et al.*, 2002).

the diet from marine foods in both the medieval (10th- to 16th-century) and post-medieval periods (Mays S.A., 1997). Rather the diet was mixed with contributions from animal and plant protein (Richards, *et al.*, 2002). Wharram is also the only British site with published data on age of weaning (Mays S.A., *et al.*, 2002; Richards, *et al.*, 2002; Fuller, *et al.*, 2003; Mays S., 2003). Rib samples from 70 infants and juveniles and 29 adults indicated a sharp rise in $\delta^{15}N$ in the first few weeks of life followed by a rapid drop in $\delta^{15}N$ between 1 and 2 years. This was interpreted as a cessation of breastfeeding between 1 and 2 years, a more accurate estimation was not possible due to the difficulty of estimating collagen turnover times in growing bone. Subsequently, teeth were measured for 22 of these juveniles and 15 of the adults, reinforcing this age of weaning and indicating that there is no turnover of dentine in fully formed teeth. Serial sections of teeth indicated that the enriched $\delta^{15}N$ values were most apparent in deciduous 2nd molar crowns, with values becoming more depleted in the cervical and then the apical root sections, followed by the rib. An enrichment pattern in teeth and ribs formed during the estimated period of breastfeeding was also noted in $\delta^{13}C$ values, indicating the possibility of a carnivore affect in carbon values.

Mays (1997) also analysed samples from four other medieval site from northern England: York Fishergate, Hartlepool Greyfriars, Newcastle Blackfriars and Scarborough Castle Hill. These were a mix of monastic and lay burials from coastal and inland sites. Mays concluded that while all the diets were largely terrestrial, some marine resources were being consumed; this was more pronounced in individuals from monastic and costal sites. Three further sites analysed by Müldner and Richards (2005) do not fit into this observed pattern. The rural hospital of St Giles by Brompton Bridge (North Yorkshire), the Augustinian Friary at Warrington and the Towton mass grave (North Yorkshire) all have very enriched $\delta^{15}N$ values combined with almost entirely terrestrial carbon signals. They suggest that a mixed diet of terrestrial, marine and freshwater resources is most likely, with no protein coming from plants. A coastal Cistercian monastic community, Koksijde (12th- to 15th-century) in Belgium consumed a diet based largely on terrestrial foods, but also including marine resources as a form of protein (Polet and

Katzenberg, 2003). When compared with two inland early medieval lay sites, Torgny and Ciply (6th- to 7th-century) it was shown that Koksijde was well differentiated from the Merovingian sites. This was due to higher isotopic ratios in the Cistercian site.

The context of the current research

Stable isotopes have been used with success for many years to characterise palaeodiet and determine age of weaning in a number of populations. Other studies published since this project began have illustrated the potential of using teeth to track childhood diet. The current research builds on this background, developing a method to sequentially extract stable isotope data from molar crowns with the aim of tracking dietary change from birth to adulthood. This will characterise dietary behaviour for northern England in the early medieval period and allow a focus on individual dietary habits through life.

Chapter 4: Materials and Methods

Materials

Individuals were analysed from two cemeteries located in the North East and East Midlands respectively, both are located on estuarine rivers (figure 4.1). These samples were supplemented with individuals from three smaller cemeteries from the East Midlands. This chapter describes the cemeteries from which samples were analysed and gives the numbers of males, females, unsexed and juveniles in each cemetery group. For the purposes of this thesis, an adult is taken to be an individual whose third molar crown is complete; generally an individual will be over 12 years which fits well with the known Anglo-Saxon age of majority discussed in chapter 2. I then discuss the sampling methodology and the methods developed for dental anthropology and isotopic analysis. The latter section includes a discussion of the whole tooth method for sequential extraction of C, N, S and O developed and used in this project. The final section outlines the mass spectrometry and the methods used to correct the raw data outputted from the spectrometer.

Figure 4.1: Map showing the locations of sampled cemeteries.

Black Gate Cemetery[9]

The Black Gate cemetery is located in Newcastle upon Tyne, England and dates from between the late 7th and the early 12th centuries AD, the site is adjacent to the Norman castle. It overlies a Roman fort, the site having been used intermittently from the 2nd century AD onwards, including the early Anglo-Saxon period, possibly for agricultural or industrial purposes (Snape, et al., 2002). Post-conquest burials, probably relating to the castle, occurred in the cemetery, but all funerary activity ceased when a stone castle was built to replace the wooden keep in 1168. The cemetery was excavated by Newcastle City Council between 1978 and 1992 and an assemblage of over 800 individuals, including 660 burials, was recovered. It is likely that much of the cemetery was destroyed over the years, sections of the cemetery were lost in the building of the new castle, the construction of civil war fortifications in the 17th-century, and the building of the railway viaduct in the 19th-century There is currently no settlement evidence associated with the cemetery, but it has been suggested that it may have been used a lay community serving a monastery, or possibly a trading settlement (Merrony, et al., 1996). Analysis of the skeletons initially suggested a bias towards adult male burials in the cemetery, but inclusion of charnel remains in the analysis indicates that the cemetery was likely to have served the entire community (Boulter and Rega, 1993). The majority of the archaeological excavation was centred around the keep and underneath the railway arches of the nineteenth century viaduct. Most of graves were either plain or stone lined, but there is evidence for wooden coffins and cist burials in the cemetery, thought to date to the post conquest period. In total, 23 adults (7 'female'/'female?', 11 'male'/'male?' and 5 'unsexed') and 21 juveniles were sampled for isotope analysis.

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[9] The description of the Black Gate site is a summary of information published by the following: (Knowles, 1926; Webster and Cherry, 1978; Goedburn, *et al.*, 1979; Webster and Cherry, 1979; Youngs and Clark, 1982; Ellison M. and Harbottle, 1983; Youngs, *et al.*, 1983, 1985, 1986; Youngs, *et al.*, 1988; Gainster, *et al.*, 1990; Nenk, *et al.*, 1991, 1993; Snape, *et al.*, 2002)

St Peter's Barton on Humber[10]

Made redundant in 1970, St Peter's Church in Barton on Humber, North Lincolnshire, was invested in the Department of Environment for public guardianship and display and is now owned and managed by English Heritage. As the church was in a state of dilapidation, a long term programme of repairs and improvements was instigated. Excavations were carried out between 1978 and 1984 as part of this programme, during which over 2800 graves were excavated. The cemetery spans over 10 centuries, burial probably started in the late 8th century and continued into the 19th. Phase E represents the late Anglo-Saxon period and is dated to the late 8th to the 12th century; it consists of 620 individual burials (Buckberry J., 2004). The cemetery has had a stone built church associated with it since the 10th century and lies adjacent to a settlement occupied from the mid-Saxon period onwards. 25 adults (13 'female'/'female?', 9 'male' and 3 'unsexed') and 21 juveniles were sampled for isotope analysis.

Church Lane, Whitton

In 1987, human bones were found in the rear garden a house at of Church View Whitton, North Lincolnshire. A small excavation by the local police and by staff at The North Lincolnshire Museum established that they came from an archaeological site, noting that there were around 11 burials (Field, 1988). Further excavation was carried out by the Department of Archaeology, University of Sheffield in 2001 & 2002 uncovered the remains of 43 individuals (Hadley and Davies, 2001; Hadley, 2002). The west-east aligned burials with no evidence for grave goods, in conjunction with the coffin fittings indicated the cemetery was Anglo-Saxon in date, while inter-cutting of burials indicated that the cemetery had been in use for more than one generation. Three radiocarbon dates indicated that the cemetery was in use between approximately 560 and 960 AD (Buckberry J., 2004).

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[10] The description of St Peter's, Barton on Humber is a summary of information published by the following: (Rodwell and Rodwell, 1979; Webster and Cherry, 1979; Rodwell and Rodwell, 1980; Webster and Cherry, 1980; Rodwell and Rodwell, 1981b, a; Youngs and Clark, 1981; Rodwell and Rodwell, 1982; Youngs and Clark, 1982; Youngs, *et al.*, 1983, 1984, 1985)

Fillingham

Six west-east aligned stone lined graves were excavated by the Department of Archaeology, University of Sheffield in 2000 at a property in Chapel Road Fillingham, North Lincolnshire (Buckberry J., 2000). The presence of pillow stones and residual early-mid Anglo-Saxon ceramic indicated that the cemetery was of late Anglo-Saxon date, this was subsequently confirmed by radiocarbon dates of between 660 and 1160 AD (Buckberry J., 2004). Two adults (1 female, 1 male) were sampled from this site and one juvenile mandible, which was a later find from the same locality, handed over by the police to the Department of Archaeology.

Kilton Hill

Building works in 1986 at the Bassetlaw District Hospital, Kilton Hill, Nottinghamshire uncovered what was thought to be a mammoth bone. Excavations were carried out which uncovered a number of human internments in shallow multiple pit type burials. These went unanalysed until 2004 when the remains were transferred to the University of Sheffield (White L., 2004). Possible explanations for the presence of human remains at the site included an execution cemetery or a mass grave for plague/disease victims. The latter explanation was thought less likely as the cemetery appeared to be in use over a long period of time and has very tentatively been dated to the Anglo-Saxon period. Preservation of bone at this site was extremely poor: bones had been consolidated with PVA glue at the time of excavation, and this had penetrated into the fabric of the bone making removal extremely difficult. Two adult males were sampled from this site.

Preparation of teeth and bone for isotope analysis.

Method Development

During the course of this study revised methods were developed for sample selection, dental anthropology, collagen extraction and precipitation of bioapatite as silver phosphate based on the available literature and the practices of the National Isotopic Geosciences Laboratory, Bradford University Department of Archaeological Science Isotope Laboratory and the Oxford University Research Laboratory for Archaeology and the History of Art. Methods were subsequently developed to maximise sample yields and provide as comprehensive a body of information as possible from a non replaceable resource. This included developing a sequential collagen extraction and Ag_3PO_4 precipitation for carbon, nitrogen and sulphur, and oxygen analysis respectively.

Sampling teeth and bone

Teeth

Human teeth are low crowned, formed over a period of several years, and represent discrete periods in an individual's early life (see table 4.1).

Teeth selected.

Mandibular teeth were selected for isotope analysis due to the relative richness of data available on tooth formation and mineralisation timings. Due to the practical difficulties of radiographic visualization (Smith B.H., 1991; Scheuer and Black, 2000), fewer studies of tooth development have been carried out on maxillary permanent teeth and thus tooth formation sequences are incompletely understood. Molars were selected to provide a discrete series of samples from the same adult with no overlap between one crown completing and the next crown initiating, even taking into account the variations between the results of different studies (Levesque, *et al.*, 1981; Smith B.H., 1991; Hillson, 1996). Mandibular permanent first molar crowns form from birth, or shortly after and complete between 2 and 3 years; second molar crowns initiate between 3.5 and 4 years and complete between 6 and 7 years; third molars crowns initiate between 9 and 10 years, completing between 12 and 13 years. The pilot study also used deciduous first and

second molars to gain insight into nutrient intake both in utero and in the first year of life. Subsequent analyses utilised the deciduous second molar only as results from first and second molars were statistically similar. To extend the infant/early child growth window and provide an overlap with values from adult skeletons, the deciduous second molar root was sampled, plus permanent first and second molars from selected juveniles. The crown of the deciduous first molar forms between 16 weeks LMP[11] and 5.5 months post partum; the deciduous second molar crown forms between 18 weeks LMP and 11 months post partum (Lunt and Law, 1974; Sunderland, *et al.*, 1987; Smith B.H., 1991; Hillson, 1996; Liversidge and Molleson, 2004). Deciduous second molar roots form between 11 months post partum and 3.5 years.

[11] The Last Menstrual Period, typically two weeks before fertilization, is the standard obstetric terminology for fetal age.

Deciduous Teeth	Crown formation (years)	Root formation (years)	Permanent Teeth	Crown formation (years)	Root formation (years)
i^1	-0.28 – 0.12	0.12 – 2.26	I^1	0.28 – 3.82	3.82 – 9.67
i^2	-0.47 – 0.10	0.10 – 1.98	I^2	0.9 – 4.3	4.3 – 10.37
c'	-0.45 – 0.83	0.83 – 3.33	C'	0.25 – 5.18	5.18 – 13.06
m^1	-0.47 – 0.35	0.35 – 2.87	P^1	1.75 – 5.83	5.83 – 12.7
m^2	-0.39 – 0.78	0.78 – 3.92	P^2	3.03 – 6.48	6.48 – 13.3
i_1	-0.49 – 0.10	0.10 – 1.98	M^1	0.00 – 3.15	3.15 – 9.55
i_2	-0.49 – 0.32	0.32 – 2.39	M^2	3.42 – 7.03	7.03 – 14.92
c,	-0.46 – 0.81	0.81 – 3.51	M^3	9.02 – 13.33	13.33 – 19.85
m_1	-0.47 – 0.48	0.48 – 2.91	I_1	0.28 – 4.12	4.12 – 7.7
m_2	-0.42 – 0.92	0.92 – 3.54	I_2	0.28 – 4.05	4.05 – 8.6
			C,	0.6 – 4.95	4.95 – 11.5
			P_1	2.05 – 5.5	5.5 – 12.15
			P_2	3.25 – 6.55	6.55 – 13.15
			M_1	0.15 – 2.45	2.45 – 8.2
			M_2	3.7 – 6.7	6.7 – 13.7
			M_3	9.7 – 12.5	12.5 – 19.3

Table 4.1: Formation timings for permanent and deciduous teeth, given in years post natal. Permanent teeth timings based on Hillson (1996), and Smith (1991) (all ages are mid-sex means). Deciduous tooth timings based on Lunt & Law (1974) and Liversidge & Molleson (2004).[12]

[12] The letters indicate tooth type, where I is incisor, C canine, P premolar and M molar. The accompanying number indicates the tooth number, the super- or subscript whether the tooth is maxillary (upper) or mandibular (lower).

Individuals selected.

It was necessary for each individual to have a complete set of two deciduous or three permanent mandibular molars in good condition of preservation in order to provide a longitudinal dimension to the study. An approximately equal number of adults and juveniles were selected for the two main sites, consisting of 42 individuals for Black Gate and 46 individuals for Barton on Humber. In addition 8 individuals were analysed from the Whitton, Fillingham and Kilton Hill cemeteries. Each cohort also consisted, as far as possible, of an equal number of males and females, and, for Black Gate, an equal distribution throughout the excavated cemetery area. Sampling for Barton on Humber was undertaken without access to cemetery plans.

The pilot study sampled 16 archaeological skeletons from the Black Gate cemetery (4 males, 2 females, 4 unsexed adults and 6 children). Individuals were selected according to the quality of preservation of their teeth and extent of pathology and tooth wear. Teeth displaying post-depositional alteration or enamel loss were immediately excluded. Occlusal wear where more than a third of the dentine was exposed was also the basis for rejection, as were carious lesions that had destroyed more than one third of the tooth crown. Where possible, teeth were removed from the same side of the mandible, although in some cases it was necessary to sample both left and right teeth. Focusing primarily on adults obviates the need to compensate for the risk of skewed data due to the possibility that those infants who were unwell and subsequently died were given a different diet. The possibility of a different 'invalid diet' was taken into account when analysing the juvenile samples although work carried out by Fuller et al (2003) indicates that for the later medieval period at least, this was unlikely to be the case, or to have had an effect on carbon and nitrogen stable isotope values.

Site	Males	Females	Unsexed	Juveniles	Total
Black Gate	4	2	4	6	16

Table 4.2: Individuals analysed in the pilot study.

The subsequent full study sampled a further 80 individuals, selected according to the same criteria as the pilot study (table 4.3). Rates of wear were relaxed for some individuals from Barton on Humber in order to sample a greater number of individuals: teeth with one third to one half of the occlusal surface exposing dentine were also included.

Cemetery	Males	Females	Juveniles	Total
Black Gate	5	5	15	26
Barton on Humber	12	13	21	46
Whitton		2	1	3
Fillingham	1	1	1	3
Kilton Hill	2			2

Table 4.3: Individuals analysed in the full study.

Bone

Bone selected.

There is very little literature on collagen turnover, although some research has been carried out on the uptake of bomb ^{14}C, and the likely rates of tissue turnover (Libby, *et al.*, 1964; Stenhouse and Baxter, 1979; Katzenberg and Krouse, 1989; Sealy, *et al.*, 1995; Bailey, *et al.*, 1999; Babraj, *et al.*, 2002; Compston, 2002). It is generally accepted that turnover rates of individual tissues can vary widely, depending chiefly on blood supply and function. Collagen turnover varies according to how much stress a bone is put under during an individual's life time. It accepted that bone is remodelled on average once every 10 years, but this masks a wide variation depending on bone functionality. At a basic level, cancellous bone, which has a rich blood supply, has an estimated turnover rate of 25% per year (Huiskes, *et al.*, 2000) and 30% per year (Hochberg, *et al.*, 2002), faster than the turnover rates of dense cortical bone, discussed in chapter 3. Amongst cortical bone, cranial bones have an extremely slow turnover rate; once they have finished growing they are unlikely to achieve a complete turnover again (Richards, 2003, pers. comm.). Femurs are a load bearing bone and can achieve a

complete turnover every 20 years; ribs are likely to achieve a more rapid rate of turnover (*ibid.*).

It is accepted practice, where possible, to sample the same bone from each individual. Ribs have been selected as they are often already damaged and thus have little further osteological use beyond the recording of presence/absence. Ribs undergo a high amount of stress and movement during breathing and therefore also have a relatively high bone turnover rate and thus reflect the most recent dietary influences. Where it was not possible to sample rib, long bone was taken by preference, where there was very little skeleton preserved, a cranial sample or a sample of fragmentary bone was used.

In order to assess the comparability of rib and tooth samples, rib bone samples were also taken from some Black Gate juveniles, these were supplemented by ribs from other Black Gate juveniles of varying ages in order to provide a series of data points for carbon and nitrogen values throughout childhood.

Faunal remains

Bones from herbivores and omnivores were selected to build up a picture of the local food web for each human population sampled for isotope analysis. It was not possible to select wild carnivore bone as faunal bone was sampled from domestic faunal assemblages as close to the cemetery sites in time and place as possible. Even dog bone from such an assemblage would have an omnivorous signal as domestic canines were often fed on household scraps, essentially reflecting the diet of its owner (Cannon, *et al.*, 1999; Richards, *et al.*, 2003b). The selection of body part for animal bone was more varied, depending principally on what had been preserved. Cortical limb bone was used by preference, or, in pigs and dogs, a tooth. Teeth are not suitable samples for cattle and sheep as they are a hypsodont species, i.e., high crowned and formed over a period of months in incremental layers; they can therefore display significant seasonal variation in their isotopic signals (Fricke and O'Neil, 1996; Wiedermann, *et al.*, 1999; Balasse, *et al.*, 2001; Balasse,

2002, 2003). Faunal bone was taken from commingled remains in the Black Gate cemetery, this bone is likely to be either Saxon or Roman in date (see the description of the Black Gate site), and would have been farmed in the same region as the cemetery. The animals' food sources would have remained unchanged over the Roman and Saxon periods and so provide suitable samples for constructing the local food web. A second sample of faunal bones was taken from the Anglo-Saxon layers at West Halton to provide data for the food web in North Lincolnshire.

Dental Osteology Methodology

Skeletons selected for isotopic analysis had their teeth recorded in as much detail as possible before teeth were removed.

Each mandible was digitally photographed from above, the left and the right. A compact disc of the images was left with the curator of the collection and a removal card was placed in the skeletons box to provide a record of what had been sampled.

For the University of Sheffield's Black Gate collection, Dr Pia Nystrom took moulds of the left and right mandibular molars from suitable skeletons for future dental microwear analysis.

Each individual had their mandible and maxilla examined for the following modifications and pathologies:

- Signs of bone loss or periodontal disease.
- Level of calculus (recorded according to Brothwell (Hillson, 1996) as none, slight, moderate or severe).
- The location, position and size of any caries (as defined by Hillson, *ibid.*).
- Enamel hypoplasias were noted as slight/medium/severe (Hillson, 1996).
- The level of tooth wear was recorded using Scott (1979)for molar teeth and Murphy (1959)for all other teeth.
- Dental age was assessed from dental development and wear (Schwartz, 1995) and a check was made for any dental pathologies recorded on skeletal inventory sheets.

- The age and sex of skeletons was also checked and the skeletal records were checked for any other pathologies present.

Chemical extraction of samples for isotope analysis

For the pilot study, tooth crowns were separated into enamel and dentine for extraction of apatite (in enamel) and collagenous material (in dentine). It was felt that this method lost too much material in the separating process and so a combined, sequential extraction method for apatite and collagen was developed. This outlined in detail below but essentially consisted of retaining the solution of HCl and tooth hydroxyapatite from the demineralising stage of collagen extraction and precipitating silver phosphate from an aliquot of this solution. Before this is possible the chlorides must be driven off by evaporation with concentrated HNO_3 and any remaining organics are then removed with H_2O_2. The evaporated mineral solution is then put into solution with 2M HNO_3 and stored until required for precipitation. Initially 14 teeth were put through both separate extraction protocols and the whole tooth protocol, using half a tooth crown for each method. In addition 9 teeth also had apatite extracted from the dentine.

There are a number of reasons why there might be differences in the oxygen ratios between enamel, dentine and whole tooth crown: there may be differences in the formation timing of enamel and dentine apatite leading in those teeth formed over the breast feeding/weaning period to exhibit stratification in $\delta^{18}O$ with earlier forming enamel having a more pronounced breast feeding signal than dentine. Differences in the formation timing may also be subject to seasonal variations in $\delta^{18}O$, particularly where enamel apatite is mostly formed in one season while the majority of dentine represents another. Dentine apatite is also more susceptible to diagenetic processes than enamel apatite, as the organic component is greater. This may take the form of microbial or fungal attack, leading to greater fractionation of oxygen through the metabolic processes of the organisms. This more fractionated oxygen may then be incorporated in to the apatite lattice during recrystallization. There may also be systemic differences in the way oxygen fractionates as it is incorporated in enamel and dentine apatite.

Analysis of samples from enamel, dentine and enamel plus dentine from the same tooth do not differ to any significant degree, or in a systematic manner

(see table 4. below). Univariate analysis was carried out on the data to confirm this and showed that while there was some variation in $\delta^{18}O$ between tooth types[13] (significance is 0.027), there was no variation between the different materials analysed for either the whole tooth method, enamel only or dentine only (significance is 0.894).

For the full study, the whole tooth method was used on the majority of samples, with checks carried out on 10% of teeth using the separate methods. The whole tooth method improved the probability of extracting useable apatite and collagen from particularly small samples. The normal sample size for bone is around 500mg; due to their small size, some of the deciduous teeth had sample sizes as small as 25-100mg, any loss would therefore seriously impair the chances of useable samples at the end of the extraction protocols.

[13] As some teeth analysed would have formed during breastfeeding and some afterwards this is an expected outcome

Identifier	Dentition	Materials	$\delta^{18}O$ Mean	Standard deviation	Materials	$\delta^{13}C$ Mean	Standard deviation	$\delta^{15}N$ Mean	Standard deviation	C:N	Standard deviation
BG030	M1	enamel/dentine/ half tooth crown	17.6	0.5	dentine	-20.6	0.4	11.8	0.3	3.1	0.4
BG030	M2	enamel/half tooth crown	17.6	0.1	dentine/half tooth crown	-20.6	0.4	10.7	0.2	3.1	0.4
BG030	M3	enamel/dentine/ half tooth crown	17.9	0.2	dentine/half tooth crown	-20.1	0.2	11.4	0.3	3.1	0.5
BG174	dm2c	enamel/dentine	18.9	0.1							
BG252	M1	enamel/half tooth crown	18.1	0.2	dentine/half tooth crown	-20.8	0.4	11.8	0.5	3.1	0.4
BG252	M2	enamel/dentine/ half tooth crown	17.6	0.1	dentine/half tooth crown	-20.8	0.5	10.8	0.4	3.3	0.6
BG252	M3	enamel/dentine/ half tooth crown	17.3	0.3	dentine/half tooth crown	-20.9	0.3	11.0	0.2	3.1	0.4
BG278	dm1c	enamel/half tooth crown	19.2	0.2							
BG278	dm2c	enamel/half tooth crown	19.0	0.5	dentine/half tooth crown	-20.9	0.3	12.2	0.5	3.4	0.1

Identifier	Dentition	Materials	$\delta^{18}O$ Mean	Standard deviation	Materials	$\delta^{13}C$ Mean	Standard deviation	$\delta^{15}N$ Mean	Standard deviation	C:N	Standard deviation
BG567	M1	enamel/dentine/ half tooth crown	17.3	0.3	dentine/half tooth crown	-20.6	0.2	15.2	0.0	3.1	0.2
BG567	M2	enamel/half tooth crown	17.2	0.1	dentine/half tooth crown	-19.1	0.3	12.4	0.7	3.1	0.2
BG567	M3	enamel/half tooth crown	16.7	0.5	dentine/half tooth crown	-18.9	0.3	13.3	0.3	3.0	0.1
BG591	M1	enamel/half tooth crown	17.7	0.5							
BG591	M3	enamel/dentine	18.1	0.1							
BG595	dm1c	enamel/half tooth crown	19.0	0.3	dentine/half tooth crown	-19.5	0.2	14.2	0.2	3.5	0.3
BG595	dm2c	enamel/half tooth crown	18.5	0.2							

Table 4.4 Mean results for different material types.

Stage 1a: Cleaning and preparing the enamel and dentine.

A clean working environment was achieved by utilising a fume cupboard, which was brushed down between each tooth, and cleaned thoroughly on a regular basis. All drill bits were cleaned each time they were changed using distilled H_2O and Dichloromethane (CH_2Cl_2). The following protocol was observed:

Sampling

1. Burr off the outer 100μm of the crown surface, ensuring that all dirt, calculus and other debris is removed. Where the enamel has worn through to the dentine, burr the surface off the dentine. If the enamel is chipped and starts flaking off follow the alternate sampling procedure below. Drill out any caries until clean dentine shows.
2. For deciduous second molars, burr off the outer surface of the root and ensure any dirt is removed from the inside of the root if the apex is open.
3. Cut the tooth in half transversely, retaining the unused half in case re-sampling is required.
4. Drill out any secondary dentine, visible as a darker layer of dentine surrounding the pulp cavity. Any dentine affected by diagenesis should also be removed. This can be recognised as a chalky deposit found around the root surface and pulp cavity, it is relatively loose and easy to drill. The remaining dentine should be a consistent cream to yellow colour and, should not be affected by either the formation of later dentine or diagenetic change.

The following stages were only observed during the pilot study. When separate analysis of enamel and dentine was required in the main study, slivers of enamel were cut from one half of the tooth, ensuring material from the occlusal surface to the CEJ was collected and half the crown was cut from the roots.

5. Line a clean petri dish with foil to catch the dentine sample.
6. Using appropriate sized, clean, burrs, drill out the dentine from the cemento-enamel junction up to the tooth crown, ensuring that as much of the resulting powder is caught in the petri dish as possible.

7. Keep checking under the microscope to ensure that all the dentine is being drilled off the enamel. Small, constricted areas of dentine may need to be drilled out under the microscope.
8. As the dentine is removed, the tooth may fracture into small chunks. These should also have the enamel separated from the dentine.
9. When the enamel is as free from dentine as possible, cut off any remaining root and place the enamel in a labelled bag.
10. Bend the foil into a funnel and tip the dentine powder into a labelled sample tube.

Alternate sampling procedure

1. If the enamel chips off as the outer surface is burred clean, collect and clean off all the chips, placing them in a labelled sample bag.
2. Cut the tooth in half transversally, retaining the unused half in case re-sampling is required.
3. Cut the remaining enamel off the dentine, if necessary drill off any dentine still attached to the enamel.
4. Cut off any slivers of enamel remaining on the dentine.
5. Cut the root off the dentine.
6. Drill out any secondary dentine, visible as a darker layer of dentine surrounding the pulp cavity. Any dentine affected by diagenesis should also be removed.
7. Place the remaining chunk of dentine in a labelled sample tube.

This alternate procedure reduces the sample size and should only be used where it is too difficult to drill the dentine out from the enamel.

Stage 1b: Cleaning and preparing bone samples

The same method was used for human rib samples and faunal bone.

1. Remove 2-500mg of bone from the sample, either by sawing or fracturing. If there is a suitable sized fragment, this is used by preference.
2. Drill off the cancellous bone from the cortex.

3. Clean samples by repeated ultra sounding, changing the distilled H_2O every 5 minutes until the water remains clear. Leave samples to dry overnight at room temperature.

Stages 2 and 3 and the Whole Tooth Method

The whole tooth method does not differ substantially from the separate methods outlined in stages 2 and 3 below. The methods are followed sequentially and the demineralising fluid from the collagen extraction is retained for precipitation of Ag_3PO_4. As hydrochloric acid is used to demineralise samples, this must be driven off in order to prevent the formation of silver chloride in the precipitation stage and an extra procedure (stage 2a) is followed between collagen extraction and Ag_3PO_4 precipitation.

Stage 2: Collagen Extraction

The protocol followed was based on that observed at the University of Bradford Biological Anthropology Research Centre (M. Richards, pers. com.) and that of Brown (1988). The methods developed by Grootes (Chisholm, 1989) and Semal and Orban (Semal and Orban, 1995) were also tested but the former was felt to take too long and the latter to be too harsh a treatment.

Demineralization

1. Place 2-500mg of clean cortical bone, half a tooth crown or 1 root into a labelled test tube and add 7.5ml 0.5M HCl (cold stored in a fridge). Where powder is used, it is best to start with 5ml and mix or shake the sample before adding the rest of the acid.
2. Store archaeological samples in the fridge during the demineralising process. Modern samples can be stored at room temperature as the collagen is more robust.
3. Powder will demineralise overnight, chunks of bone can take up to 5 days and whole teeth up to two weeks. Bubbles should form around the sample if demineralisation is taking place. Samples should be agitated once or twice a day to disperse any microenvironments that may have formed and be impeding the demineralising process. Should the sample stop bubbling before demineralising is complete, change the acid, remembering to retain this 'demineralising solution' if using the whole tooth method. If the demineralising process is going very slowly samples can be taken out of the fridge for a few hours to speed up the process.

When completely demineralised the remaining organic material will be like a firm jelly.

4. If tooth or bone chunks, pour off the acid solution and rinse 3 times with H_2O, ensuring the sample has become neutral. If ground tooth or bone material, centrifuge (3000rpm for 10 minutes), pour off acid solution and rinse sample 3 times by filling tube with H_2O, agitating and centrifuging.
5. Retain any demineralising solution which will be used in the whole tooth method in weighed and labelled sample bottles.

Solubilization

1. Add 7.5ml pH3 H_2O to the test tubes containing samples; cover each tube with a foil cap.
2. Place samples in a hot block or water bath at 70°C. Gelatinization is complete after 48 hours, when the collagen should be completely dissolved.

Filtration

Samples are filtered to eliminate any mineral, lipid and salt contaminants. Collagen consists of three equal-sized chains of approximately 1000 amino acid residues, each approximately 300 nanometers in length. Molecules are ordered functionally into fibrils 10-200nm in diameter (Schwarcz and Schoeninger, 1991). In poorly preserved samples it is expected that some collagen degredation into its component amino acids will have occurred, which can have significantly different $\delta^{13}C$ and $\delta^{15}N$ values (Tuross, *et al.*, 1988; Hare, *et al.*, 1991; Liden, *et al.*, 1995; Fogel M.L., *et al.*, 1997; Fogel M.L. and Tuross, 2003). As it is not always possible to tell which samples will are poorly preserved, all samples were double filtered using first a 8µm EZ filter to remove diagenetic contaminants and then a 30KDa ultra filter to remove the larger and smaller non-collagenous molecules. Filtered samples are stored freeze dried until use.

1. Place the EZ filter into the test tube and slowly push down until the filter touches the base of the tube.
2. Pour off the resulting supernatant fluid into a 30KD ultra-filter unit.

3. Centrifuge and transfer the filtered collagen solution to a pre-weighed, labelled sample bottle, cover with foil and freeze.

Freeze drying

1. Transfer the frozen sample to a freeze dryer. When freeze drying is complete, weigh and store in a cool dry place until use.

Stage 2a, removing chlorides from the demineralising solution

It is important to remove the chloride contaminants from samples before proceeding to the silver phosphate precipitation. Failure to do this will result in silver chloride forming in the precipitation phase, preventing phosphate from the bioapatite from bonding with the silver in the ammoniacal solution of silver nitrate. This will reduce the extracted sample size and affect the stable isotope results. This stage will also remove any residual organics left from the demineralising process.

1) Place the demineralising solution in its weighed and labelled sample bottle on a hot plate to evaporate to dryness. The bottles can then be weighed to determine the sample weight, capped and stored until ready to use.
2) Dissolve the sample with 5ml 2M HNO_3 and transfer to a labelled beaker, wash the sample bottle down with 0.5-1ml 2M HNO_3. Add 10ml concentrated HNO_3 and place on a hotplate to evaporate.
3) When the sample is dry add 5ml concentrated HNO_3 and 5ml H_2O_2, agitate gently and evaporate. If the sample still fizzes, towards the end of the evaporation process, the solution can be toped up with H_2O_2 and the stage repeated until all organics are removed.
4) The sample must now be dissolved in HNO_3 in order that aliquots can be taken for precipitation of Ag_3PO_4 the quantities are determined by the following calculations. These are based on using 1ml each of the reagents (KOH and HF), plus 7.5ml of ammoniacal silver nitrate solution.

a) Convert the sample weight to milligrams (S)

b) Number of 30mg aliquots in a theoretical 10ml solution (X) =S/30

c) Amount of sample in a 1 ml aliquot if 10ml solution (Y) =S/10

d) Ideal size of aliquot (ml) from a 10ml solution (Z) =10/X

e) Amount to aliquot from a 10ml solution (A) = Z
rounded up or down to give a bio-phosphate weight of between 15 & 30mg

f) Amount of sample in aliquot (mg) from a 10ml solution (B) =YA

g) Make up solution to (ml) (L) = An
arbitrary amount that will allow an aliquot to be taken to make the solution up to a concentration that will not overbalance the pH in the precipitation: i.e. no more than 1ml

h) Aliquot from solution L (M) =
normally A unless the solution is more concentrated, in which case a 1ml aliquot will be taken

i) Amount in aliquot (N) 10/LHM

5) Add 2.5 – 5ml 2M HNO_3 to the dried mineral sample and leave to dissolve, agitating if necessary. Add the rest of the 2M HNO_3 to make up the solution to the required quantity and decant into labelled test tubes. Stopper until ready to use.

It is now possible to proceed directly to the dissolution of phosphate in the Ag_3PO_4 protocol.

Stage 3: Silver Phosphate Precipitation

The success of the following method described below relies on careful cleaning of sample material to remove all traces of residual organic material (also described). As well as tooth material, analytical standard samples of the minerals NBS 120C and ACC1 are prepared at the same time to control for batch contamination

The entire procedure (cleaning through to Ag_3PO_4 recovery) can take at least 3 days, and up to 5 days for materials with a high organic content.[14] It is advisable to work with batches of 16-25 samples, aiming to start cleaning samples at the beginning of a day and the addition of HF at the end of a day.

Cleaning sample

1. Start with a finely ground sample of tooth enamel[15] and weigh out 15mg into a 50ml beaker.[16]
2. Add 15ml H_2O_2 to each sample, cover with a watch glass and leave on a hotplate at 60°C overnight, or until the samples are dry. If the sample can be supervised, the hotplate can be turned up to 80°C for a faster drying time.[17] When the sample is completely dry, it can be dissolved or stored for later use.

Dissolution of phosphate

1. Add 1ml HNO_3 to the dry sample in the beaker, agitate gently, cover and leave to dissolve. Time needed to dissolve each sample must be judged separately, coarse samples can take up to 8 hours, but they can be left overnight if well covered.[18]

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[14] For mineral apatite not contaminated with organic matter step 1 can be eliminated and the procedure can be expected to take 2 days.
[15] Using an initial sample of 60-150mg enamel (usually 0.25-0.5% of the tooth crown) prepared as per the tooth sampling protocol, crush the enamel fragments in a piston mortar to a coarse grain and continue in an agate mortar until a fine-grained powder is achieved. The finer the grain, the more effective the cleaning will be.
[16] If a greater quantity of silver phosphate is required, a 100 ml beaker will take 30mg of sample and double the subsequent volumes of chemicals given here.
[17] If the sample completely dries out at this temperature, it is liable to explode.
[18] Samples may be gently heated or ultra-sounded to speed up dissolution.

2. Transfer the sample to a clean, dry, 15ml polypropylene test tube, rinse the beaker with 1ml milliq H_2O and add to the test tube.[19]
3. Add 1ml 2 molar KOH solution to the test tube. When all the samples have been treated, gently agitate the test tubes to dissolve the colloid that has formed.
4. Add 1ml 2 molar HF to the test tube and leave overnight.[20]
5. Centrifuge test tube for 10 minutes at 3000 rpm with no brake.

Precipitation of Ag_3PO_4

1. Add 7.5ml ammoniacal silver nitrate solution to a clean, dry beaker. Carefully decant the centrifuged phosphate solution into the beaker containing the ammoniacal silver nitrate solution, leaving the pellet at the bottom of the test tube.
2. Place the beaker onto a temperature-controlled hotplate between 70 and 90 °C.[21] The solution now has a pH of about 10. Heating will drive off the ammonia and the pH will decrease. Precipitation of Ag_3PO_4 will begin at pH 8.5 and will finish at pH ~6.6.[22]

   Note: It is important that Cl, Br, Iodine, cyanates, tiocyanates and oxalates are not introduced into the system because insoluble compounds of Ag may form.
3. After precipitation commences periodically test the pH to determine when precipitation is complete (< pH 7.5 but > pH 6.5).[23] If the pH goes lower than pH 6.5 Fag (silver fluoride) may form.
4. Once precipitation is complete, pour the contents of the beaker into a filter, rinse out the beaker with milliq H_2O into the filter, refill the beaker over the solution level and ultrasound for approximately 3 minutes. Meanwhile, continue to wash the filter through with distilled water. Remove the beaker from the ultrasound bath, pour the contents through the filter and rinse out the beaker several times through the filter. Refill

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[19] The beaker may be rinsed a second time if necessary, this will increase the precipitation time.
[20] Addition of HF causes the calcium to precipitate as CaF_2
[21] If the hotplate is set above 70, the samples should be supervised, as the reaction time will speed up.
[22] Slow precipitation will produce large crystals, this is more desirable as less material will be lost in the final filtering stage.
[23] To test pH, dip a slip of pH indicator into the solution. If pH decreases below pH 6.5, other components may begin to precipitate.

the beaker and ultrasound again for another minute. Filter the contents of the beaker and repeatedly rinse out the beaker until the precipitate has been removed.[24] Place the filter paper on a labelled watch glass and dry in a moderate drying oven. Homogenise the sample by grinding to a fine powder in a mortar and pestle.[25]

[24] It may be helpful to manually 'scrub' out the beaker with a plastic probe at this stage to remove precipitate still adhering to the beaker walls and base.
[25] It is important to homogenise the sample as oxygen is fractionated between coarse and fine crystals (Chenery, C. 2003, pers. comm.).

Stage 4: Mass Spectrometry

Sample weighing

^{13}C and ^{15}N

Samples in the pilot study were weighed out in duplicate, for subsequent analyses, collagen samples were weighed out in triplicate; 640-660µg of the sample is placed in a tin capsule and crushed to a small ball. Approximately 26 standards of M1360p (powdered gelatine, the NIGL in house standard), 3 C3 (an in house tooth collagen) or cow bone standard (supplied by the RLAHA Oxford lab or made in house) and (from batch 5 onwards) 3 bovine liver samples are also weighed as controls. The batch consists of 99 samples in total, including 6 empty capsules to prime the spectrometer at the start of the run.

^{18}O

Silver phosphate samples and controls prepared in the same precipitation are weighed in triplicate; 345-355µg, or in later runs where the precision of the mass spectrometer had improved, 290-310µg of sample is placed in a silver capsule and crushed to a small ball. Approximately 20 standards, typically NBS 120C, ACC-1 and Mx2 are weighed out for each batch consisting of 99 samples in total (including 6 empty capsules).

Mass Spectrometer loading and running

Analytical measurement of $\delta^{13}C$ and ^{15}N was by a Thermo Finnegan TC/EA coupled to a Thermo Finnegan Delta Plus XL continuous flow isotope ratio mass spectrometer operating isodat NT software version 1.50. The in-house gelatine reference material has an expected value for $\delta^{13}C$ of -20.23‰ calibrated against IAEA-CH-7 and NBS22, and for $\delta^{15}N$ of +8.12‰ calibrated against IAEA-N1 and IAEA-N-2. All samples for the main study were analysed in triplicate, samples from the pilot study were analysed in duplicate. Samples are randomised within a batch, interspersed with standards and loaded on a carousel. Reproducibility for the full set of analyses was calculated by taking the averages of the standard deviations from batches 1 to 4 (where C3 was used as a standard) and batches 5 to 12

(where bovine liver was used). Reproducibility is ±0.05 (1sd) for carbon and ±0.22 (1sd) for nitrogen.

Analytical measurement of $\delta^{18}O$ was by a Thermo Finnegan ConFlo III high temperature conversion elemental analyser coupled to a Thermo Finnegan Delta Plus XL continuous flow isotope ratio mass spectrometry (TC-CFIRMS) also operating isodat NT software version 1.50. The reference material NBS120C, calibrated against certified reference material NBS127, has an expected value of 21.70‰. Each sample was analysed in triplicate and randomised within a batch. The mass spectrometer reproducibility for the method was calculated from the ACC-1 standards. Two separate mixed were used during the course of the analysis: batches 1 to 8 used ACC-9, batches 9 to 23 used ACC1-MX1. The average of the standard deviations from both standards is ±0.17‰ (1sd).

Results

When the run is complete the results are exported into an Excel file and the delta values for the isotope ratios are calculated using the following formulas:

$$\delta^{18}O = \left[\frac{(^{18}O/^{16}O)_{sample}}{(^{18}O/^{16}O)_{standard}} - 1 \right] \times 1000‰$$

$$\delta^{13}C = \left[\frac{(^{13}C/^{14}C)_{sample}}{(^{13}C/^{14}C)_{standard}} - 1 \right] \times 1000‰$$

$$\delta^{15}N = \left[\frac{(^{15}N/^{14}N)_{sample}}{} - 1 \right] \times 1000‰$$

$(^{15}N/^{14}N)_{standard}$

All the standards are calibrated against certified reference materials. Corrections are then made for drift and against the expected values of the standards.

Drinking water (O_w) values derived from phosphate oxygen (O_p) are calculated using Levinson's equation (Levinson, et al., 1987), developed through the fluorination of samples prepared as bismuth phosphate ($BiPO_4$). Analysis of samples prepared as silver phosphate requires a correction for the difference of 1.4‰ observed between the average published values for NBS120C and that observed at NIGL (Chenery, 2005). The equation becomes:

$$\delta^{18}O_w = (\delta^{18}O_{p\text{-NIGLvalue}} - 19.4)/0.46$$

This equation appears to give realistic results in the UK when applied to data for tooth phosphate from presumed indigenous populations (*ibid.*).

Chapter 5: Results for the Black Gate Cemetery

Dental anthropology, pathology and stable isotopes

The results for the dental anthropology, pathology and stable isotope analysis carried out on individuals from the Black Gate cemetery are presented below. The chapter consists of results from these analyses followed by a final section presenting the results of the statistical analysis carried out between the different sexes and material types.

Dental anthropology

Calculus

Calculus is caused by a high carbohydrate diet, particularly in cases where oral hygiene is poor. The levels of calculus varied across the teeth within as well as between individuals. Only 2 individuals, a young adult male and female had severe calculus on any teeth. Results for the varying amounts of calculus in adults and juveniles are given below in table 5.1. The large percentage of juveniles who display no calculus are almost all young individuals, below 6 years only 3 out of 13 individuals display slight calculus. Between 6 and 12 years, 5 out of 8 individuals display slight to moderate calculus, the remaining 3 have none. All individuals over 12 have been grouped with the adults and display similar habits. The only individual who displayed no calculus was an adolescent of 13 to 15 years. There was no age related trend (Spearman's correlation coefficient was 0.068 with a significance of 0.756) amongst the adult individuals, perhaps because most of the individuals studied were adolescents and young adults, with only 3 over 30 and 1 likely to be over 40.

	No. individuals	*% with no calculus*	*% with mild calculus*	*% with moderate calculus*	*% with severe calculus*
Juveniles	21	62	33	5	0
Adults	23	4	35	52	9

Table 5.1: severity of calculus for adults and children sampled from the Black Gate Cemetery.

Caries

Like calculus, caries, caused by a diet high in sugars and starches are not seen in the very young. Before 6 years, only one child (age estimate 4 to 8 years) has caries, while in the 6 to 12 age group, 50% of individuals have caries. This is a small group consisting of 6 individuals and this high prevalence of caries is not seen in the adult sample (see table 5.2). Generally few individuals have any caries, but those who do are more likely to have multiple pits and lesions rather than a single one. Again there are no significant correlations in adults between age and number or extent of caries.

	No. individuals	***% with no caries***	***% with 1 caries***	***% with multiple caries***
Juveniles	21	81	5	14
Adults	23	74	9	17

Table 5.2: distribution of caries for adults and children sampled from the Black Gate Cemetery.

Other dental pathologies

The most prevalent dental pathology is enamel hypoplasias, with 44% of all individuals exhibiting some and 16% exhibiting severe hypoplasias. Table 5.3 illustrates that as with other dental pathologies, while there is no age-related correlation in adults, the children do not exhibit hypoplasias to the same degree. Hypoplasias are caused when the body undergoes systemic stresses, such as illness (for example a fever) or a poor diet. The lack of hypoplasias in young children is likely to be because deciduous teeth are chiefly formed in utero and during infancy when the placenta and later breast milk can provide a cushioned environment. Two of the juveniles with severe enamel hypoplasias have been identified as possibly having congenital syphilis (see Roberts C. and Manchester, 1995: 155 for a description). BG477 has mulberry form mandibular 1st molars and some deformation could be seen in the deciduous 2nd molars; the upper deciduous canines are deformed and curve around the 2nd incisors. The hypoplasias take the form of pitting on all the deciduous 2nd molars and the canines. This individual

died when they were between 3.5 and 5 years old. BG575 (age 8 to 12), exhibits severe hypoplasia including waisting of the permanent 1st and 2nd incisors and the canines, seen also on the mandibular left 2nd premolar and right 1st molar. These individuals were included in the isotope analysis sample to determine if they had a significantly different diet to their apparently healthy contemporaries.

Bone loss around the dentition (shown in table 5.3) is the only factor other than wear correlated with age (Spearman's correlation coefficient was 0.575 with a significance of 0.004). No juveniles exhibited any bone loss; this was restricted to the older adults. As there are no old adults in the sample, this bone loss can be attributed principally to poor oral health leading to periodontal disease (Hillson, 1996: 263-6), although no correlations were found between calculus or caries and bone loss.

	No. individuals	***% with none***	***% with mild***	***% with moderate***	***% with severe***
Juvenile hypoplasia	21	81	5	5	10
Adults hypoplasia	23	35	26	17	22
Juvenile bone loss	21	100			
Adult bone loss	23	83	9	4	4

Table 5.3: Incidence of enamel hypoplasias and horizontal bone loss for adults and children sampled from the Black Gate Cemetery.

Wear

Individual wear scores were assigned to each tooth, in the case of molars, Scott's system involves assigning an individual wear score to each quadrant of the tooth. For gross comparisons with other teeth, these scores were divided by 4. A mean wear score was then given to each individual by dividing the total amount of wear by the number of teeth (figure 5.1). Both

adult and juvenile tooth wear in adults was significantly correlated with age at the 0.01 level.

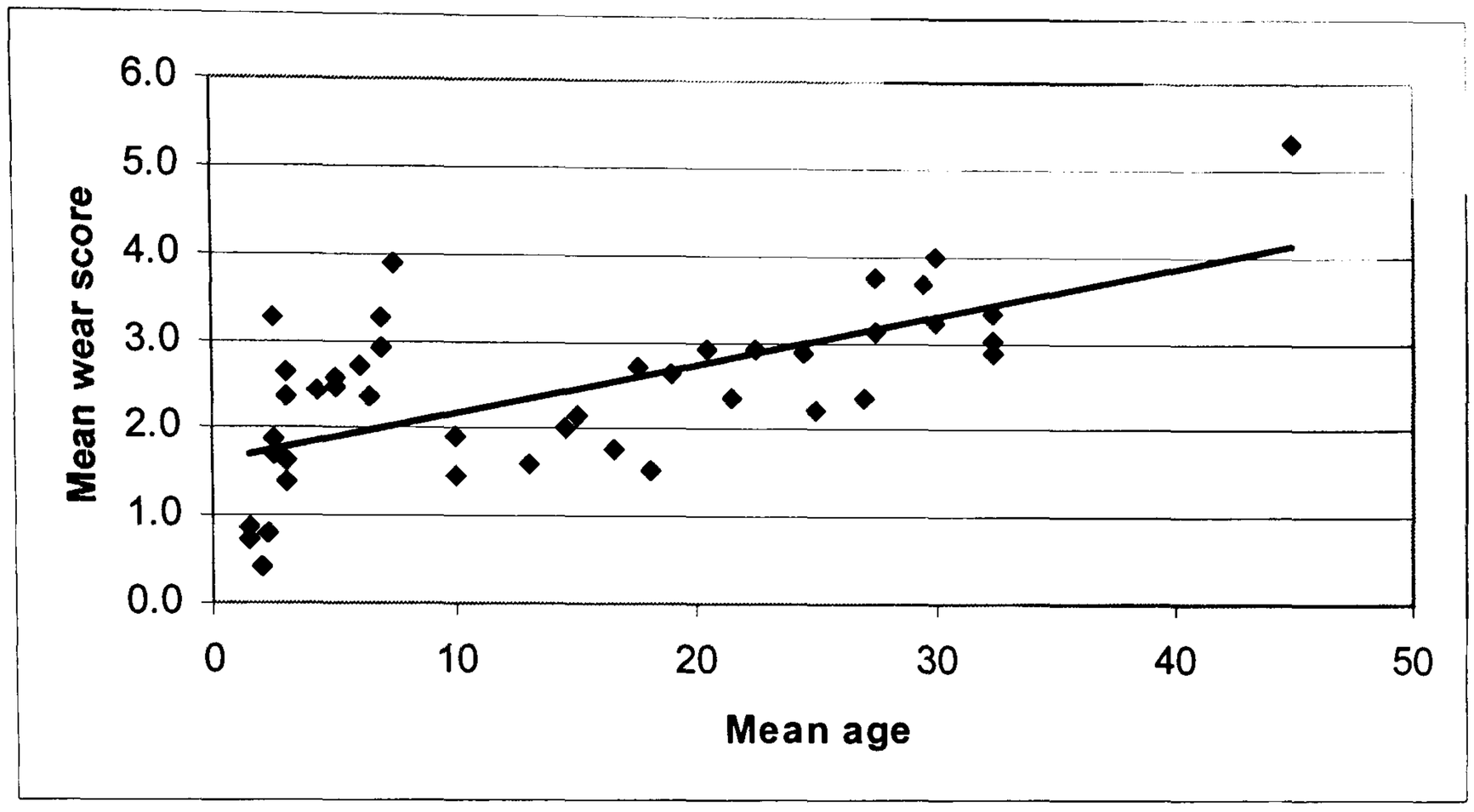

Figure 5.1: Mean wear scores versus age for adults and children sampled from the Black Gate Cemetery.

Pathology

Assessment of pathology was undertaken by various researchers at the Universities of Durham and Sheffield, the quality of which appears to be variable. Not all individuals were examined for pathologies and there was extremely variable preservation between the samples selected. The only skeletal element which all individuals have in common is molars suitable for isotope analysis. What follows is an amalgamated summary of the findings for the individuals sampled taken from the skeleton recording forms completed at Sheffield, and the summaries of skeletons written at Durham. Most individuals displayed no major pathologies other than some age related changes. One juvenile (BG262, a 4-6 year old) displayed bowing of the femur and tibia and flaring of the distal epiphyses of the femurs and proximal epiphyses of the tibias, the child also displayed cribra orbitalia. Bowing of limbs has been related to vitamin D deficiency resulting in rickets (Roberts C. and Manchester, 1995: 173-5), the presence of cribra orbitalia indicate that the child may also have been suffering from anaemia. Iron-deficiency anaemia can be caused by a diet low iron, but also through excessive blood loss through injury, chronic disease and parasitic infection of the gut and in severe cases causes bony changes including cribra orbitalia and thinning

and porosity of the skull (Roberts and Manchester, 1995: 165-9). Bone changes probably only occur in childhood, but adults do display inactive lesions (ibid.). The Black Gate adults do not display any signs of anaemia but cribra orbitalia or porotic hyperostosis was observed in 42% of the juveniles indicating that this condition may have been fairly prevalent for the children buried in this cemetery. As discussed above two juveniles may also have had congenital syphilis.

Pathology and dental anthropology conclusions

It is apparent that the Black Gate individuals sampled demonstrated good oral and general health. This is not a conclusion that can be applied to the cemetery as a whole as the selection process biases towards healthy individuals with good teeth. It does mean that, with the exception of the two potentially syphilitic children and one who may have had rickets, analysis was carried out on the individuals who were most likely to be consuming the diet associated with the healthy members of this population.

Preservation

Of the 231 samples processed for the carbon and nitrogen for the Black Gate cemetery, 131 yielded enough collagen for analysis (table 5.4). The average sample yield was 4.2% (standard deviation 5.1); much higher yields are not expected due to the use of ultrafilters to purify the samples. Some samples were processed without ultrafilters due to extremely low yields when the extraction was performed with the ultrafiltration stage. The average yield for these samples was 11.2% (standard deviation 5.4), 25% of these samples had C:N ratios that were, at 2.8, just below the minimum of the accepted range. Of the 131 samples analysed, 116 yielded results that were considered biogenic signals and have been used for statistical analysis. This included 10 samples that were outside the accepted range of 2.9-3.6 (Ambrose, 1993), but had carbon and nitrogen values that were within 1 standard deviation of the sample averages[26] (table 5.5) and were therefore felt to represent a biogenic signal. Approximately half the material sampled

[26] Calculated without those with a poor C:N

yielded useable results; this is consistent with a site where levels of preservation can vary both within and between skeletons.

Faunal preservation was also variable, of 20 samples processed for collagen, of those 19 yielded material suitable for stable isotope analysis (table 5.4). However C:N ratios indicated that 6 of these were poorly preserved and did not display a biogenic signal.

Using the phosphate component of tooth mineral meant that there were no major preservation problems for analysis of oxygen in silver phosphate: all 176 samples processed yielded suitable analite. Of these, two samples had a $\delta^{18}O$ value that is unlikely to represent an in vivo signal. BG314 M3 had poorly preserved collagen and the $\delta^{18}O$ for the whole tooth sample was unusually low. Comparison with an enamel sample for the same tooth indicated that the whole tooth was depleted by 1.36‰ relative to enamel and so this sample was excluded from the statistical analysis. The second sample, BG492 dm2r again did not produce collagen and had an unusually low $\delta^{18}O$ value and so was excluded from statistical analysis. It was suggested in chapter 4 that diagenetic alteration may be caused by microbial and fungal action on tooth dentine, as apatite crystals are dissolved and then re-crystallise during diagenesis, they will incorporate oxygen from the available pool. As this oxygen may have undergone fractionation by a number of different micro fauna, it is not possible to predict whether the resulting re-crystallised apatite will be enriched or depleted in ^{18}O. Unlike bone, it is less likely that dentine apatite will be subjected to the diagenetic processes caused by soil hydrology in the burial matrix, which leads apatite oxygen to equilibrate with local oxygen values. This is because dentine is partially protected from the burial matrix by the much stronger enamel cap.

Identifier	*Sex*	*Mean Age*	*Sample Type*	*$\delta^{13}C$ Mean*	*$\delta^{15}N$ Mean*	*C:N*	*Yield (% of start weight)*
BG039	-	2	dm2c	-21.59	11.7	4.3	0.0
BG048	-	6.5	dm2r	-21.20	10.5	3.5	0.2
BG048			M1	-21.31	10.0	3.4	3.7
BG103	-	3	Rib	-21.08	10.4	3.5	3.5
BG174	-	1.5	dm1c	-20.55	14.3	3.5	0.6
BG174			dm2c	-20.44	14.4	3.5	0.6
BG174			Rib	-20.03	14.07	3.2	4.1
BG227	-	3	dm2cXUF	-20.25	13.03	2.9	0.4
BG227			dm2r	-20.95	12.3	3.9	0.4
BG241	-	1.5	dm2cXUF	-19.64	13.96	3.3	18.0
BG241			Rib	-20.60	12.12	3.1	8.9
BG244	-	2.25	dm2cXUF	-19.48	14.94	2.8	4.9
BG248	-	7	Rib	-21.51	10.96	4.4	1.3
BG262	-	5	dm2c	-20.42	13.56	3.5	7.1
BG262			dm2r	-20.8	12.52	3.6	10.3
BG278	-	6	dm1c	-21.01	12.0	3.4	13.1
BG278			dm2c	-21.09	12.5	3.3	0.5
BG365	-	7	Rib	-19.88	10.78	3.1	6.9
BG403	-	11	cran	-21.28	12.86	3.6	9.6
BG422	-	8	dm1c	-21.43	11.9	3.7	9.9
BG422			dm2c	-21.12	12.2	3.4	0.5
BG422			M1	-21.04	11.79	3.7	5.9
BG466	-	3	dm1c	-19.41	12.4	3.5	2.3
BG466			dm2c	-19.31	12.9	3.4	1.0
BG477	-	4.25	dm2c	-20.28	12.85	3.5	6.6
BG477			dm2r	-19.59	12.49	3.5	8.4
BG477			Rib	-19.72	12.64	3.1	2.8
BG492	-	3.75	dm1c	-20.53	12.5	3.4	3.7
BG492			dm2c	-20.53	11.8	3.4	0.8
BG492			Rib	-20.68	13.88	3.6	15.6

Identifier	Sex	Mean Age	Sample Type	$\delta^{13}C$ Mean	$\delta^{15}N$ Mean	C:N	Yield (% of start weight)
BG546	-	5	Rib	-20.67	10.67	3.2	3.0
BG575	-	10	M2XUF	-19.91	10.23	3.3	1.5
BG575			Rib	-19.89	10.30	3.1	12.6
BG584	-	2.5	dm2cXUF	-19.74	14.03	3.2	16.8
BG584			dm2rXUF	-19.75	12.84	2.9	6.2
BG584			M1XUF	-19.74	13.32	3.0	3.6
BG595	-	5	dm1c	-19.39	14.4	3.3	0.6
BG595			dm2c	-19.65	13.7	3.5	0.3
BG601	-	10	dm2cXUF	-20.55	13.49	3.0	15.0
BG601			dm2rXUF	-20.39	11.65	2.9	19.9
BG601			M1XUF	-20.43	11.89	3.1	11.4
BG601			M2XUF	-20.44	9.72	2.9	10.6
BG601			Rib	-20.81	9.06	3.0	4.4
BG608	-	13	Rib	-20.48	10.90	3.3	6.7
BG624	-	11	Rib	-20.64	11.77	3.0	4.5
BG632	-	2.5	dm2c	-20.69	14.04	3.7	3.7
BG632			dm2r	-20.87	12.38	3.6	13.4
BG030	??	15	M1	-20.86	11.6	3.3	0.5
BG030			M2	-20.90	10.6	3.3	1.3
BG030			M3	-20.26	11.2	3.4	1.4
BG030			Rib	-20.61	10.8	3.3	0.9
BG040	M?	30	M1	-20.42	12.22	3.3	0.5
BG053	FF	30	M1XUF	-20.82	10.42	2.8	6.9
BG053			M2XUF	-20.83	11.28	3.2	8.5
BG053			M3XUF	-20.91	11.07	2.8	4.8
BG053			rib	-20.78	10.91	3.17	0.8
BG078	F?	40	rib	-20.00	11.53	3.00	3.2
BG132	M?	17	Rib	-21.12	11.8	3.5	0.8
BG155	M?	18	M1XUF	-20.33	12.99	2.8	0.9

Identifier	Sex	Mean Age	Sample Type	$\delta^{13}C$ Mean	$\delta^{15}N$ Mean	C:N	Yield (% of start weight)
BG155			M2XUF	-20.02	12.81	2.8	3.4
BG155			M3XUF	-19.78	12.53	2.8	1.7
BG155			Rib	-20.49	11.3	3.6	0.4
BG252	MM	20.5	M1	-21.05	11.5	3.4	0.4
BG252			M2	-21.20	10.5	3.7	9.0
BG252			M3	-21.06	10.9	3.4	0.6
BG252			Rib	-20.67	10.6	3.3	0.4
BG268	MM	19	Rib	-20.55	10.90	3.5	9.2
BG314	??	17.5	M1XUF	-20.65	11.98	2.8	9.9
BG314			M2XUF	-20.43	10.71	2.8	9.7
BG314			M3XUF	-20.40	11.64	2.8	12.0
BG314			Rib	-20.66	10.54	3.1	9.6
BG344	FF	24.5	Rib	-21.16	11.40	3.6	5.2
BG386	M?	19	M1	-20.59	12.27	3.8	14.2
BG386			M2	-20.89	10.86	2.9	8.9
BG386			M3	-20.81	11.96	3.8	11.2
BG386			Rib	-20.34	11.35	3.2	1.3
BG404	MM	30	Rib	-20.74	11.97	3.4	18.0
BG433	MM	32.5	M1	-20.09	12.0	3.5	0.3
BG433			M2	-20.73	10.2	3.7	0.0
BG433			M3	-19.94	10.2	3.4	5.3
BG433			Rib	-19.99	11.2	3.3	0.2
BG498	FF	16.5	M1XUF	-19.14	12.96	2.9	6.3
BG498			M3XUF	-19.09	11.85	3.1	14.5
BG498			Rib	-19.12	12.12	3.3	8.4
BG499	MM	27	M1XUF	-19.86	11.93	3.0	16.0
BG499			M2XUF	-19.70	10.84	3.0	15.6
BG499			M3XUF	-19.71	11.55	2.9	17.4
BG499			Rib	-20.63	12.32	2.9	2.8
BG527	F?	24.5	M1XUF	-19.81	14.55	3.0	11.7

Identifier	Sex	Mean Age	Sample Type	$\delta^{13}C$ Mean	$\delta^{15}N$ Mean	C:N	Yield (% of start weight)
BG527			M2XUF	-18.79	15.45	2.9	9.0
BG527			M3XUF	-19.58	13.05	3.3	14.9
BG527			Humerus	-19.97	12.16	3.7	6.0
BG534	FF	21.5	M1	-21.07	10.1	3.4	0.5
BG534			M2	-21.07	9.9	3.4	0.6
BG534			M3	-20.83	11.3	3.4	0.6
BG534			Rib	-20.75	11.2	3.1	1.1
BG567	MM	25	M1	-20.43	15.2	2.9	0.8
BG567			M2	-18.95	11.9	2.9	0.8
BG567			M3	-18.67	13.5	2.9	1.5
BG567			Rib	-19.76	11.3	3.2	1.6
BG573	F?	15.5	Rib	-19.98	11.01	2.9	12.1
BG576	??	14.5	M1	-19.78	15.0	3.3	0.6
BG576			M2	-20.51	12.5	3.7	0.2
BG576			M3	-20.32	12.2	3.3	0.6
BG576			Rib	-20.75	10.6	3.6	0.9
BG581	??	13	M1XUF	-20.01	11.80	3.3	16.2
BG581			M2XUF	-20.22	9.82	3.2	10.4
BG581			M3XUF	-19.97	11.75	2.9	14.4
BG581			Rib	-20.16	11.01	3.4	10.8
BG591	FF	45	M1	-20.46	9.9	3.4	0.6
BG591			M2	-20.42	9.8	3.5	0.3
BG591			M3	-20.26	10.2	3.6	0.9
BG591			Rib	-20.17	10.8	3.0	0.8
BG626	M?	22	M1XUF	-20.57	12.98	2.9	13.7
BG626			M2XUF	-20.26	12.31	3.2	14.2
BG626			M3	-20.07	12.38	3.3	0.6
BG626			Rib	-20.51	11.34	3.4	5.3
BG635	FF	27	M2	-20.83	11.6	3.4	8.2
BG635			M3	-21.02	11.8	3.5	6.2

Identifier	Sex	Mean Age	Sample Type	$\delta^{13}C$ Mean	$\delta^{15}N$ Mean	C:N	Yield (% of start weight)
BG635			Rib	-20.99	11.79	3.5	3.4
BG637	MM	32.5	M1	-20.93	10.5	3.3	0.7
BG637			M2	-21.01	9.0	3.4	0.4
BG637			M3	-20.64	10.3	3.4	0.8
BG637			Rib	-20.02	10.5	3.1	0.5
BG654	M?	29.5	M1XUF	-20.69	12.54	3.0	17.0
BG654			M2	-21.21	10.9	3.5	1.8
BG654			M3XUF	-20.54	12.21	3.0	13.7
BG654			Rib	-21.20	11.1	3.7	2.8
BG659	FF	30	M1	-20.96	11.3	3.5	3.3
BG659			M2	-20.90	11.7	3.4	7.0
BG659			Rib	-20.37	12.64	3.3	4.0
BG170-C			Cow	-22.43	6.17	3.2	0.1
BG271-C			Cow	-21.60	6.71	3.2	0.6
BG587-C			Cow	-22.11	5.47	3.1	11.7
BG652-C			Cow	-21.75	8.44	3.0	3.0
BG443-C			Cow	-21.60	5.19	3.7	0.7
BG558-C			Cow	-22.30	6.77	4.2	2.9
BG043 /4-D			Dog	-19.80	11.27	5.3	0.4
BG602-P			Pig	-22.06	10.35	4.4	1.8
BG043/ 4-P			Pig	-21.82	7.16	3.1	0.3
BG568-P			Pig	-21.02	9.95	3.4	9.1
BG635-P			Pig	-20.79	6.09	3.3	5.4
BG638 (1)-P			Pig	-21.40	7.58	3.6	2.9
BG638 (2)-P			Pig	-20.89	8.62	3.0	3.2

Identifier	Sex	Mean Age	Sample Type	$\delta^{13}C$ Mean	$\delta^{15}N$ Mean	C:N	Yield (% of start weight)
BG455-S			Sheep	-21.81	5.39	3.9	0.4
BG482-S			Sheep	-21.97	5.29	4.2	0.2
BG535-S			Sheep	-22.05	8.65	3.5	2.7
BG553-S			Sheep	-22.06	6.80	3.5	10.7

Table 5.4: Stable carbon and nitrogen results for all samples from the Black Gate cemetery. Samples in grey were not considered to have a biogenic signal and were not used for statistical analysis. Teeth with XUF after the tooth type were processed without the ultrafiltration step.

Sample type	*Number*	*Mean $\delta^{13}C$*	*standard deviation*	*Mean $\delta^{15}N$*	*standard deviation*
dm1c	5	-20.18	0.73	13.13	1.15
dm2c	12	-20.25	0.57	13.20	0.78
dm2r	7	-20.51	0.62	12.09	0.79
juv. rib	11	-20.31	0.40	11.56	1.52
M1	22	-20.42	0.53	12.20	1.47
M2	19	-20.42	0.67	11.03	1.43
M3	18	-20.16	0.64	11.69	0.92
adult rib	24	-20.48	0.49	11.37	0.66

Table 5.5: Mean values for $\delta^{13}C$ and $\delta^{15}N$ for each human sample type from the Black Gate cemetery. Juv. ribs are from individuals aged between 0 and 13 who did not have a full set of permanent molars analysed.

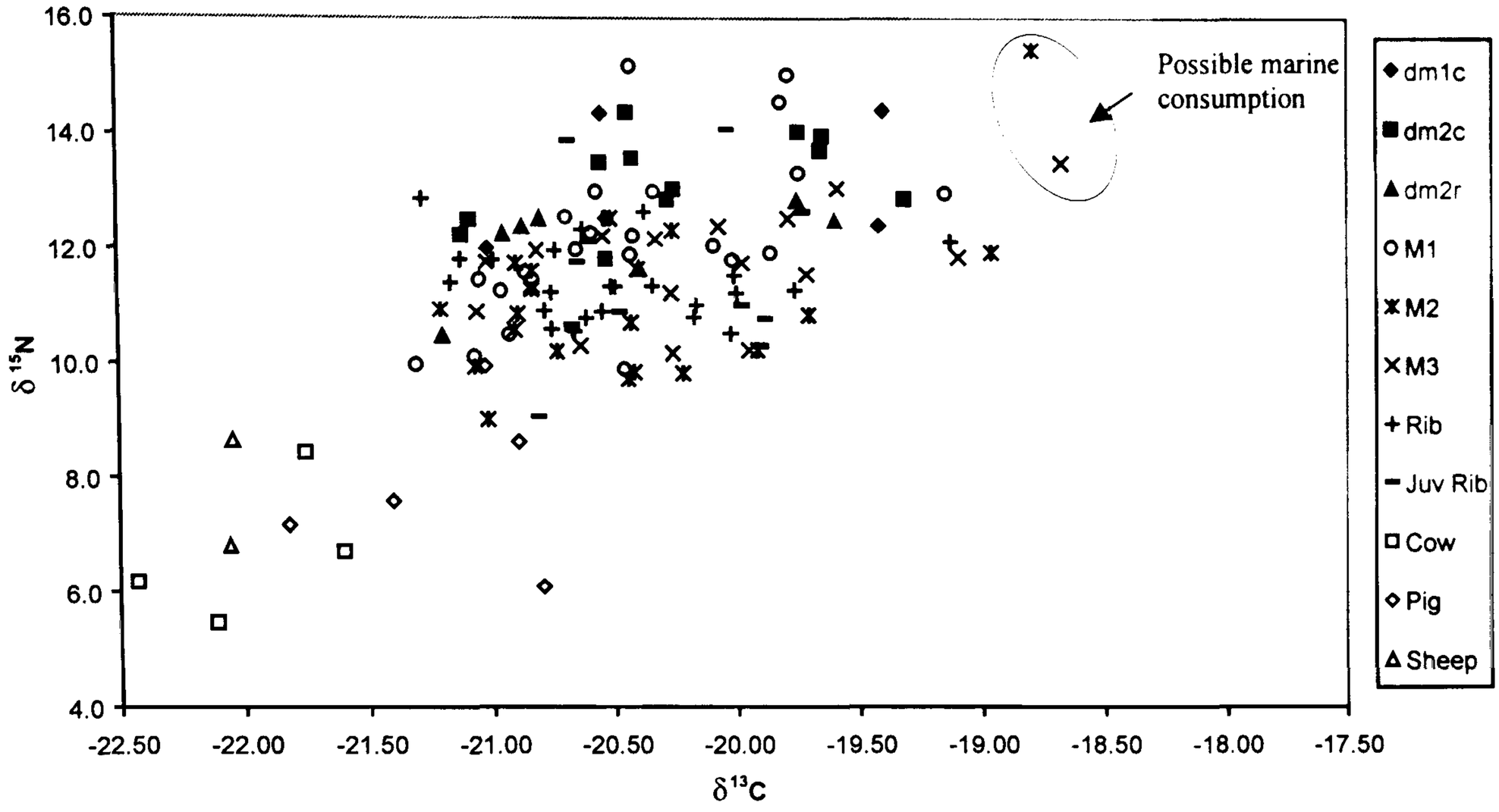

Figure 5.2: Human and faunal stable carbon and nitrogen isotope data from the Black Gate cemetery for all individuals retaining a biogenic signal.

Stable isotopes and diet

Carbon

The carbon stable isotope values for the faunal material range between -22.4 and -19.8‰ (table 5.4, figure 5.2), within the expected range for C_3 consumers (Ambrose, 1993). The carbon stable isotope range for the human material is -21.6 to -18.67‰. Only two samples indicate any marine component in the diet: BG527M2 (-18.79‰) and BG567M3 (-18.67‰, figure 5.2). All other samples are consistent with a diet of C_3 terrestrial protein. Visually, values for all samples seem to have an overlapping range (figure 5.3). However students paired t-tests indicate significant differences at the 95% confidence interval between dm2c's and M1's and M2's (table 5.6). Although most of the significant differences are between dm2c's and other teeth formed later in childhood, the lack of difference between dm2c's and M3's and dm1c's and any other material type mitigates against this being a trophic effect for breastfeeding. The differences are more likely due to individual dietary variation, or possibly an artefact of sampling.

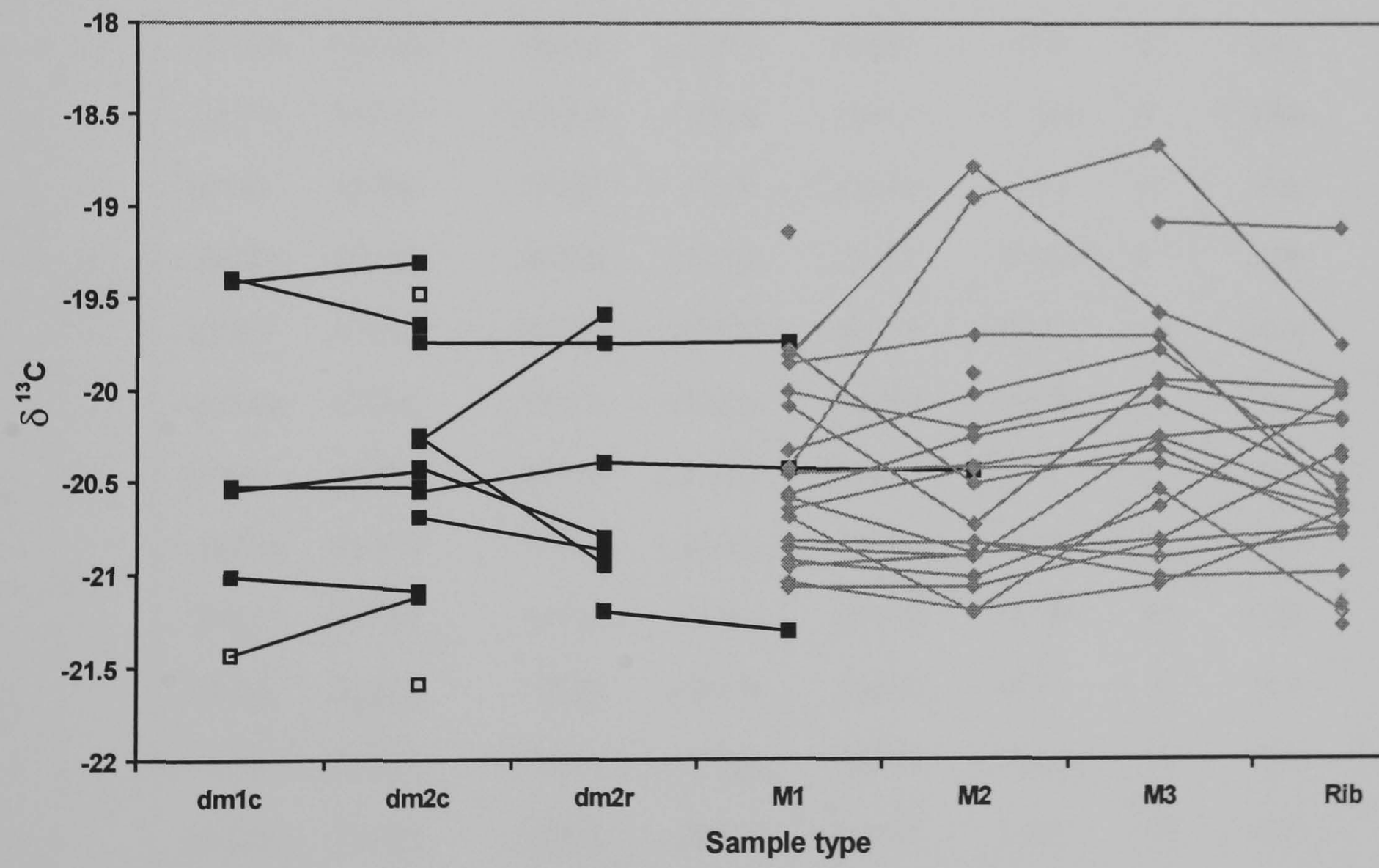

Figure 5.3: Stable carbon isotope ratios for all humans analysed from the Black Gate Cemetery. Hollow points are for those samples which did not preserve a biogenic signal.

Sample Pairs	*Paired Differences*					*t*	*df*	*Sig. (2-tailed)*
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
dm1_C - dm2c_C	.29800	.87936	.39326	-.79387	1.38987	.758	4	.491
dm1_C - dm2r_C	.50400	1.02006	.45619	-.76258	1.77058	1.105	4	.331
dm1_C - M1_C	.60200	.62396	.27904	-.17274	1.37674	2.157	4	.097
dm1_C - M2_C	.33000	.67454	.30166	-.50755	1.16755	1.094	4	.335
dm1_C - M3_C	.40200	.95659	.42780	-.78577	1.58977	.940	4	.401
dm1_C - rib_C	.65600	.88110	.39404	-.43803	1.75003	1.665	4	.171
dm1_C - juv_rib_C	.00400	.86306	.38597	-1.06764	1.07564	.010	4	.992
dm2c_C - dm2r_C	.05143	.99992	.37794	-.87335	.97620	.136	6	.896
dm2c_C - M1_C	.40333	.58801	.16974	.02973	.77693	2.376	11	.037
dm2c_C - M2_C	.43583	.62803	.18130	.03680	.83487	2.404	11	.035
dm2c_C - M3_C	.05333	.97873	.28254	-.56852	.67519	.189	11	.854
dm2c_C - rib_C	.30917	.82778	.23896	-.21678	.83512	1.294	11	.222
dm2c_C - juv_rib_C	.12000	.85019	.24543	-.42018	.66018	.489	11	.634
dm2r_C - M1_C	.26429	.72700	.27478	-.40808	.93665	.962	6	.373
dm2r_C - M2_C	-.01143	1.04506	.39500	-.97795	.95509	-.029	6	.978
dm2r_C - M3_C	-.23714	.54735	.20688	-.74336	.26907	-1.146	6	.295
dm2r_C - rib_C	.26143	.46706	.17653	-.17053	.69339	1.481	6	.189
dm2r_C - juv_rib_C	-.28429	.68794	.26002	-.92052	.35195	-1.093	6	.316
M1_C - M2_C	.02632	.57387	.13165	-.25028	.30291	.200	18	.844
M1_C - M3_C	-.22889	.67983	.16024	-.56696	.10918	-1.428	17	.171
M1_C - rib_C	.07545	.68672	.14641	-.22902	.37993	.515	21	.612
M1_C - juv_rib_C	-.28333	.60813	.17555	-.66972	.10306	-1.614	11	.135
M2_C - M3_C	-.26611	.81141	.19125	-.66962	.13739	-1.391	17	.182
M2_C - rib_C	.07684	.78442	.17996	-.30124	.45492	.427	18	.674
M2_C - juv_rib_C	-.31583	.79702	.23008	-.82224	.19057	-1.373	11	.197
M3_C - rib_C	.33333	.74713	.17610	-.03820	.70487	1.893	17	.076
M3_C - juv_rib_C	.06667	.84899	.24508	-.47276	.60609	.272	11	.791
rib_C - juv_rib_C	-.18917	.94898	.27395	-.79212	.41378	-.691	11	.504

Table 5.6: Results of student's t-tests performed for $\delta^{13}C$ between sample types for all Black Gate samples preserving a biogenic signal.

Nitrogen

Faunal nitrogen stable isotope values (figure 5.2) are slightly higher than expected for this site: cows have a mean $\delta^{15}N$ of 6.44‰, while sheep have a mean $\delta^{15}N$ of 7.72‰. The mean published values for herbivores in medieval Britain is 5.62 and 6.86‰ for cows and sheep respectively; most published data for medieval Britain falls below the Black Gate mean values (Privat, *et al.*, 2002; Müldner and Richards, 2005). This may be due to natural variation rather than any different feeding practices in the Newcastle region and does fall within values suggested for herbivores by Ambrose (Ambrose, 1993). Omnivore values fall within the range of other data for the period and indicate some animal protein in the diet of those pigs sampled.

There is a consistent pattern of change in the stable nitrogen isotope values for the Black Gate skeletons (figure 5.4). Deciduous tooth crowns are elevated by between 1 and 4‰ over adult ribs, with a mean enrichment of 2‰. There are no significant differences between 1st and 2nd deciduous molar crowns, reflecting their overlapping formation times. Subsequent discussion will focus on dm2's only. Paired students t-tests indicate that deciduous 2nd molar crowns are significantly different from permanent 2nd and 3rd molar crowns and adult ribs at the 95% confidence interval (table 5.7). This elevation is likely to represent a trophic shift associated with breastfeeding whilst the dm2 crown is being formed. There are visually observable differences between dm2 crowns and dm2 roots (figure 5.4): mean $\delta^{15}N$ for dm2 roots is 1‰ lower than that of crowns. While this is not statistically significant (students paired t-test, $P = 0.202$), the difference is real and no individual has a δ value that is higher in the dm2r than the dm2c. This implies that a decline in protein input from breast milk is being experienced by these individuals during the formation of the root.

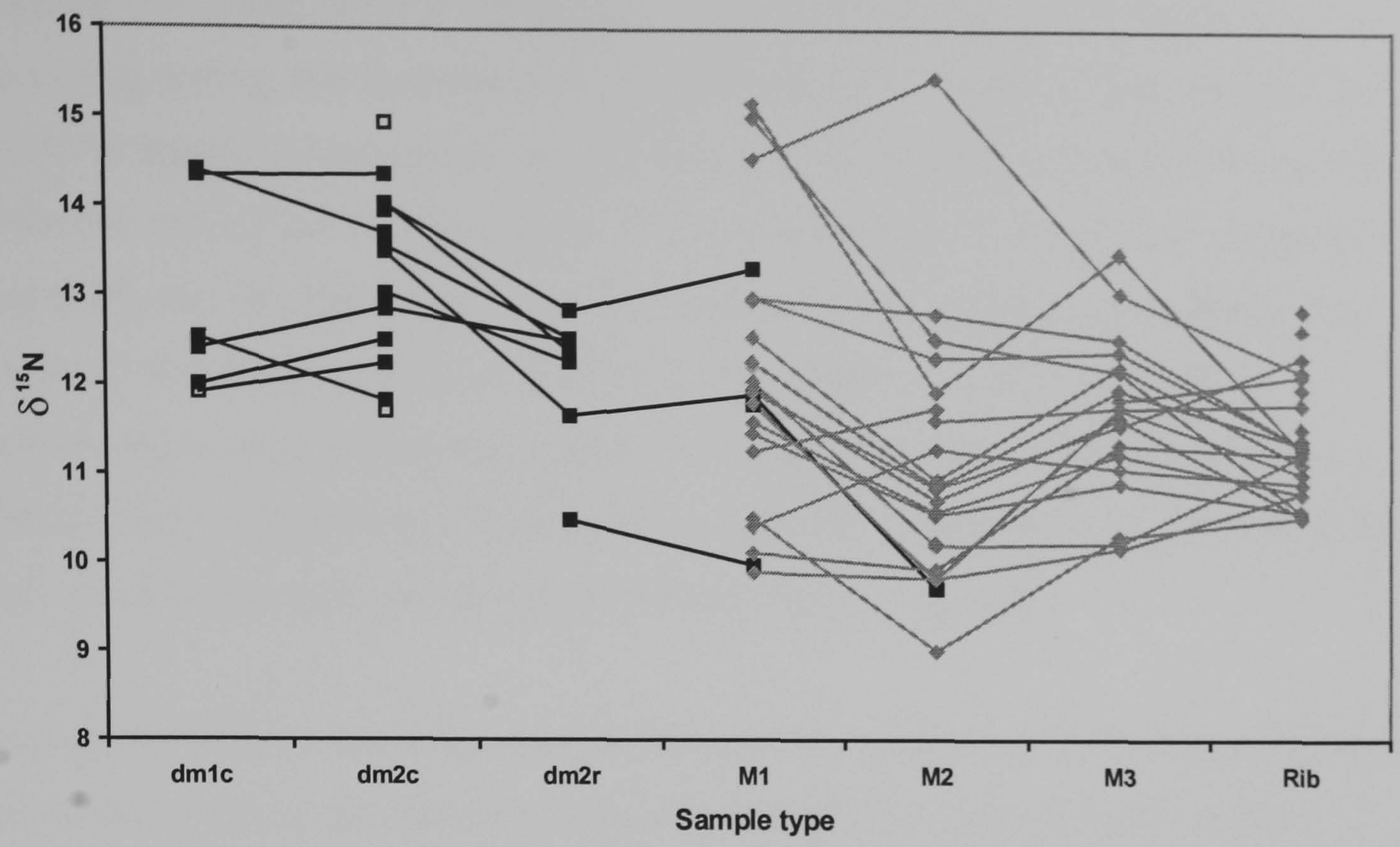

Figure 5.4: Stable nitrogen isotope ratios for all humans analysed from the Black Gate Cemetery. Hollow points are for those samples which did not preserve a biogenic signal.

Permanent 1st molars range between 9.9 and 15.2‰ and have the highest standard deviation (1.5) of all tooth types, and adult ribs. This may be due to dietary differences due to area of earlier residence, or variation in onset of weaning between individuals. It is also possible that some individuals were not breastfed: BG048, BG591, BG534 and BG637 all have $\delta^{15}N$ values in their M1's that are depleted by approximately 2‰ relative to the M1 mean. This may mean either that these individuals were not breast fed at all, or that breast feeding was of such short duration that it did not show up in the M1's. M1's show significant differences between M2's and adult ribs at the 95% confidence interval (table 5.7). That there is no significant difference between M1's and M3's may be due to the presence of some individuals (BG053, BG534, BG581, BG591 and BG637) whose $\delta^{15}N$ for their M3's is as high or higher than their M1's. Reasons for this could be ingestion of a larger proportion of omnivore protein, or freshwater fish in the M3's (discussed below) or their M1's exhibiting no breastfeeding signal. Two individuals (BG584 and BG601) had dm2 crowns and root, and M1's analysed. Results for these individuals show intermediate values for their M1's, weighted

towards the lower dm2r $\delta^{15}N$ results. This is consistent with weaning occurring during the formation of the permanent 1st molar. The elevation of the $\delta^{15}N$ signal compared to dm2r's reflects that portion of the tooth formed while the individual was breastfed. That this elevation is relatively small (0.5 and 0.2‰ for BG584 and BG601 respectively) indicates that breastfeeding declined shortly after the completion of the dm2 crown and that these individuals began to receive protein from sources other than breast milk. There is some statistical difference between M1's and dm2c's, but only at the 90% confidence interval (students paired t-test, P=0.055).

Results for $\delta^{15}N$ in M2's are less dispersed than those of M1's; the standard deviation of 1.4 is elevated by two samples (BG527 and BG637) at the extreme ends of the data range. Although students paired t-tests indicate that M2's are not significantly different from M3's and adult ribs, there is a mean depletion of 0.5‰ between these sample types. As this depletion is seen in M2's and teeth formed over a similar age range in other studies (Fuller, et al., 2003, Eriksson, 2004), it is likely that the effect is physiological rather than dietary. Of all individuals for whom there are results for each sample type, 66% exhibit depletion in their M2's; the lack of statistical significance may be obscured by variation on an individual level. Results from the oxygen isotope determinations indicate a high level of mobility in this population; this level of residential diversity may mask observed physiological differences with dietary variation.

Mean values for M3's and ribs are almost identical (11.7 and 11.4‰ respectively) and the two samples have overlapping ranges. The range for M3's is slightly larger, but this may reflect the relatively longer turnover time for rib collagen (at least 5 years) compared with 3rd molar crown formation (approximately 3 years), yielding a $\delta^{15}N$ value that has been averaged out over a greater number of years. This implies that the diet of older children (from 9 years of age upwards) was identical to that of adults. Comparison with the faunal nitrogen values for Black Gate indicates that the dietary protein of these individuals came largely from terrestrial mammals. Between M3's and ribs, and cow bone, there is a mean difference of 4.5‰; between

these samples and sheep, 3‰; and between these samples and pig there is a mean difference of 3‰. This suggests a greater reliance on sheep and pig protein than cow. However a number of these individuals did not grow up in the Black Gate region (discussed below), comparisons between them and local faunal material can therefore only be an indication of dietary input. The two samples with a carbon marine signal (BG527M2 and BG567M3) also display elevated nitrogen values, consistent with some marine protein input into the diet (15.5 and 13.5‰ respectively).

Sample Pairs	*Paired Differences*					*t*	*df*	*Sig. (2-tailed)*
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
dm1_N - dm2c_N	.00800	1.09468	.48955	-1.35122	1.36722	.016	4	.988
dm1_N - dm2r_N	1.08200	1.78685	.79910	-1.13666	3.30066	1.354	4	.247
dm1_N - M1_N	1.64600	1.04479	.46724	.34873	2.94327	3.523	4	.024
dm1_N - M2_N	2.42800	.91702	.41010	1.28937	3.56663	5.920	4	.004
dm1_N - M3_N	2.00800	1.19930	.53634	.51887	3.49713	3.744	4	.020
dm1_N - rib_N	1.64800	1.24238	.55561	.10538	3.19062	2.966	4	.041
dm1_N - juv_rib_N	.42200	.72306	.32336	-.47580	1.31980	1.305	4	.262
dm2c_N - dm2r_N	.79000	1.46096	.55219	-.56116	2.14116	1.431	6	.202
dm2c_N - M1_N	1.33833	2.15573	.62230	-.03135	2.70802	2.151	11	.055
dm2c_N - M2_N	2.34833	1.02620	.29624	1.69632	3.00035	7.927	11	.000
dm2c_N - M3_N	1.66250	1.46955	.42422	.72879	2.59621	3.919	11	.002
dm2c_N - rib_N	1.79833	.68221	.19694	1.36488	2.23179	9.131	11	.000
dm2c_N - juv_rib_N	1.73500	1.56347	.45134	.74162	2.72838	3.844	11	.003
dm2r_N - M1_N	.28714	2.13175	.80573	-1.68440	2.25868	.356	6	.734
dm2r_N - M2_N	1.27429	1.04690	.39569	.30607	2.24250	3.220	6	.018
dm2r_N - M3_N	.48857	1.17198	.44297	-.59533	1.57248	1.103	6	.312
dm2r_N - rib_N	.84000	1.47077	.55590	-.52024	2.20024	1.511	6	.182
dm2r_N - juv_rib_N	-.07000	1.96476	.74261	-1.88710	1.74710	-.094	6	.928
M1_N - M2_N	1.13000	2.23043	.51169	.05497	2.20503	2.208	18	.040
M1_N - M3_N	.46556	1.87372	.44164	-.46622	1.39733	1.054	17	.307
M1_N - rib_N	.82682	1.72886	.36859	.06028	1.59335	2.243	21	.036
M1_N - juv_rib_N	.39667	2.34835	.67791	-1.09541	1.88874	.585	11	.570
M2_N - M3_N	-.75056	1.76932	.41703	-1.63042	.12931	-1.800	17	.090
M2_N - rib_N	-.32053	1.55892	.35764	-1.07190	.43085	-.896	18	.382
M2_N - juv_rib_N	-.61333	1.60013	.46192	-1.63001	.40334	-1.328	11	.211
M3_N - rib_N	.35833	1.20511	.28405	-.24096	.95762	1.262	17	.224
M3_N - juv_rib_N	.07250	2.16648	.62541	-1.30401	1.44901	.116	11	.910
rib_C - juv_rib_C	-.18917	.94898	.27395	-.79212	.41378	-.691	11	.504

Table 5.7: Results of student's t-tests performed for $\delta^{15}N$ between sample types for all Black Gate samples preserving a biogenic signal.

The Juvenile Nutrition Curve

Rib samples taken from juveniles analysed were ordered longitudinally (represented in figures 5.5 and 5.6). There were no significant correlations between $\delta^{13}C$ or $\delta^{15}N$ and age, possibly due to the small sample size and the fluctuating nature of the isotope values. However results can be seen to mirror the trends seen in the dental material, the highest $\delta^{15}N$ values in the youngest individuals and lower average values in children aged between 3 and 10 years.

Figure 5.5: Polynomial regression of stable carbon isotope values for ribs samples from Black Gate individuals (3rd order).

Figure 5.6: Polynomial regression of stable nitrogen isotope values for rib samples from Black Gate individuals (3rd order).

Sulphur

The stable isotopes of sulphur were measured in collagen from 4 individuals from Black Gate (table 5.8). The results for these four individuals fit into the range for inland medieval England as defined by Richards et al. (2001), confirming the terrestrial nature of these individuals diet. At this stage, too little research has been carried out on the nature of sulphur variation in terrestrial and freshwater environments to determine whether or not any freshwater protein consumption occurred in this population. The sample identified as possibly representing consumption of a proportion of marine protein, BG567M3, also has an elevated $\delta^{34}S$ value, adding weight to the supposition that this man consumed marine protein as an older child.

Identifier	***Sex***	***Mean Age***	***Sample type***	***Mean $\delta^{34}S$***	***Mean $\delta^{13}C$***
BG030	??	15	M1	12.71	-20.86
BG030			M2	12.71	-20.90
BG030			M3	14.35	-20.26
BG030			rib	14.17	-20.61
BG252	MM	20.5	M1	13.86	-21.05
BG252			M2	11.85	-21.20
BG252			M3	13.03	-21.06
BG567	MM	25	M1	9.00	-20.43
BG567			M2	14.54	-18.95
BG567			M3	16.90	-18.67
BG567			rib	11.34	-19.76
BG576	??	14.5	M3	7.83	-20.32
BH576			rib	12.89	-20.75

Table 5.8: Stable sulphur and carbon isotope results for those individuals analysed for sulphur.

Oxygen: weaning and mobility

Stable oxygen isotope values ranged between 15.84 and 19.4‰ for Black Gate individuals (table 5.9, figure 5.7); the mean value for permanent teeth is 17.5‰, with a standard deviation of 0.5‰. Following on from the pilot study and the development of the whole tooth method, 10 further individuals had both tooth and enamel analysed. Univariate analysis indicated that there was no significant variation between the $\delta^{18}O$ of the tooth and enamel pairs; it should however be noted that there was a slightly greater tendency for whole tooth samples to be enriched over enamel samples (in 12 cases as opposed to 9). In addition, repeats of enamel extractions were carried out on samples, it was found that a repeat precipitation of a 2nd aliquot from a homogenised sample could vary by up to ±1‰, although the mean variation was ±0.4‰.

Identifier	*Sex*	*Mean Age*	*Sample type*	*Material*	*$\delta^{18}O$ Mean*	*drinking water correction*
BG039	-	2	dm2c	E	18.58	-4.82
			dm2c	T	18.79	-4.37
BG048	-	6.5	dm2c	E	18.41	-5.20
			M1	E	17.73	-6.68
BG103	-	3	dm2c	E	18.24	-5.56
			dm2r	T	17.73	-6.68
BG144	-	2.5	dm2c	E	18.78	-4.39
			dm2r	T	18.00	-6.08
BG174	-	1.5	dm1c	E	19.12	-3.65
			dm2c	D	18.85	-4.25
			dm2c	E	18.92	-4.08
BG227	-	3	dm2c	E	18.73	-4.49
			dm2r	T	18.28	-5.48
BG241	-	1.5	dm2c	T	18.01	-6.06
BG244	-	2.25	dm2c		17.87	-6.36
			dm2r	T	17.81	-6.49

Identifier	Sex	Mean Age	Sample type	Material	$\delta^{18}O$ Mean	drinking water correction
BG248	-	7	dm2c	E	18.15	-5.76
			M1	E	17.72	-6.69
			M2	E	17.39	-7.41
BG262	-	5	dm2c	E	18.71	-4.54
			dm2r	T	17.28	-7.65
BG278	-	6	dm1c	E	19.09	-3.72
			dm1c	E	19.40	-3.04
			dm1c	T	18.27	-5.50
			dm2c	E	18.67	-4.64
			dm2c	T	19.39	-3.07
			dm2r	T	17.72	-6.69
BG365	-	7	dm2r	T	17.93	-6.25
			M1	E	17.85	-6.42
BG402	-	1.5	dm2c	T	18.44	-5.13
BG422	-	8	dm1c	E	17.83	-6.47
			dm2c	E	17.60	-6.96
			dm2r	T	17.10	-8.03
			M1	E	17.18	-7.87
BG466	-	3	dm1c	E	18.27	-5.51
			dm2c	E	18.27	-5.50
			dm2r	T	17.37	-7.47
BG477	-	4.25	dm2c	E	19.03	-3.85
			dm2r	T	18.12	-5.83
BG492	-	3.75	dm1c	E	17.72	-6.71
			dm2c	E	18.71	-4.55
			dm2r	T	15.84	-10.79
BG575	-	10	M2	T	17.53	-7.10
BG584	-	2.5	dm2c	T	17.80	-6.52
			dm2r	T	17.05	-8.16
BG595	-	5	dm1c	E	18.83	-4.28

Identifier	Sex	Mean Age	Sample type	Material	$\delta^{18}O$ Mean	drinking water correction
			dm1c	T	19.22	-3.43
			dm2c	E	18.50	-4.99
			dm2c	T	18.79	-4.38
			dm2c	Tr	18.35	-5.33
			M1	E	17.98	-6.12
BG601	-	10	dm2c	T	18.18	-5.69
			dm2r	T	17.86	-6.39
			M1	T	17.89	-6.33
			M2	T	17.16	-7.92
BG632	-	2.5	dm2c	E	17.99	-6.11
			dm2c	Er	18.83	-4.27
			dm2r	T	17.55	-7.06
			dm2r	Tr	17.57	-7.02
BG030	??	15	M1	D	16.92	-8.44
			M1	Dr	17.92	-6.26
			M1	E	17.81	-6.51
			M1	T	17.68	-6.78
			M2	E	17.65	-6.86
			M2	T	17.55	-7.06
			M3	D	18.17	-5.73
			M3	E	17.87	-6.37
			M3	T	17.80	-6.53
BG040	M?	30	M1	E	17.93	-6.24
			M2	E	17.82	-6.48
			M3	E	18.01	-6.07
BG053	FF	30	M1	T	17.45	-7.29
			M2	T	16.39	-9.60
			M3	T	16.60	-9.14
BG155	M?	18	M1	T	17.43	-7.32

Identifier	Sex	Mean Age	Sample type	Material	$\delta^{18}O$ Mean	drinking water correction
			M2	T	16.99	-8.27
			M3	T	17.02	-8.21
BG252	MM	20.5	M1	E	18.30	-5.43
			M1	T	17.98	-6.14
			M2	D	17.62	-6.91
			M2	E	17.44	-7.31
			M2	Er	17.47	-7.23
			M2	T	17.60	-6.96
			M3	D	17.58	-7.01
			M3	E	17.47	-7.24
			M3	Er	17.31	-7.59
			M3	T	16.94	-8.38
BG314	??	17.5	M1	E	17.92	-6.26
			M1	T	17.92	-6.26
			M2	E	17.76	-6.61
			M2	T	17.22	-7.77
			M3	E	17.25	-7.73
			M3	T	15.89	-10.68
BG386	M?	19	M1	E	17.57	-7.03
			M2	E	17.35	-7.49
			M3	E	17.45	-7.28
BG433	MM	32.5	M1	E	17.14	-7.95
			M2	E	17.53	-7.12
			M2	Er	17.40	-7.39
			M3	E	17.52	-7.14
			M3	Er	17.04	-8.17
BG498	FF	16.5	M1	E	18.00	-6.09
			M1	T	18.39	-5.24
			M2	E	17.53	-7.11
			M2	T	17.31	-7.60

Identifier	Sex	Mean Age	Sample type	Material	$\delta^{18}O$ Mean	drinking water correction
			M3	E	17.27	-7.67
			M3	T	17.28	-7.66
BG499	MM	27	M1	E	17.41	-7.36
			M1	T	17.37	-7.45
			M1	Tr	17.64	-6.88
			M2	E	17.50	-7.18
			M2	T	17.62	-6.92
			M3	E	18.04	-5.99
			M3	T	18.22	-5.61
			M3	Tr	17.83	-6.46
BG527	F?	24.5	M1	T	17.06	-8.14
			M2	T	16.14	-10.13
			M3	T	17.44	-7.31
BG534	FF	21.5	M1	E	16.93	-8.42
			M2	E	17.05	-8.15
			M2	Er	16.94	-8.39
			M3	E	16.91	-8.46
			M3	Er	16.99	-8.28
BG567	MM	25	M1	D	17.09	-8.07
			M1	E	17.08	-8.09
			M1	T	17.56	-7.05
			M1	Tr	17.49	-7.19
			M2	E	17.17	-7.88
			M2	T	17.30	-7.61
			M3	E	16.36	-9.66
			M3	Er	15.88	-10.69
			M3	T	17.07	-8.11
BG576	??	14.5	M1	E	18.19	-5.68
			M1	Er	17.78	-6.56
			M1	T	17.99	-6.10

Identifier	Sex	Mean Age	Sample type	Material	$\delta^{18}O$ Mean	drinking water correction
			M2	E	17.68	-6.78
			M2	T	17.57	-7.03
			M3	E	17.78	-6.57
			M3	T	17.70	-6.74
BG581	??	13	M1	E	17.40	-7.38
			M1	T	17.76	-6.61
			M2	E	16.78	-8.75
			M2	T	16.99	-8.27
			M3	E	17.10	-8.04
			M3	T	17.69	-6.76
BG591	FF	45	M1	D	17.31	-7.58
			M1	E	18.02	-6.03
			M1	T	17.54	-7.08
			M2	E	17.72	-6.70
			M2	Er	16.73	-8.84
			M3	D	18.16	-5.73
			M3	E	18.06	-5.95
			M3	Er	17.73	-6.68
BG626	M?	22	M1	E	17.34	-7.52
			M1	T	17.77	-6.59
			M2	E	17.12	-7.99
			M2	T	17.46	-7.27
			M3	E	16.81	-8.67
			M3	T	17.04	-8.18
BG635	FF	27	M1	T	18.11	-5.85
			M2	T	17.84	-6.44
			M2	Tr	18.01	-6.07
			M3	T	16.46	-9.43
			M3	Tr	17.30	-7.60
BG637	MM	32.5	M1	E	18.51	-4.97

Identifier	Sex	Mean Age	Sample type	Material	$\delta^{18}O$ Mean	drinking water correction
			M2	E	18.39	-5.24
			M3	E	17.97	-6.15
BG654	M?	29.5	M1	T	16.52	-9.30
			M2	T	17.54	-7.08
			M3	T	17.21	-7.81
BG659	FF	30	M1	E	17.13	-7.97
			M1	T	17.40	-7.40
			M2	E	17.07	-8.11
			M2	T	17.48	-7.21
			M3	E	16.79	-8.71
			M3	T	17.51	-7.14

Table 5.9: Stable oxygen isotope results for each human sample type from the Black Gate cemetery. Material: D = dentine, E = enamel and T = half a tooth crown or 1 root; an r after the material indicates the sample is a repeat. The expected value for drinking water in this area is between -7 and -8‰

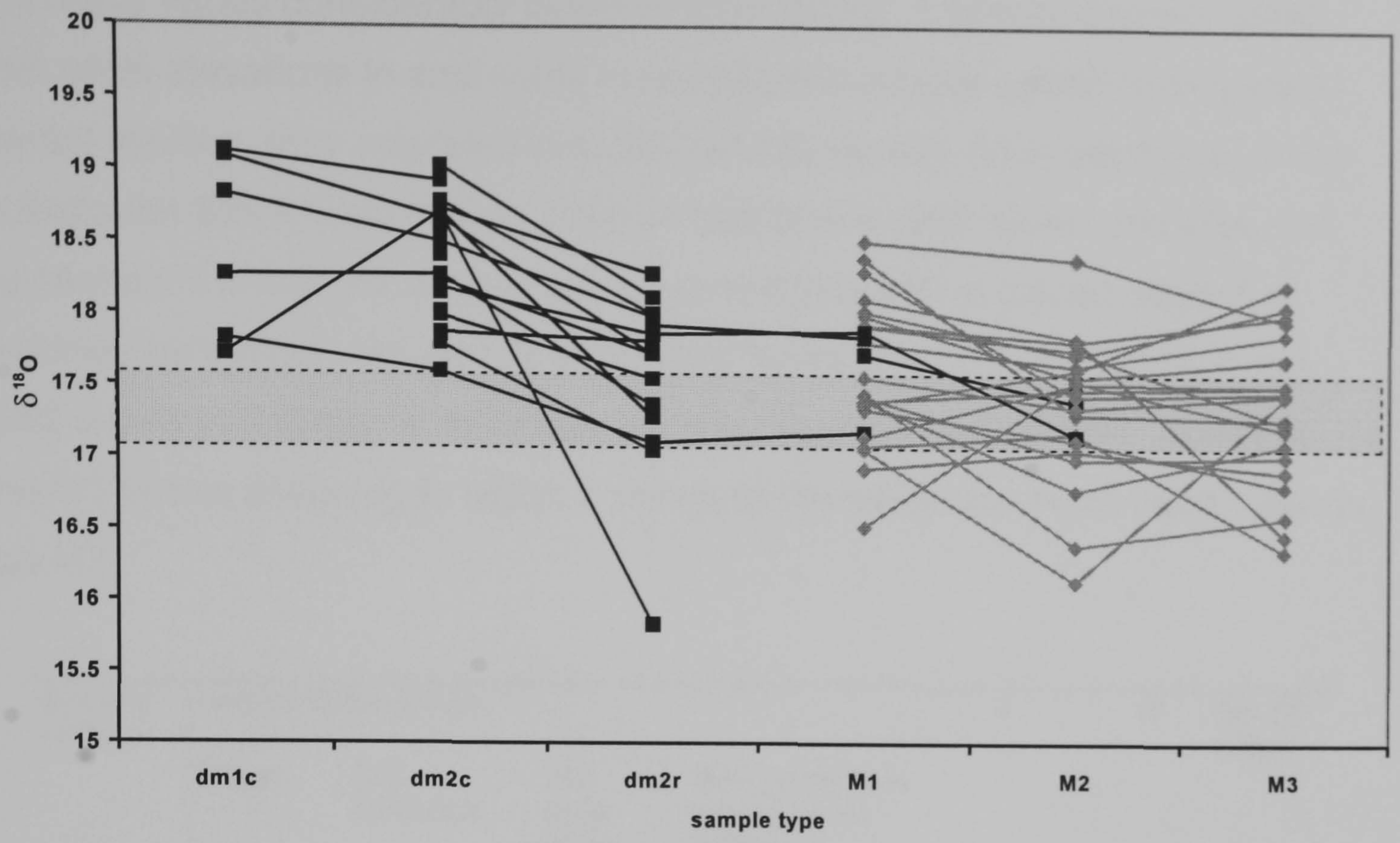

Figure 5.7: Stable oxygen isotope results for each individual from the Black Gate cemetery. The shaded bar indicates the expected range of $\delta^{18}O$ for the Black Gate region.

Paired sample t-tests indicate that deciduous 1st and 2nd molar crowns are significantly different to all permanent teeth at the 95% confidence interval (table 5.10). The mean value for dm2 crowns is over 1‰ more enriched than M2's or M3's implying that this difference is a trophic shift associated with breast feeding. This level of enrichment is slightly greater than the 0.5 to 0.7‰ enrichment seen by Wright and Schwarcz (1998) in human tooth enamel carbonate from Kaminaljuyú, however these authors were using permanent M1's, premolars and M3's. M1's from Blackgate individuals are also significantly different from M2's and M3's, the mean enrichment is 0.3‰ this would imply that the duration of breastfeeding was not as long as that of the Kaminaljuyú individuals and that weaning for most individuals occurred during the formation of the M1. The onset of weaning is most likely to be around the time of completion of the dm2 crown and the onset of root formation: dm2 roots are significantly different to dm2 crowns but not to permanent molars, and in fact have the same mean value as the permanent teeth analysed. However the range of the dm2 roots (15.84-18.28) indicate that the point at which breast feeding declines enough to show a significant

decrease varies considerably between individuals. It should also be noted that while elevations in dm2 roots may indicate a longer period of exclusive breast feeding, they may also indicate individuals who were previously living outside the Black Gate region. BG601 had both a dm2 crown and root, and permanent M1 and M2 crowns analysed and provides a classic pattern of weaning behaviour. As can be seen from figure 5.8, $\delta^{18}O$ is highest in the dm2 crown and drops in the dm2 root; the value is then elevated slightly in the M1 before dropping to within 1 standard deviation the mean adult value in the M2.

Sample pairs	***Paired Differences***					***t***	***df***	***Sig. (2-tailed)***
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
dm1_O - dm2c_O	-.14333	.58776	.23995	-.76015	.47349	-.597	5	.576
dm1_O - dm2r_O	.67333	.66929	.27324	-.02904	1.37571	2.464	5	.057
dm1_O - M1_O	.80500	.65583	.26774	.11675	1.49325	3.007	5	.030
dm1_O - M2_O	1.1783 3	.68450	.27944	.46000	1.89667	4.217	5	.008
dm1_O - M3_O	1.0150 0	.66425	.27118	.31791	1.71209	3.743	5	.013
dm2c_O - dm2r_O	.87571	.75556	.20193	.43947	1.31196	4.337	13	.001
dm2c_O - M1_O	.74333	.46622	.10174	.53111	.95556	7.306	20	.000
dm2c_O - M2_O	1.0733 3	.58306	.12723	.80793	1.33874	8.436	20	.000
dm2c_O - M3_O	1.0709 5	.65912	.14383	.77092	1.37098	7.446	20	.000
dm2r_O - M1_O	-.20214	.72654	.19418	-.62164	.21735	-1.041	13	.317
dm2r_O - M2_O	.15071	.70390	.18812	-.25570	.55713	.801	13	.437
dm2r_O - M3_O	.23071	.78792	.21058	-.22422	.68565	1.096	13	.293
M1_O - M2_O	.31647	.59369	.10182	.10932	.52362	3.108	33	.004
M1_O - M3_O	.37581	.73828	.13260	.10500	.64661	2.834	30	.008
M2_O - M3_O	.06516	.63786	.11456	-.16881	.29913	.569	30	.574

Table 5.10: Results of student's t-tests performed for $\delta^{18}O$ between sample types for all Black Gate individuals.

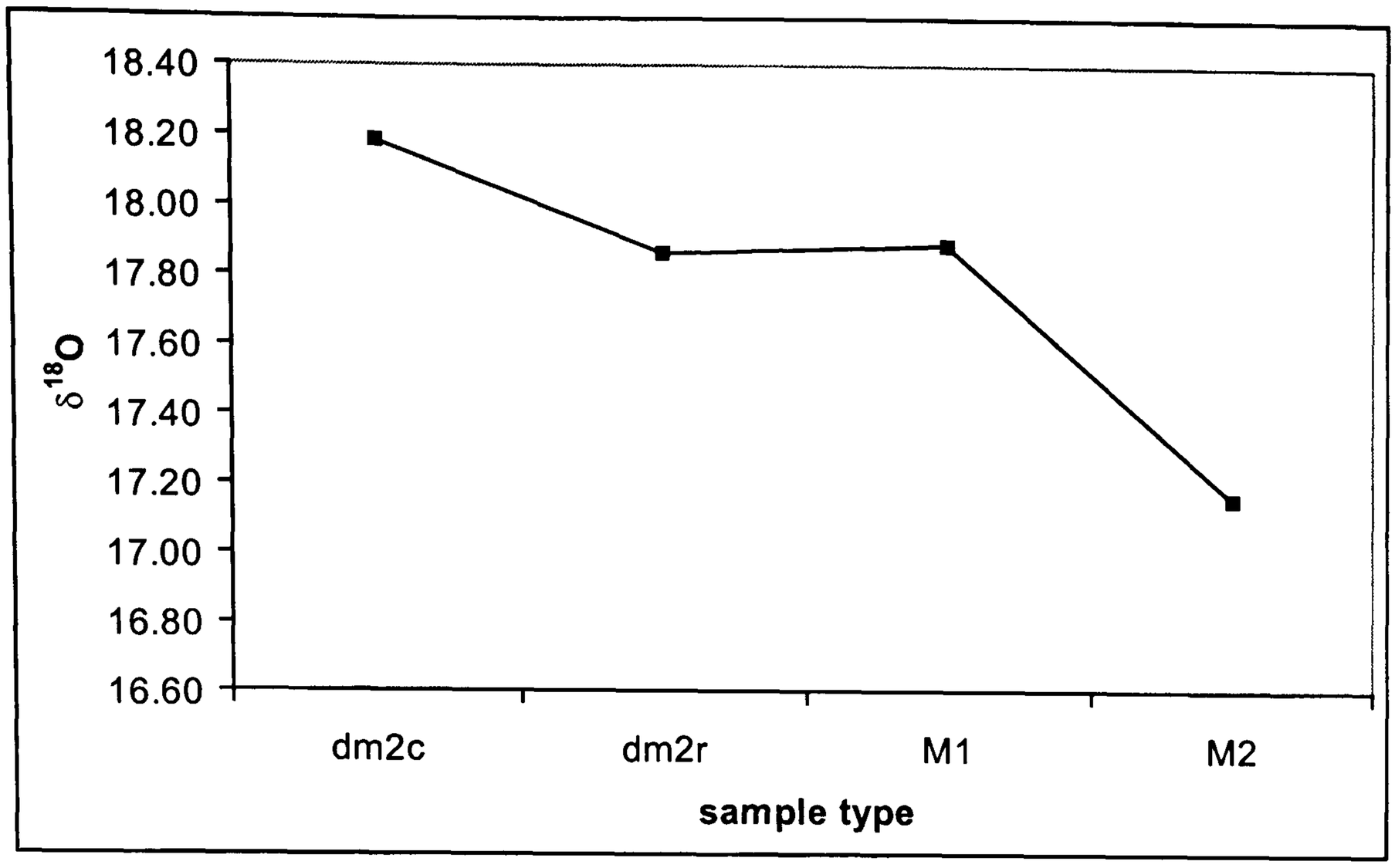

Figure 5.8: $\delta^{18}O$ values for BG601 illustrating the transition from breast fed to weaned.

Three individuals do not fit this general pattern: BG244 does not display an elevated $\delta^{18}O$ value, moreover the dm2 root also analysed for this individual shows a level of variation within machine error. It is therefore possible that BG244 received little to no breast milk during his or her life. The second two individuals, BG422 & BG584 do display elevated $\delta^{18}O$ in their dm2 crowns compared with dm2 roots and M1's. It is therefore likely that these two individuals were breast fed during the first year of life, but that their oxygen isotope values are outside the mean range for the Black Gate population.

Drinking water corrections were applied to all teeth (table 5.9) and highlight the varied origin of those individuals inhumed at the Black Gate cemetery. The expected drinking water range for the area including the Black Gate cemetery is -7 to -8 (Darling and Talbot, 2003a, b), with those individuals lying further away from this range more likely to have lived outside the locality (figure 3.2). Of the 21 adults sampled, 5 spent all their childhood in a region consistent with the Black Gate cemetery and surrounding area, including two individuals who have elevated $\delta^{18}O$ in their M1's. This elevation in the M1's may well reflect a more extended period of breast feeding compared with the Black Gate norm. The three individuals who spent their childhood in an area

colder than that of Black Gate also include two individuals with elevated $\delta^{18}O$ in their M1's, again the degree of enrichment is approximately 1‰, consistent with an extended period of breast feeding. These 'colder' drinking water values may derive from the British Isles in 2 of the cases, the closest areas being Yorkshire and Scotland, however the third individual, BG053 is likely to have spent her childhood outside Britain. Her drinking water values are consistent with an area ranging from northern Norway, western Sweden through to the Alps. Drinking water values consistent with residence in an area warmer than that of Black Gate are exhibited by 4 individuals. The closest areas to Black Gate that display these 'warmer' drinking water values are the west coast of Britain and central and western Ireland, further afield, these individuals may also have originated from western France. Of these three individuals, BG637 has such elevated drinking water values that he is unlikely to have come from closer than Cornwall or the West Coast of Ireland. The remaining 9 individuals all display fluctuating drinking water values, indicating that they spent portions of their childhood in different regions before coming to the Black Gate area at some point before their death. Most of these individuals spent some of their childhood in an area with a drinking water value consistent with that of Black Gate; however BG635 spent no part of her childhood in the region. Her 1st and 2nd molars have 'warm' drinking water values, consistent with an early childhood spent on the west coast of Britain, Wales or central Ireland. She then spent the period during the formation of her 3rd molar in a much colder region, consistent with northern or central Europe.

Statistical analysis

Correlates with age/sex

Not all individuals had a biological sex assigned, due to the fragmentary nature of their remains, or a lack of sexual dimorphism in their skeletons, a sub-sample of 19 individuals (8 female/female? and 11 male/male?) was therefore assessed for any age related dietary and mobility differences. Some individuals did not provide useable results for each sample type and so numbers within sub-samples were often smaller (table 5.11). Students paired sample t-tests indicated no significant differences in $\delta^{13}C$ or $\delta^{15}N$

between sexes for any age category. It is therefore reasonable to assume that there were no gender based differences in source of dietary protein for these individuals. There were also no significant differences in $\delta^{18}O$ when paired sample t-tests were performed between sexes for each sample type indicating that both males and females were equally likely to migrate at some point in their lives.

Skeleton	*Sex*	*t-tests for carbon and nitrogen*	*t-tests for oxygen*
BG053	FF	M2 & rib	M1, M2 & M3
BG078	F?	Rib	
BG344	FF	Rib	
BG498	FF	M1, M3 & rib	M1, M2 & M3
BG527	F?	M1, M2 & M3	M1, M2 & M3
BG534	FF	M1, M2, M3 & rib	M1, M2 & M3
BG591	FF	M1, M2, M3 & rib	M1, M2 & M3
BG635	FF	M2, M3 & rib	M1, M2 & M3
BG659	FF	M1, M2 & rib	M1, M2 & M3
BG040	M?		M1, M2 & M3
BG132	M?	Rib	
BG155	M?	M1, M3 & rib	M1, M2 & M3
BG252	MM	M1, M3 & rib	M1, M2 & M3
BG268	MM	Rib	
BG386	M?	M1, M2, M3 & rib	M1, M2 & M3
BG404	MM	Rib	
BG433	MM	M1, M2, M3 & rib	M1, M2 & M3
BG499	MM	M1, M2, M3 & rib	M1, M2 & M3
BG567	MM	M1, M2, M3 & rib	M1, M2 & M3
BG626	M?	M1, M2, M3 & rib	M1, M2 & M3
BG637	MM	M1, M2, M3 & rib	M1, M2 & M3
BG654	M?	M1, M2 & M3	M1, M2 & M3

Table 5.11: Sexed Black Gate individuals and sample types used for students paired t-tests between sexes.

Correlates with pathology

The δ13C and δ15N values of the two individuals identified as possibly having congenital syphilis (BG477 and BG575) do not deviate significantly from the sample means (table 5.4 & 5.5). Oxygen data indicate that BG575 was living in the Black Gate area in the years prior to his or her death (table 5.9). However BG477 displays relatively high $\delta^{15}N$ in the dm2 root and rib samples. While this potentially indicates an extended period of breast feeding for this child (figure 5.10), oxygen data indicates that there is a trophic level shift between the deciduous 2nd molar crown and root. Drinking water corrections indicate, even taking into account the expected elevation associated with breast feeding, this child was unlikely to have been born in the Black Gate area. The closest region from which this child could have originated is Cornwall or the west coast of Ireland. As there is no elevation in δ13C, the high $\delta^{15}N$ may be due to a high level of animal protein (perhaps from milk) in the diet.

BG262, the child who may have suffered from rickets also did not display any significant deviation from the sample means. Nitrogen and oxygen data show that the child was breast fed, and weaned after the completion of the dm2 crown (figure 5.11). Drinking water values further indicate that this child resided in a region consistent with the Black Gate area before death.

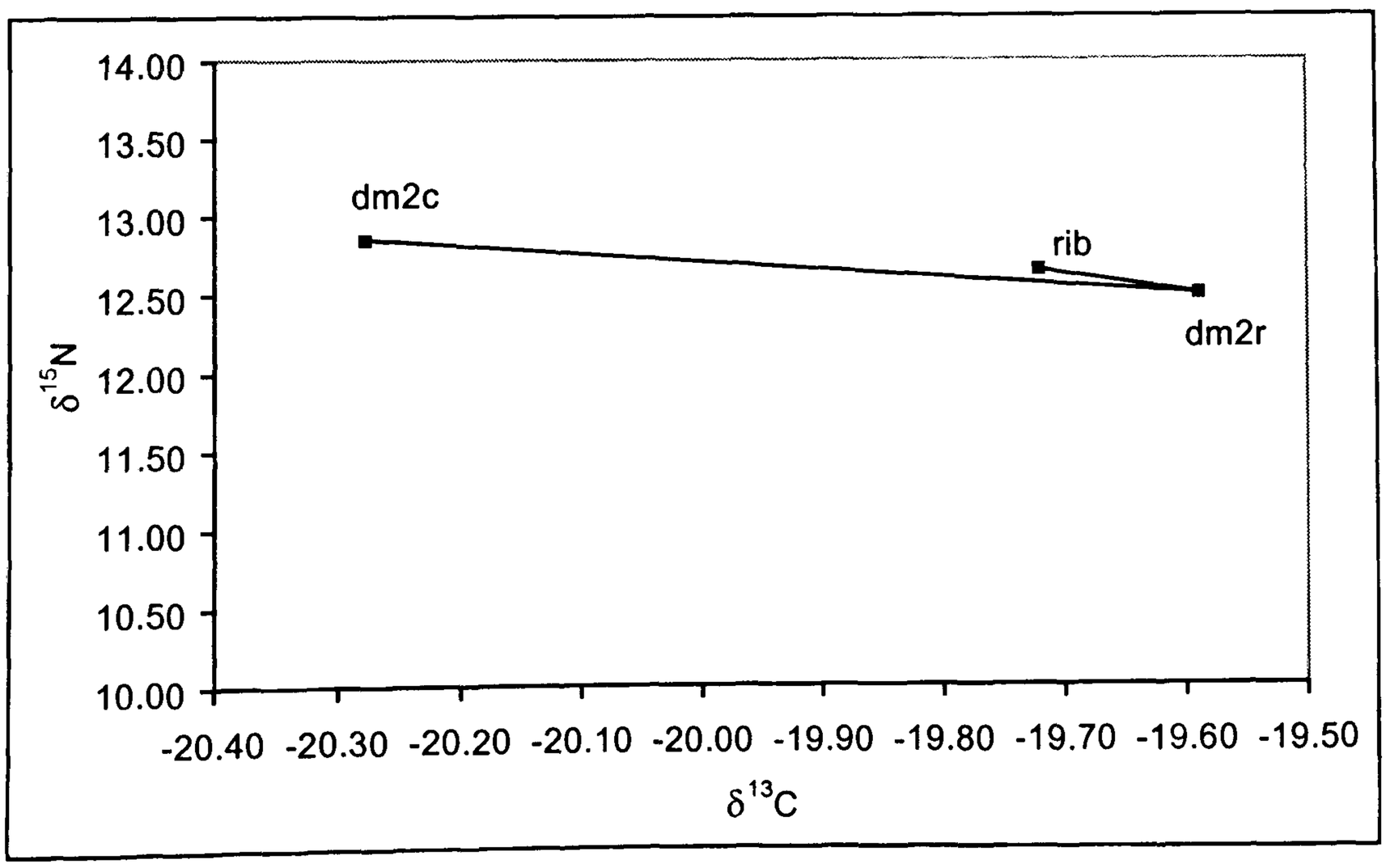

Figure 5.9: Stable carbon and nitrogen isotope values for BG477.

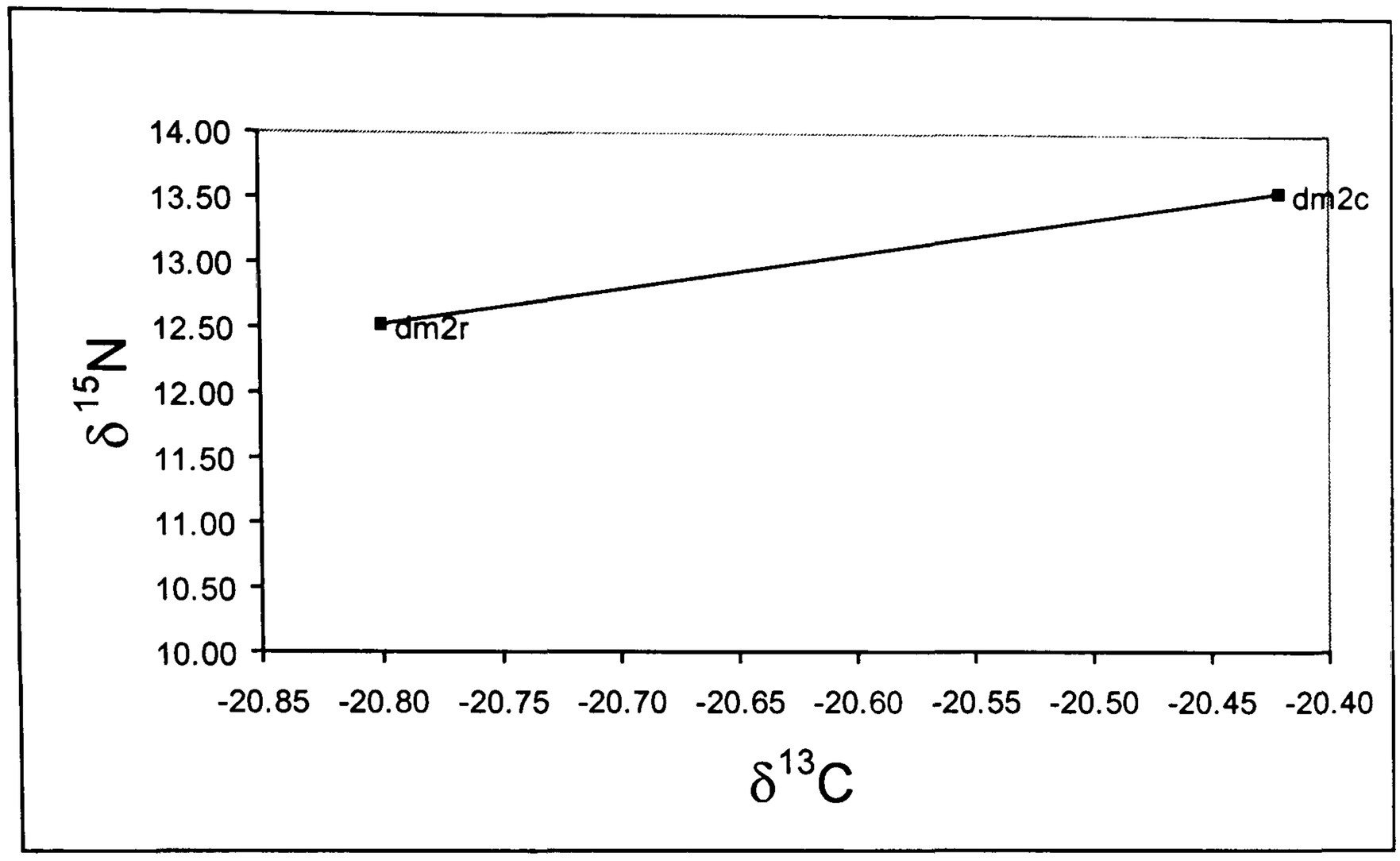

Figure 5.10: Stable carbon and nitrogen isotope values for BG262

Conclusions of the stable isotope analysis

Black Gate skeletons generally had good levels of organic preservation and yielded enough collagen from different material types for statistically robust analysis. Inorganic preservation was excellent, and all individuals yielded some material suitable for analysis, there seemed to be no significant or systematic bias between samples derived from enamel or whole tooth. Data from $\delta^{13}C$, δ15N and $\delta^{34}S$ analysis indicated that this population consumed a predominantly terrestrial diet, favouring meat from sheep and pig over cows, with evidence for the consumption of marine protein in only two samples. The depletion observed for ^{15}N in M2's is not statistically significant, nevertheless it is noticeable and of the order of 0.5‰.

Breastfeeding was of relatively short duration in this population: both $\delta^{15}N$ and $\delta^{18}O$ indicate that children were breast fed until they were approximately 9 months old and then weaned over a relatively short period of probably a few months. It is likely that these children were usually fully weaned by their first birthday. Oxygen and nitrogen isotope data have suggested that different individuals were not breast fed, this may be because $\delta^{18}O$ measures water source and $\delta^{15}N$ measures protein source. The child whose $\delta^{18}O$

value suggested a lack of breast feeding had poorly preserved collagen so direct comparison between the isotopes cannot be made. Those individuals for whom their $\delta^{15}N$ data was lower than expected for breast feeding, may genuinely not have been breastfed, or they may have been fed by mothers who were not eating enough animal protein to effect a trophic shift in their children relative to the population means. Certainly BG048 has $\delta^{18}O$ values consistent with breastfeeding, the data also suggest that this child may not have been born in the region. The remaining three individuals were also not from the Black Gate region and so may have come from populations whose dietary sources were different.

Oxygen isotope data emphasises the mobile nature of the late Anglo-Saxon population. Individuals buried in the Black Gate cemetery are likely to have originated from a number of locations in Britain, Ireland and continental Europe. This is not surprising for a cemetery of this period, it is known that trade and religious networks spanned Europe and that there were also political alliances between England and the continent. Furthermore, the Black Gate cemetery continued in use in the post conquest period and it is not out of the question that those individuals who died and were buried in the garrison were from both other areas of England, and abroad.

Chapter Conclusions

Results from the analysis of Black Gate individuals have demonstrated the utility of stable isotope analysis for the investigation of past dietary behaviour and mobility. Dental anthropology assessments confirmed the suitability of individuals for inclusion in the sample and indicated that the individuals analysed were likely to represent the normal diet of the healthy population. All samples discussed and included in statistical analysis had good C:N ratios and $\delta^{18}O$ values and were considered to have retained biogenic signals. The Black Gate population probably gained all their required protein from animal sources, and seemed to have favoured meat from sheep and pigs over cows. The depletions seen in the M2's is likely to represent a physiological process whereby ^{14}N is preferentially incorporated into collagen over ^{15}N. This may potentially be the result of recycling urea while under

energy stress (Badaloo, *et al.*, 1999; Millward, *et al.*, 2000), and will be discussed in more detail in chapter 7. The Black Gate population appears to have exclusively breastfed their children until they were approximately 9 months of age, after which they were weaned over a period of a few months. Oxygen isotopes reflect a great variation in drinking water source for this population. The varying $\delta^{18}O$ values are likely to represent the different locations in which these people lived over the course of their lives.

Chapter 6: Results for sites in North Lincolnshire

Dental anthropology, pathology and stable isotopes

The results for the dental anthropology, pathology and stable isotope analyses carried out on individuals from North Lincolnshire are presented below. The individuals from all four cemeteries, St Peters, Barton upon Humber, Fillingham, Kilton Hill and Whitton are discussed together, with similarities and differences drawn out. Results are also contrasted with those from the Black Gate cemetery discussed in the previous chapter. A final section presents the results of the statistical analysis carried out between the isotope results for age/sex comparisons.

Dental anthropology

Calculus

Calculus is again principally seen in the adult population: only one individual below 5 has mild calculus and all other children who do have calculus are mild cases. In adults the level of calculus is more severe than that seen in the Black Gate population, with 62% of individuals displaying either moderate or severe calculus. While Barton upon Humber has provided most of the individuals for analysis, it can be seen in table 6.1 that the individuals from other sites fit into the overall pattern. The only significant correlate with calculus was horizontal bone loss (Spearman's correlation coefficient was significant at the 0.01 level), this is in contrast to the Black Gate population where no correlation between these two factors was found.

	No. individuals	*% with no calculus*	*% with mild calculus*	*% with moderate calculus*	*% with severe calculus*
Barton upon Humber					
Juveniles	21	76	33		
Adults	25	8	32	48	12
Fillingham					
Juveniles	1	100			
Adults	2			100	
Kilton Hill					
Juveniles					
Adults	2	50	50		
Whitton					
Juveniles	1	100			
Adults	2		50		50
Total Juvenile	**23**	**70**	**30**		
Total Adult	**31**	**10**	**32**	**45**	**13**

Table 6.1: Severity of calculus for adults and children sampled from sites in North Lincolnshire

Caries

Rates of caries are also far higher in the North Lincolnshire sites than at Black Gate, with 59% of adults having one or more caries, compared with 26% at Black Gate. The number of caries in adults is positively correlated with the extent of caries at the 0.01 level: in those individuals with multiple caries it is more likely that some of those caries will be extensive, i.e. have destroyed more than 50% of the tooth crown. The extent of caries is also positively correlated with age (at the 0.01 level). Conversely juveniles have a lower rate of caries (4% compared to 19%) the one child who did exhibit caries, a 2-3 year old displayed carious lesions on the cemento-enamel

junction of multiple teeth, a typical pattern for juveniles of this period (O'Sullivan, et al., 1993).

	No. individuals	***% with no caries***	***% with 1 caries***	***% with multiple caries***
Barton upon Humber				
Juveniles	21	95	5	
Adults	25	44	20	36
Fillingham				
Juveniles	1	100		
Adults	2		50	50
Kilton Hill				
Juveniles				
Adults	2	1		1
Whitton				
Juveniles	1	100		
Adults	2	50		50
Total	**23**	**96**	**4**	
Juvenile				
Total	**31**	**42**	**19**	**39**
Adult				

Table 6.2: distribution of caries for adults and children sampled from sites in North Lincolnshire

Other dental pathologies

Overall both hypoplasias and bone loss from the maxilla and mandible are less prevalent in North Lincolnshire than in Black Gate. Indicating fewer systemic stresses in childhood (in the case of hypoplasias) and potentially better oral health. Enamel hypoplasias had no significant correlations. Bone loss was significantly positively correlated with calculus at the 0.01 level, and age and wear at the 0.05 level.

	No. individuals	***% with none***	***% with mild***	***% with moderate***	***% with severe***
Barton upon Humber					
Juvenile hypoplasia	21	95	5		
Adults hypoplasia	25	60	16	12	8
Juvenile bone loss	21	100			
Adult bone loss	25	84	16		
Fillingham					
Juvenile hypoplasia	1	100			
Adults hypoplasia	2			100	
Juvenile bone loss	1	100			
Adult bone loss	2			100	
Kilton Hill					
Adults hypoplasia	2			100	
Adult bone loss	2	100			
Whitton					
Juvenile hypoplasia	1	100			
Adults hypoplasia	2	50		50	
Juvenile	1	100			

bone loss					
Adult bone loss	2	50		50	
Total Juvenile hypoplasia	**23**	**96**	**4**		
Total Adult hypoplasia	**31**	**52**	**23**	**19**	**6**
Total Juvenile bone loss	**23**	**100**			
Total Adult bone loss	**31**	**77**	**19**	**3**	

Table 6.3: Incidence of enamel hypoplasias and horizontal bone loss for adults and children sampled from sites in North Lincolnshire

<u>Wear</u>

In addition to bone loss, wear was significantly correlated with age in both adults and juveniles at the 0.05 level (figure 6.1)

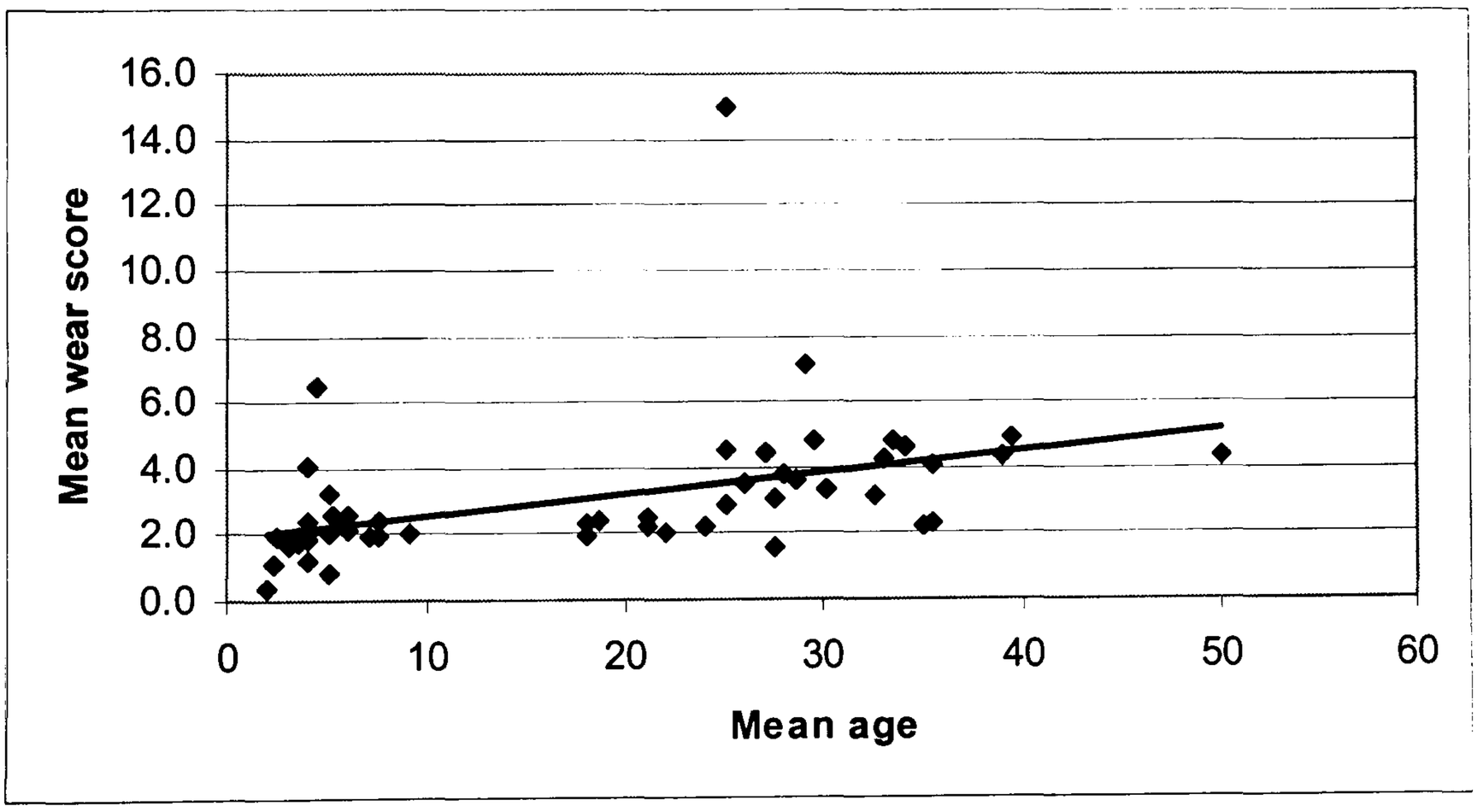

Figure 6.1: Mean wear scores versus age for adults and children sampled from North Lincolnshire.

Pathology

Skeletal pathologies for Barton upon Humber individuals were recorded by Juliet Rogers, it should be noted that, as with Black Gate, the level of preservation of the sampled skeletons was extremely variable, different skeletal elements were present for different individuals therefore a comprehensive pathological assessment was not possible. None of the individuals sampled from Barton exhibited any significant pathology outside the dental arcade, beyond some degenerative bone change in the older individuals. Specifically there was a very low level of pathologies with a nutritional aetiology: 3 adults (1 female, 2 males) displayed cribra orbitalia as did one child (aged 5-7) as second child (aged 5-6) displayed cribra orbitalia and a fine porosity on the palate. Cribra orbitalia has been linked to iron-deficiency anaemia (Roberts C. and Manchester, 1995), as only 13% of the total population display these symptoms, it is likely that there is a low level of anaemia in the Barton upon Humber population. Skeletons from Fillingham were examined by Jo Buckberry (2000) who noted no significant pathologies for the two adults analysed in this study. As the juvenile teeth came from an isolated mandible, assessment of skeletal pathologies was not possible. No pathologies were noted for the two individuals from Kilton Hill, however it should be noted that the bones were in very poor condition. No complete skeletons were removed from the cemetery at Whitton, as a result, only estimation of age and sex was carried out, recording of pathology was not undertaken.

Dental anthropology and pathology conclusions

The oral health of the North Lincolnshire individuals seems to have been poorer than that of those buried at Black Gate: levels of calculus and prevalence of caries are both higher, indicating a greater access to carbohydrate rich foodstuffs. A corollary of this is the lower levels of systemic stress in childhood, seen in the lower levels of enamel hypoplasias and indicators of iron-deficiency anaemia than that of the Black Gate skeletons. Overall, the North Lincolnshire skeletons seem to have been in good health both as adults and children, it is possible that the diet that

contributed to their poor oral health buffered them from other types of systemic stresses.

Preservation

Preservation of the Fillingham and Whitton samples was the best of the North Lincolnshire cemeteries, 19 out of 20 samples yielded enough collagen for analysis, only the FCR01 dm2c produced little collagen, probably due to its small size and hence low organic content (table 6.4). The average yield for these two cemeteries was 2.5% (standard deviation 3.1). C:N ratios were also good for these samples: 16 of 19 samples had C:N ratios within the accepted range for biogenic collagen (Ambrose, 1993). Kilton Hill was extremely poorly preserved, 4 out of 8 samples yielded collagen that was suitable for isotope analysis, average collagen yield was 0.5% (standard deviation 0.3), much of which as sticky and acidic. Of the four samples analysed, only one had a C:N ratio within the accepted range. Collagen from Barton upon Humber skeletons was also poorly preserved, despite this being a well preserved cemetery on a macroscopic level. 148 samples were processed, only 9 yielded collagen suitable for analysis. Average yield was 2.6% (standard deviation 3.6) however most extracted samples were sticky and acidic. Those samples that appeared to have a reasonable amount of extract were re-dissolved in 5-10ml milliQ water and re-freeze dried, in some cases this process was repeated a second time to no avail. The lack of organic preservation of these skeletons may be due to the fluctuating water levels on the site (Nielsen-Marsh and Hedges, 2000a), wooden coffins were preserved in an area through which a drain ran, but the majority of the site was subject to rises and falls in water levels. Of the 9 samples run, 6 had C:N ratios within the accepted range of 2.9 to 3.6. A further 2 samples had poor C:N ratios but fell within 1 standard deviation of the North Lincolnshire means and so were included in analysis.

Faunal bone was sampled from Anglo-Saxon layers at West Halton, North Lincolnshire. Preservation was moderately good with 8 out of 9 samples yielding collagen suitable for analysis. Of these 8, two samples had poor C:N

ratios and their nitrogen values were too far away from site means to be used for food web comparisons (tables 6.4 and 6.5).

Teeth from all 150 samples had well preserved dental material from which silver phosphate was successfully precipitated. Analysis of $\delta^{18}O$ indicated that all samples from Fillingham, Kilton Hill and Whitton are likely to preserve a biogenic signal of water source. Again, Barton upon Humber was less well preserved and 5 individuals had $\delta^{18}O$ values that may represent diagenetic alteration in some or all of their tooth samples. BH522 dm2c was significantly warmer than was expected, a drinking water correction gave a value of -2.97, even taking the additional fractionation associated with breast feeding, this child of 3 years would have had to have travelled from an area with a drinking water range between -3.5 and -4, well outside Britain or western Europe. This individual was therefore excluded from statistical analysis. BH0580, BH1309 and BH1882 also had higher than expected $\delta^{18}O$ values in some or all of their teeth and were therefore excluded from statistical analysis as the possibility of diagenetic alteration could not be ruled out. BH1213 and BH0956 had a much lower $\delta^{18}O$ values than was expected, these individual were also excluded from statistical analysis on the grounds that diagenetic alteration could not be discounted.

Identifier	*Sex*	*Mean Age*	*Sample Type*	*d13C Mean*	*d15N Mean*	*C:N*	*Yield (% of start weight)*
Barton upon Humber							
BH0434	F?	27	Rib	-20.12	12.01	3.6	21.6
BH0580	FF	25	Rib	-20.30	12.20	3.4	6.2
BH1029	FF	33	Rib	-21.05	10.74	3.3	0.3
BH1136	MM	35	Rib	-20.36	11.22	4.1	9.9
BH1221	MM	28	Cranium	-20.35	11.63	3.3	4.4
BH1266	FF	50	Rib	-19.79	12.43	3.1	5.7
BH1327	MM	34	Rib	-20.17	12.10	4.2	9.6
BH1880	MM	29.5	Rib	-20.57	12.22	3.4	4.5
BH1927	FF	32.5	M3	-21.32	10.99	5.1	3.0
Fillingham							
FCR01	-	5	dm2r	-20.27	12.6	3.9	3.5
FCR03	FF	35.5	M1	-20.90	13.35	3.5	0.7
FCR03			M2	-20.51	9.82	4.3	0.8
FCR03			M3	-21.26	10.81	3.9	0.7
FCR03			Rib	-20.37	10.47	2.85	2.9
FCR04	MM	35.5	M1	-20.36	11.68	3.5	9.9
FCR04			M2	-20.47	10.94	2.9	8.8
FCR04			M3	-20.28	11.67	3.4	3.1
FCR04			Rib	-20.63	11.84	3.2	0.4
Kilton Hill							
KH49	MM	29	M2	-20.76	7.6	3.8	0.7
KH49			M3	-20.25	8.0	3.9	1.0
KH54	M?	21	M2	-20.45	13.0	4.0	0.5
KH54			M3	-20.63	12.8	3.5	0.5
Whitton							
WCL01	-	4	dm1c	-20.51	12.8	3.3	0.6

Identifier	Sex	Mean Age	Sample Type	d13C Mean	d15N Mean	C:N	Yield (% of start weight)
WCL01			dm2c	-20.65	12.2	3.3	0.7
WCL22	FF	33.5	M1	-20.35	12.3	3.4	0.8
WCL22			M2	-20.68	11.7	3.4	0.7
WCL22			M3	-20.79	13.8	3.4	1.0
WCL22			humerus	-20.68	11.4	3.4	0.4
WCL22			humerus repeat	-20.23	11.29	3.1	12.1
WCL30	FF	21	M1	-20.63	11.6	3.6	1.8
WCL30			M2	-20.76	11.5	3.4	8.3
WCL30			M3	-20.56	10.9	3.4	0.9
WCL30			ulna	-20.42	10.9	3.3	1.1
Faunal							
WH3016C1			cow	-22.81	3.91	3.8	0.9
WH3016C2			cow	-21.54	9.08	3.3	1.3
WH3016C3			cow	-21.32	6.22	3.3	1.6
WH3016D1			dog	-20.63	11.44	3.6	3.4
WH3016P1			pig	-21.71	10.64	3.8	1.9
WH3016P2			pig	-21.61	12.07	3.4	2.5
WH3016S1			sheep	-21.44	8.00	3.5	6.6
WH3016S2			sheep	-21.79	9.48	3.5	2.3
WH3016S3			sheep	-22.26	9.44	3.5	1.1

Table 6.4: Stable carbon and nitrogen results for all samples from North Lincolnshire. Samples in grey were not considered to have a biogenic signal and were not used for statistical analysis.

Sample Type	Number	$\delta^{13}C$	standard deviation	Mean $\delta^{15}N$	standard deviation
dm1c	1	-20.51		12.81	
dm2c	1	-20.65		12.23	
M1	4	-20.56	0.26	12.23	0.81
M2	3	-20.63	0.15	11.40	0.41
M3	4	-20.56	0.21	12.30	1.31
Rib	13	-20.42	0.32	11.66	0.53

Table 6.5: Mean values for $\delta^{13}C$ and $\delta^{15}N$ for each human sample type from North Lincolnshire.

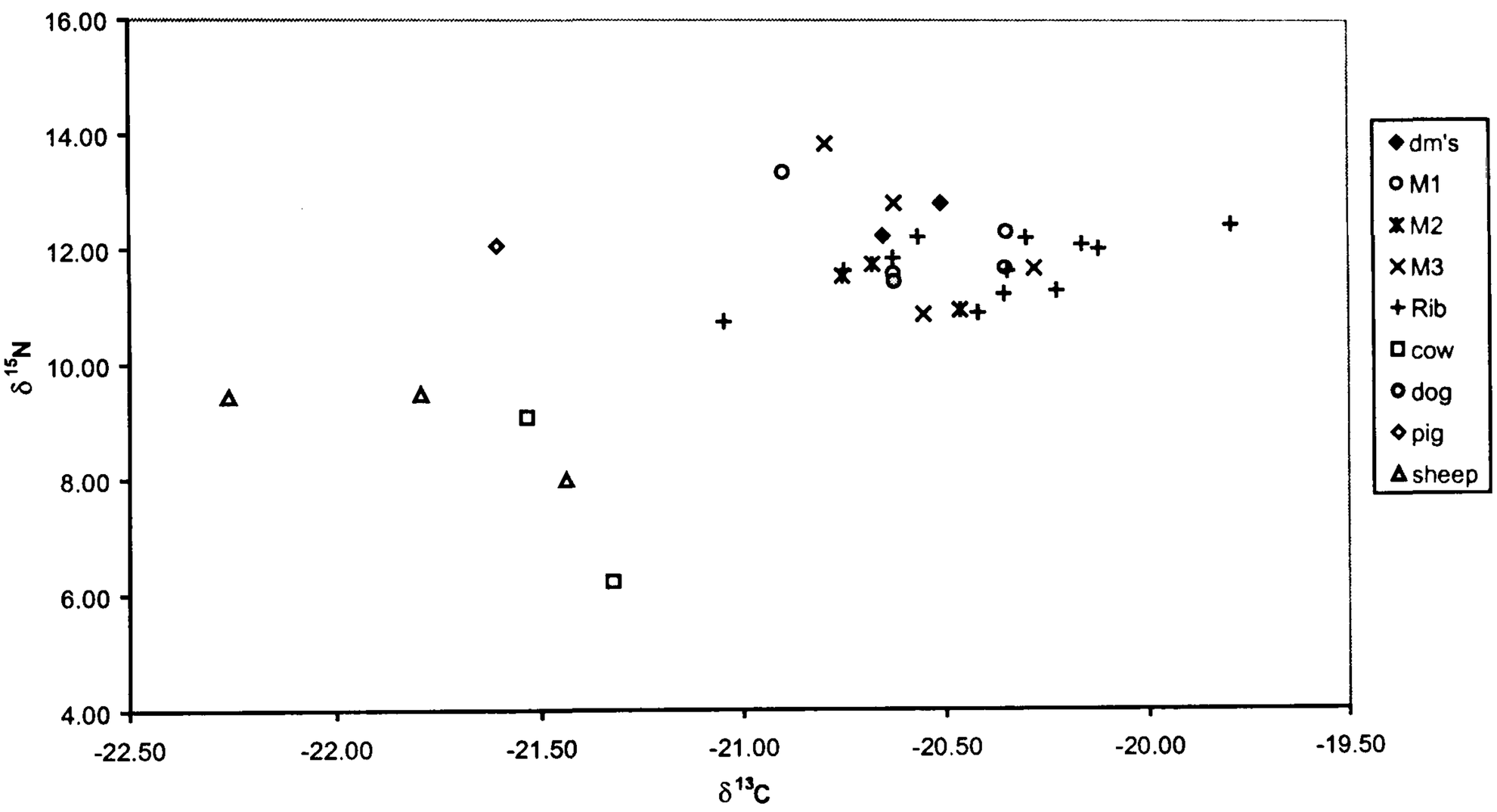

Figure 6.2: Human and faunal stable carbon and nitrogen isotope data from North Lincolnshire for all individuals retaining a biogenic signal.

Stable isotopes and diet

Carbon

Carbon stable isotope values for faunal material were between -22.26 and -20.63‰, within the expected range for C_3 consuming terrestrial mammals. Stable isotope values for the human material are more enriched than the faunal, indicating a higher position in the local food web. There is however no indication of any consumption of marine protein amongst these individuals. Students paired t-tests indicate no significant differences between the sample types.

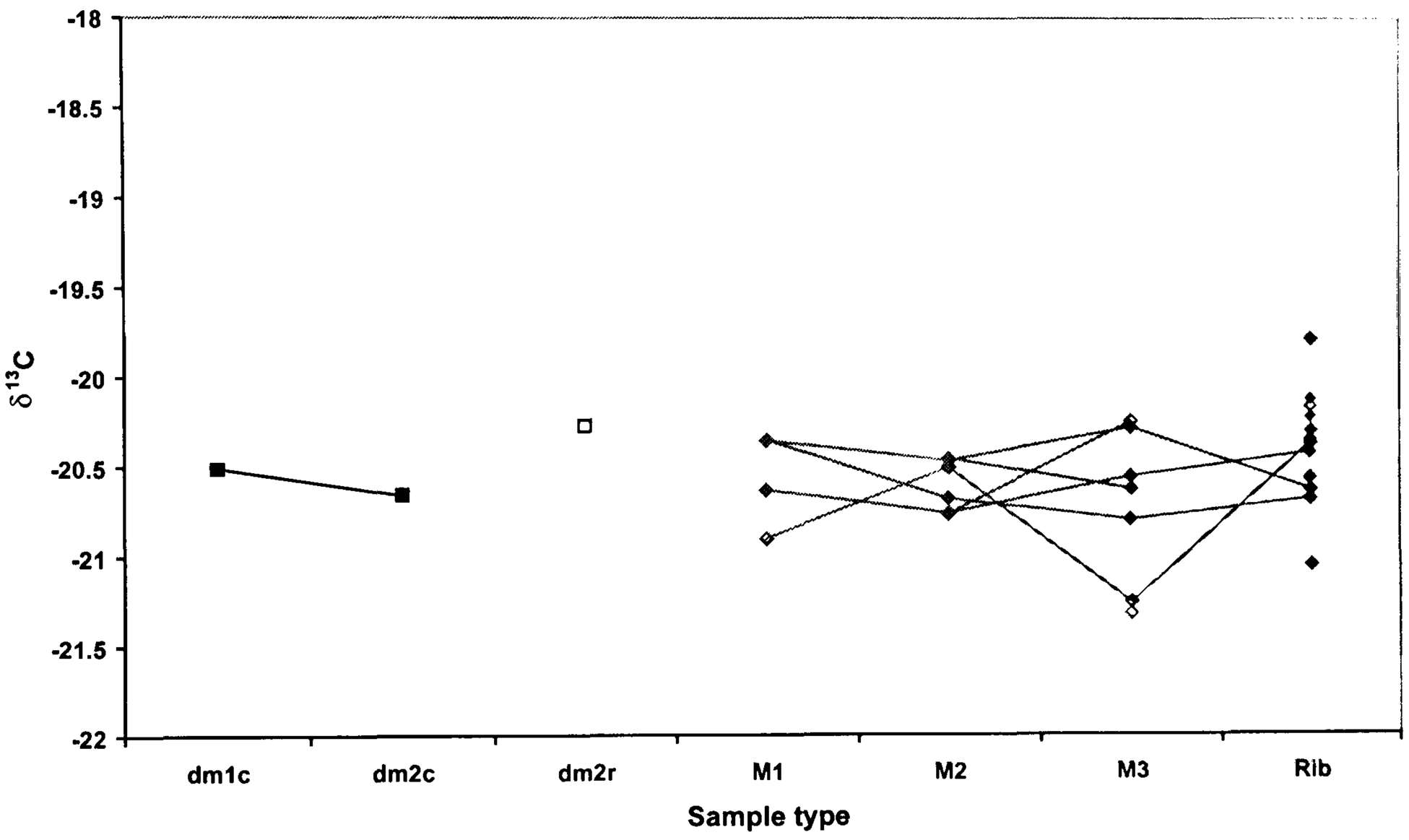

Figure 6.3: Stable carbon isotope ratios for all humans analysed from all North Lincolnshire. Hollow points are for those samples which did not preserve a biogenic signal.

Sample Pairs	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
M1_C - M2_C	.10000	.23065	.13317	-.47297	.67297	.751	2	.531
M1_C - M3_C	.00500	.45384	.22692	-.71715	.72715	.022	3	.984
M1_C - Rib_C	-.13500	.41106	.20553	-.78908	.51908	-.657	3	.558
M2_C - M3_C	-.09333	.40067	.23132	-1.08864	.90198	-.403	2	.726
M2_C - Rib_C	-.42000	.27622	.15948	-1.10618	.26618	-2.634	2	.119
M3_C - Rib_C	-.14000	.66568	.33284	-1.19925	.91925	-.421	3	.702

Table 6.6: Results of student's t-tests performed for $\delta^{13}C$ between sample types for North Lincolnshire samples preserving a biogenic signal.

Nitrogen

Herbivore values (for cow and sheep) were between 6.22 and 9.48‰; this higher than expected value for Holocene herbivores. The mean published values for herbivores in medieval Britain is 5.62 and 6.86‰ for cows and sheep respectively (Privat, *et al.*, 2002; Müldner and Richards, 2005). As West Halton is located adjacent to the Humber estuary, it is possible that animals from here were foddering on seaweed and other marine foods. The omnivores (pigs and dogs) show a further elevation from the herbivore levels indicating that some of their dietary protein was coming from animal sources.

Mean adult bone samples from North Lincolnshire are between 2.7 and 4‰ more enriched in $\delta^{15}N$ than mean values for herbivores, indicating a trophic shift between the two groups. This indicates that all these individuals were gaining their nitrogen from animal protein. Human adult rib bones fall into the same range as the pig value, implying that little to no animal protein was coming from pork. The $\delta^{15}N$ of the dog also falls in amongst the human values, it is therefore likely that this beast was eating roughly the same diet as its human counterparts. Results for the two deciduous teeth fall within the human sample range of 10.74 to 13.85‰. It is therefore possible that the individual sampled was not breast fed. The depletion observed in M2's in the Black Gate material was apparent in the North Lincolnshire sample, however

the depletion is less pronounced (0.3‰), possibly due to poor sample size. Equally the students paired t-tests carried out for these samples showed no significant differences, probably because most categories only consisted of 3-4 samples. For two of the three individuals for whom it was possible to analyse a full set of samples, there is a depletion in the M2 relative to the M3 and rib.

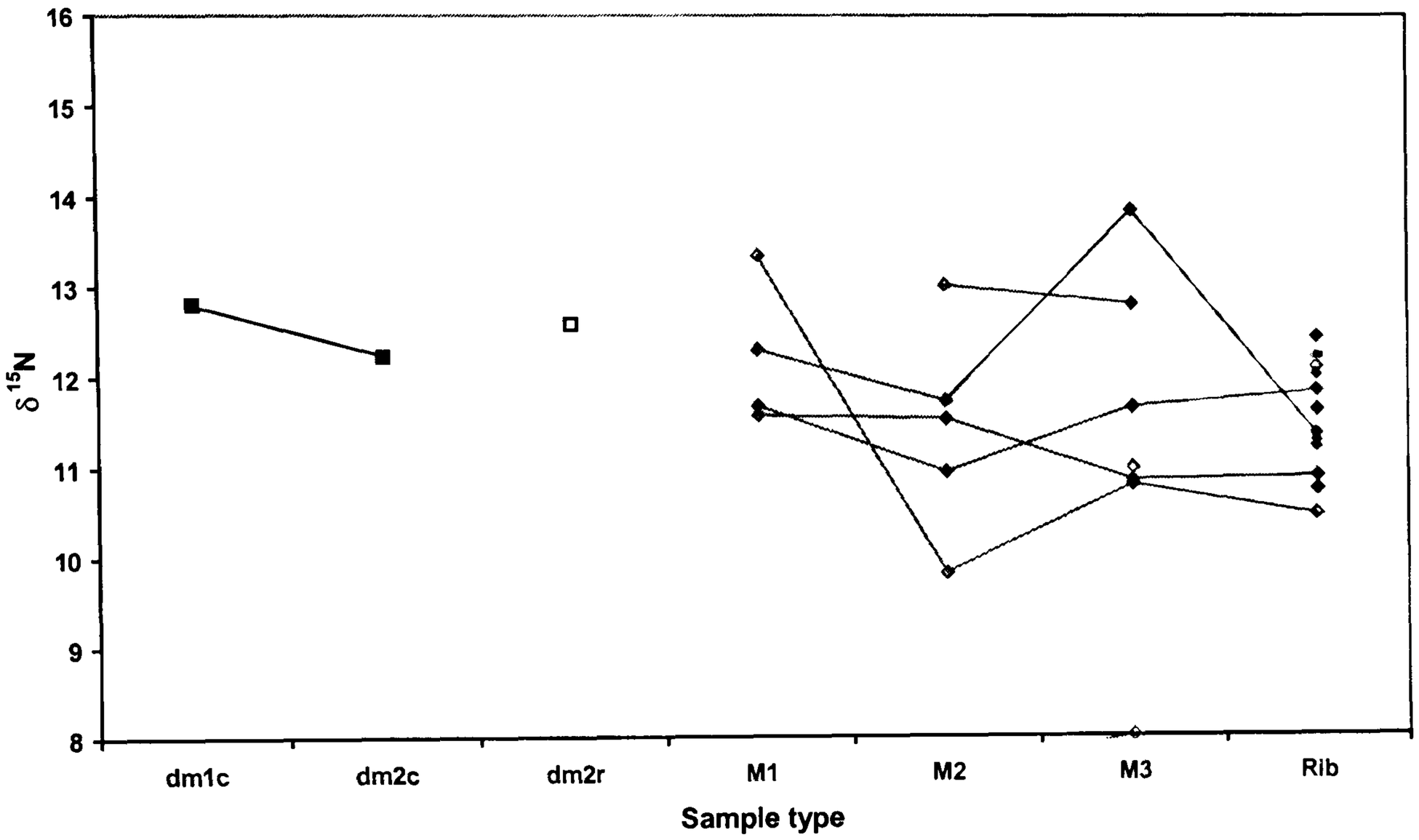

Figure 6.4: Stable nitrogen isotope ratios for all humans analysed from the North Lincolnshire. Hollow points are for those samples which did not preserve a biogenic signal.

Sample Pairs	*Paired Differences*					*t*	*df*	*Sig. (2-tailed)*
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
M1_N - M2_N	1.06333	.96966	.55983	-1.34543	3.47209	1.899	2	.198
M1_N - M3_N	-.06000	1.53909	.76955	-2.50904	2.38904	-.078	3	.943
M1_N - Rib_N	.65750	.69749	.34874	-.45236	1.76736	1.885	3	.156
M2_N - M3_N	-.74333	1.89616	1.09475	-5.45366	3.96700	-.679	2	.567
M2_N - Rib_N	-.47333	.95699	.55252	-2.85063	1.90397	-.857	2	.482
M3_N - Rib_N	.71750	1.18916	.59458	-1.17471	2.60971	1.207	3	.314

Table 6.7: Results of student's t-tests performed for $\delta^{15}N$ between sample types for North Lincolnshire samples preserving a biogenic signal.

Oxygen: weaning and mobility

Stable oxygen isotopes for all individuals from North Lincolnshire range between 14.79 and 19.79‰ (table 6.8, figure 6.7). It is thought that the tooth apatite values for BH0522, BH0580, BH1213, BH1309 and BH1882 may not represent in vivo values due to diagenetic alteration of dentin apatite (discussed above), the sample range excluding these individuals is 16.42 to 18.87‰. Samples of both a half tooth crown and dental enamel were prepared from the dental material of four individuals as a check against whole tooth-enamel discrepancies. Univariate analysis indicates no significant differences between the two material types, this holds when the North Lincolnshire samples are added to those from Black Gate and the test run again; however as with the Black Gate samples, there is a tendency for whole tooth samples to be enriched over enamel samples.

Identifier	*Sex*	*Mean age*	*Sample Type*	*Material*	*d18O Mean*	*drinking water correction*
Barton upon Humber						
BH0030	-	4	dm2c	E	18.52	-4.95
			dm2c	T	18.54	-4.91
			dm2r	T	18.35	-5.33
BH0510	-	4	dm2c	T	17.89	-6.33
			dm2r	T	17.93	-6.25
BH0522	-	3	dm2c	T	19.44	-2.97
BH0542	-	4	dm2c	T	17.49	-7.19
			dm2r	T	17.65	-6.85
BH0635	-	6	dm2c	E	17.62	-6.90
			dm2c	T	17.59	-6.99
			dm2r	T	17.40	-7.40
BH0845	-	2	dm2c	T	18.21	-5.63
			dm2r	T	17.96	-6.18
BH0926	-	8	dm2c	T	18.44	-5.14
			dm2r	T	17.82	-6.47

Identifier	Sex	Mean age	Sample Type	Material	d18O Mean	drinking water correction
			M1	T	17.92	-6.26
			M2	T	17.37	-7.46
BH0927	-	9	dm2c	T	18.31	-5.42
			dm2r	T	17.94	-6.23
			M1	T	17.90	-6.30
BH0956	-	5	dm2c	T	16.63	-9.06
			dm2r	T	16.82	-8.66
BH1057	-	5	dm2c	T	18.60	-4.78
			dm2r	T	18.18	-5.70
BH1067	-	6	dm2c	T	18.61	-4.76
			dm2r	T	17.54	-7.09
BH1167	-	7	dm2c	T	18.22	-5.60
			dm2r	T	17.80	-6.52
BH1196	-	4	dm2c	T	18.65	-4.68
			dm2r	T	18.31	-5.40
BH1213	-	8	dm2c	T	15.64	-11.21
			dm2r	T	17.18	-7.86
BH1331	-	4	dm2c	T	18.40	-5.22
			dm2r	T	18.29	-5.45
BH1652	-	6	dm2c	T	17.60	-6.96
			dm2r	T	17.20	-7.83
			M1	T	17.31	-7.58
BH1888	-	2	dm2c	T	17.81	-6.50
BH1893	-	5	dm2c	T	17.91	-6.27
			dm2r	T	17.77	-6.59
BH2531	-	4	dm2c	T	17.42	-7.34
			dm2r	T	17.57	-7.03
BH2622	-	5	dm2c	T	17.78	-6.56
			dm2r	T	17.85	-6.42
BH2794	-	4	dm2c	T	17.27	-7.66

Identifier	Sex	Mean age	Sample Type	Material	d18O Mean	drinking water correction
			dm2r	T	17.46	-7.26
BH0434	F?	27	M1	T	17.86	-6.39
			M2	T	17.20	-7.82
			M3	T	16.42	-9.52
BH0580	FF	25	M1	E	18.81	-4.33
			M2	T	18.75	-4.46
			M3	T	18.98	-3.97
BH0604	MM	25	M1	T	17.92	-6.25
			M2	T	17.70	-6.73
			M3	T	17.80	-6.52
BH1029	FF	33	M1	T	16.98	-8.29
			M2	T	16.75	-8.81
			M3	T	17.18	-7.87
BH1105	FF	29	M1	E	17.13	-7.98
			M1	T	17.32	-7.56
			M2	E	16.96	-8.34
			M2	T	17.06	-8.13
			M3	E	17.30	-7.62
			M3	T	17.62	-6.92
BH1136	MM	35	M1	E	17.06	-8.13
			M1	T	17.73	-6.68
			M2	E	16.93	-8.41
			M2	T	17.40	-7.39
			M3	E	17.49	-7.19
			M3	T	17.66	-6.82
BH1143	FF	22	M1	T	17.90	-6.30
			M2	T	17.84	-6.43
			M3	T	17.85	-6.41
BH1191	FF	24	M1	T	17.73	-6.67

Identifier	Sex	Mean age	Sample Type	Material	d18O Mean	drinking water correction
			M2	T	17.45	-7.27
			M3	T	17.36	-7.48
BH1221	MM	28	M1	T	18.44	-5.12
			M1	T	18.87	-4.19
			M2	T	18.46	-5.09
			M3	T	17.39	-7.42
BH1266	FF	50	M1	T	17.76	-6.60
			M2	T	17.35	-7.49
			M3	T	17.61	-6.93
BH1305	FF	21	M1	T	16.83	-8.63
			M2	T	16.82	-8.65
			M3	T	16.71	-8.90
BH1309	MM	25	M1	T	19.23	-3.42
			M2	T	17.32	-7.56
			M3	T	19.02	-3.86
BH1318	FF	19	M1	T	17.49	-7.18
			M2	T	18.04	-5.99
			M3	T	17.43	-7.33
BH1327	MM	34	M1	T	18.86	-4.21
			M2	E	17.15	-7.93
			M3	T	17.13	-7.98
BH1758	F?	18	M1	T	18.07	-5.93
			M2&M3	T	18.59	-4.81
BH1840	FF	28	M1	T	16.93	-8.42
			M2	T	17.33	-7.54
			M3	T	17.15	-7.93
BH1880	MM	30	M1	T	17.42	-7.35
			M2	T	16.60	-9.13
			M3	T	17.71	-6.72
BH1882	MM	28	M1	T	19.49	-2.84

Identifier	Sex	Mean age	Sample Type	Material	d18O Mean	drinking water correction
			M2	T	19.64	-2.51
			M3	T	19.79	-2.20
BH1904	MM	30	M1	T	17.62	-6.92
			M2	T	16.78	-8.74
			M3	T	17.48	-7.21
BH1924	?	28	M1	T	17.87	-6.37
			M2	T	18.16	-5.73
			M3	T	18.34	-5.35
BH1927	FF	33	M1	T	17.38	-7.42
			M2	T	17.23	-7.77
			M3	T	17.55	-7.07
BH2410	MM	26	M1	T	17.40	-7.40
			M2	T	18.11	-5.86
			M3	T	17.24	-7.73
BH2433	?	39	M1	T	17.78	-6.57
			M2	T	18.37	-5.28
			M3	T	18.09	-5.89
BH2601	?	18	M1	T	18.80	-4.35
			M2	T	18.08	-5.92
			M3	T	17.84	-6.44
BH2613	FF	40	M1	T	17.43	-7.33
			M2	T	16.51	-9.33
			M3	T	17.83	-6.46
Fillingham						
FCR01	-	5	dm2c	T	17.42	-7.35
			dm2r	T	16.96	-8.35
FCR03	FF	36	M1	E	17.43	-7.32
			M2	E	16.65	-9.03
			M3	E	17.38	-7.43
FCR04	MM	36	M1	E	17.67	-6.81

Identifier	Sex	Mean age	Sample Type	Material	d18O Mean	drinking water correction
			M2	E	17.04	-8.17
			M3	E	17.53	-7.10
Kilton Hill						
KH49	MM	29	M1	E	18.23	-5.58
			M2	E	17.76	-6.61
			M3	E	17.96	-6.17
KH54	M?	21	M1	E	17.71	-6.71
			M2	E	17.62	-6.91
			M3	E	17.43	-7.33
Whitton						
WCL01	-	4	dm1c	E	16.89	-8.51
			dm2c	E	17.70	-6.74
WCL22	FF	34	M1	E	17.46	-7.27
			M2	E	16.79	-8.72
			M3	E	16.53	-9.28
WCL30	FF	21	M1	E	17.47	-7.23
			M2	E	17.60	-6.95
			M3	E	17.47	-7.24

Table 6.8: Stable oxygen isotope results for each human sample type from North Lincolnshire. Material: E = enamel and T = half a tooth crown or 1 root. The expected value for drinking water in this area is between -7 and -8‰.

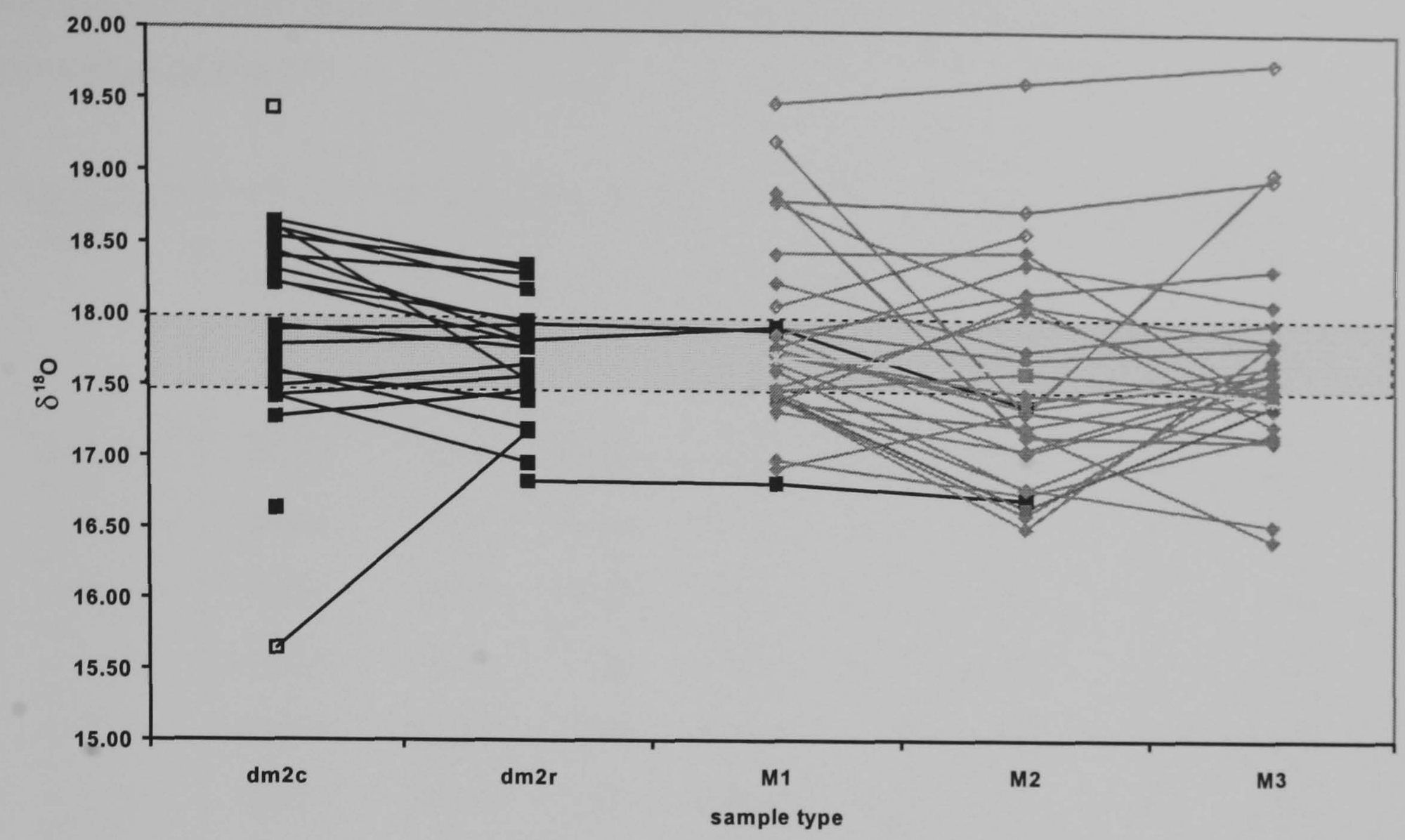

Figure 6.5: Stable oxygen isotope results for each individual from North Lincolnshire. Hollow points indicate those individuals excluded from statistical analysis. The shaded bar indicates the expected range of $\delta^{18}O$ for North Lincolnshire.

Students paired t-tests indicate a slightly different pattern of water intake to that seen in individuals from the Black Gate cemetery. Deciduous 2nd molar crowns are significantly different to dm2 roots, M2's and M3's at the 95% confidence interval, but not to M1's (table 6.9). The average level of enrichment for dm2 crowns over M3's is 0.5‰, which bears a greater resemblance to that found between premolars and M3's by Wright and Schwarcz at Kaminalhúju (1998). Indeed the mean dm2r and M1 values are only 0.3‰ enriched over the mean M3 value, whereas the difference between M1's and M3's observed by Wright and Schwarcz was 0.7‰. These observed differences are not statistically significant, only M2's are significantly different from both dm2 roots and M1's. This lack of significance may in part be due to elevated $\delta^{18}O$ levels in M3's, which are on average 0.1‰ enriched over M2's, although again this difference is not statistically significant. The evidence does however seem indicate that children experienced breast feeding for a longer period but with less intensity in North

Lincolnshire than Black Gate, possibly being weaned towards the end of the formation of the M1.

Sample Pair	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
dm2c_O - dm2r_O	.29789	.58416	.13401	.01634	.57945	2.223	18	.039
dm2c_O - M1_O	.24826	.73900	.15409	-.07131	.56783	1.611	22	.121
dm2c_O - M2_O	.49957	.76200	.15889	.17005	.82908	3.144	22	.005
dm2c_O - M3_O	.45435	.78212	.16308	.11613	.79256	2.786	22	.011
dm2r_O - M1_O	-.01474	.60581	.13898	-.30673	.27725	-.106	18	.917
dm2r_O - M2_O	.39211	.75069	.17222	.03029	.75392	2.277	18	.035
dm2r_O - M3_O	.29579	.72161	.16555	-.05202	.64360	1.787	18	.091
M1_O - M2_O	.32333	.73247	.13373	.04983	.59684	2.418	29	.022
M1_O - M3_O	.22966	.74015	.13744	-.05188	.51119	1.671	28	.106
M2_O - M3_O	-.10241	.67561	.12546	-.35940	.15457	-.816	28	.421

Table 6.9: Results of student's t-tests performed for $\delta^{18}O$ between sample types for all North Lincolnshire individuals with biogenic apatite signals.

There are a number of juveniles who are an exception to this pattern, having dm2 roots that are higher than their dm2 crowns. BH0510, BH0542, BH2531, BH2622 and BH2794 are enriched in their dm2 roots by between 0.04 and 0.19‰ over their dm2 crowns. It is possible that these individuals experienced some diagenetic alteration of their dental apatite, or some fluctuation in climate and therefore $\delta^{18}O$ values during the first years of their lives. Removing these individuals and re-running students paired t-tests leaves only dm2c – M2, dm2c – M3, dm2r - M3 and M1 – M2 with statistically significant differences (table 6.10). However this does not alter the interpretation that children from North Lincolnshire were likely to have been breast fed for a longer period than those from Black Gate.

Sample pairs	*Paired Differences*					*t*	*df*	*Sig. (2-tailed)*
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
dm2c_O - dm2r_O	.40000	.70401	.18815	-.00648	.80648	2.126	13	.053
dm2c_O - M1_O	.32056	.71557	.16866	-.03529	.67640	1.901	17	.074
dm2c_O - M2_O	.75500	.66737	.15730	.42313	1.08687	4.800	17	.000
dm2c_O - M3_O	.61944	.79344	.18702	.22488	1.01401	3.312	17	.004
dm2r_O - M1_O	-.01286	.70044	.18720	-.41728	.39157	-.069	13	.946
dm2r_O - M2_O	.35786	.71113	.19006	-.05274	.76845	1.883	13	.082
dm2r_O - M3_O	.38500	.65005	.17373	.00967	.76033	2.216	13	.045
M1_O - M2_O	.32333	.73247	.13373	.04983	.59684	2.418	29	.022
M1_O - M3_O	.22966	.74015	.13744	-.05188	.51119	1.671	28	.106
M2_O - M3_O	-.10241	.67561	.12546	-.35940	.15457	-.816	28	.421

Table 6.10: Results of student's t-tests performed for $\delta^{18}O$ between sample types for all North Lincolnshire individuals with biogenic apatite signals, excluding those individuals with dm2r's elevated over dm2c's.

Like those analysed from the Black Gate cemetery, drinking water corrections on $\delta^{18}O$ values emphasise the variability in the origins and level of childhood mobility for the individuals analysed from North Lincolnshire (table 6.8). The expected range of drinking water values for this area is between -7 and -8‰ (Darling and Talbot, 2003a, b). Of 25 adults from Barton upon Humber, 6 came from a region with drinking water values consistent with those of North Lincolnshire (figure 3.2), 2 came from 'colder' areas (such as Yorkshire, Scotland or northern and central Europe) and 6 came from areas with 'warmer' drinking water values (such as the west coast of Britain and central and western Ireland). The remaining 13 adults resided in more than one area during their childhood. Most of these individuals spent time in an area with 'colder' drinking water values than those of North Lincolnshire, but 4 people spent some time in a 'warmer' area and two individuals spent part of their childhood in a 'colder' area and part in a 'warmer' area than North Lincolnshire. Both adults analysed from Fillingham showed a mixed pattern of drinking water values. Each has a more depleted

drinking water values in their M2's with a signal consistent with North Lincolnshire in the M3's. As North Lincolnshire is close to an area with more depleted oxygen isotopes, these individuals may have lived in an area slightly to the east before moving to the location in which they were buried. The Kilton Hill skeletons grew up in two different locations, one in an area consistent with the local drinking water signal and one in a warmer area consistent with the west coast of Britain or central Ireland. The Whitton women also came from two different areas, one growing up in an area consistent with North Lincolnshire and one in a colder area consistent with northern or central Europe.

Statistical analysis

Correlates with age/sex

Statistical analysis of correlations between diet and age/sex were not carried out for the North Lincolnshire skeletons as there were not enough sexed individuals to carry out robust analysis. Student's t-tests were carried out for age/sex for oxygen values on 15 North Lincolnshire female skeletons and 10 males. None of these sample pairings indicated any significant difference between source of drinking water and sex, indicating that both males and females were equally likely to migrate.

Conclusions of the stable isotope analysis

Organic preservation of the North Lincolnshire skeletons was mixed. Those from Fillingham and Whitton were well preserved, but only 6 individuals were analysed from these sites. Kilton Hill and Barton upon Humber had very poor preservation, few individuals yielded useable collagen. Interpretations on the dietary behaviour of these individuals are therefore more tentative than those made for Black Gate. Like Black Gate, those individuals analysed did not have a significant marine protein component to their diet, rather they relied on terrestrial protein. The depletion in ^{15}N in the M2's is also present, although the overall difference is less pronounced. This may be due to the small sample size. A different breast feeding pattern is seen in the North Lincolnshire sample compared to that of the Black Gate population. Oxygen isotope data indicate that children were breastfed for a much longer period,

and that weaning was likely to be an extended process. Infants may have been receiving fluid from non breast milk sources before the completion of their dm2 crown, i.e., before they were 9 months old. However some breast feeding was practiced until well after these children's first birthdays and North Lincolnshire children were unlikely to be fully weaned until some time before their second birthday. Like Black Gate, the North Lincolnshire population has diverse origins, and may of the people analysed spent portions of their childhood in different regions.

Chapter Conclusions

North Lincolnshire individuals were more prone to calculus and caries than their Black Gate counterparts, but this did not translate in to observable differences between the stable isotopes. This is unsurprising as these differences in dental pathology are more likely to be attributable to the non-protein component of the diet. The individuals analysed for stable isotopes had a good level of general health and are therefore likely to be representative of the healthy population's diet. Overall preservation for North Lincolnshire was much poorer than for Black Gate, although this was not evident from the general condition of the skeletons sampled. Dietary evidence was only available for 14 of the 54 individuals selected for sampling. Results do indicate a terrestrial diet for these people. Inorganic preservation, while not as good as that at Black Gate was still many times better than organic preservation. Oxygen data indicated an extended period of partial breastfeeding for the North Lincolnshire children, with weaning being complete by two years. There was also a high level of mobility for these people.

Chapter 7: Interpretations

The interpretation of all results is discussed in this chapter. The overall dietary findings are outlined followed by a summation of the weaning practices and variations in childhood diet for the two study areas. The possibility that depleted $\delta^{15}N$ values in M2's are an artefact of growth is explored, and possible mechanisms for this are suggested. The dietary findings are then placed in the social context of early medieval England. The second part of this chapter discusses the $\delta^{18}O$ results in the context of migration and mobility. The level of migration in these populations is outlined, and suggestions for the causes of mobility in both adults and children are made. Finally the possibilities that variations in $\delta^{18}O$ are a result of climate change or seasonal variations are addressed and dismissed.

From milk to meals: Anglo-Saxon childhood diet

Stable carbon, nitrogen and sulphur isotope analysis of collagen samples from Black Gate and North Lincolnshire indicate that these populations consumed a predominantly terrestrial diet. Those individuals sampled from Black Gate favoured the consumption of sheep and pig protein over that of cows; however, those from North Lincolnshire appeared to consume less omnivore protein, relying instead on herbivore protein. There is no discernable marine isotope signature for either population despite the cemeteries locations on or near estuaries with close connections to the sea. A possible explanation for this is that marine fish was not a favoured source of protein in early medieval England. Fish bone evidence has been used to suggest there was a marked increase herring and gadid fishing in the decades after AD1000, before which time assemblages were dominated by freshwater species such as eel (Barrett, *et al.*, 2004). Barrett *et al.* suggest that this increase in the consumption of marine fish could be due to an expanding urban population from the late 10th century onwards leading to a greater demand for fish during periods of fasting than freshwater sources could supply. As there were no samples of freshwater fish bones available for analysis from the study areas, it is not possible to speculate whether or

not freshwater fish was widely consumed. Furthermore there is substantial evidence that the stable carbon and nitrogen isotopes of freshwater fish can vary both between and within species and environments (Dufour E., *et al.*, 1999). Indeed a sample of 84 brown trout of varying ages caught in Loch Ness and its tributary river Enrick had $\delta^{13}C$ values ranging between -27.9 and -21.1‰, and $\delta^{15}N$ values between 7.5 and 15.2‰ (Grey, 2001). Analysis of medieval freshwater fish bones from Beverly, East Yorkshire, also displayed a wide range of delta values for both carbon and nitrogen: $\delta^{13}C$ ranged from -17.6 to -24.5‰ and $\delta^{15}N$ ranged between 10.6 and 23.4‰, although this latter high value comes from a pike suggested to have been raised in a fish pond (Müldner and Richards, 2005).

As was discussed in the results chapters, there is a consistent pattern of change in the isotopic values throughout childhood. The first and most defined of these changes is the transition from breast feeding to weaning. The majority of Anglo-Saxon children were likely to have been breastfed, either by their own mothers, or by a wet nurse. Stable oxygen and nitrogen isotope results for both Black Gate and North Lincolnshire support this assertion, with both $\delta^{18}O$ and $\delta^{15}N$ values elevated in those teeth formed during breast feeding (dm2's and M1's) compared to those formed afterwards. The timing and pattern of weaning is broadly similar within the populations, although these broad trends hide a great deal of individual variation. All individuals who were breast fed appear to have been fully weaned by the time they were two years of age. There is, however, a difference in the onset and duration of the weaning process between the two sample populations.

Children buried in the Black Gate cemetery were breast fed until they were approximately 9 months old, and then weaned over the course of a few months until they were approximately 1 year old. The nature of this weaning process appears to have been a gradual reduction in the amount of protein received from breast milk, coupled with a more rapid reduction in the amount of drinking water received from breast milk. This is characterised by the lack of significant differences between dm2 crowns and M1's for $\delta^{15}N$ and a

Chapter 7: Interpretations

The interpretation of all results is discussed in this chapter. The overall dietary findings are outlined followed by a summation of the weaning practices and variations in childhood diet for the two study areas. Initial work on the development of a breastfeeding/weaning model was carried out to test the interpretations made in the thesis. The results for this model are presented and discussed. The possibility that depleted $\delta^{15}N$ values in M2's are an artefact of growth is explored, and possible mechanisms for this are suggested. The dietary findings are then placed in the social context of early medieval England. The second part of this chapter discusses the $\delta^{18}O$ results in the context of migration and mobility. The level of migration in these populations is outlined, and suggestions for the causes of mobility in both adults and children are made. Finally the possibilities that variations in $\delta^{18}O$ are a result of climate change, seasonal variations or natural variation are addressed.

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greater demand for fish during periods of fasting than freshwater sources could supply. As there were no samples of freshwater fish bones available for analysis from the study areas, it is not possible to speculate whether or not freshwater fish was widely consumed. Furthermore there is substantial evidence that the stable carbon and nitrogen isotopes of freshwater fish can vary both between and within species and environments (Dufour, et al., 1999). Indeed a sample of 84 brown trout of varying ages caught in Loch Ness and its tributary river Enrick had $\delta^{13}C$ values ranging between -27.9 and -21.1‰, and $\delta^{15}N$ values between 7.5 and 15.2‰ (Grey, 2001). Analysis of medieval freshwater fish bones from Beverly, East Yorkshire, also displayed a wide range of delta values for both carbon and nitrogen: $\delta^{13}C$ ranged from -17.6 to -24.5‰ and $\delta^{15}N$ ranged between 10.6 and 23.4‰, although this latter high value comes from a pike suggested to have been raised in a fish pond (Müldner and Richards, 2005).

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Children buried in the Black Gate cemetery were breast fed until they were approximately 9 months old, and then weaned over the course of a few months until they were approximately 1 year old. The nature of this weaning process appears to have been a gradual reduction in the amount of protein

received from breast milk, coupled with a more rapid reduction in the amount of drinking water received from breast milk. This is characterised by the lack of significant differences between dm2 crowns and M1's for $\delta^{15}N$ and a significant difference between these two teeth for $\delta^{18}O$. This may be due to the use of weaning foods such as pap (bread or finely ground cereal soaked in milk or water), particularly if this was made using water, lowering its protein content relative to breast milk and causing the child's body to favour breast milk as a protein source as long as it was available.

Although $\delta^{15}N$ data is lacking for North Lincolnshire, $\delta^{18}O$ data indicates that breast milk was a source of drinking water for longer than at Black Gate. The lack of significant difference between dm2 crowns and M1's and the significant difference between M1's and M2's and M3's indicate that some breast feeding was likely throughout the formation of the M1 crown, i.e. until approximately 2 years. However the level of enrichment between dm2 crowns and M3's in North Lincolnshire is lower than that at Black Gate (0.5‰ as opposed to 1‰) indicating that the intensity of breast feeding may not have been as great. Results indicate that a regimen of partial breast feeding, supplemented with other foodstuffs is more likely in this area.

This further refinement of the timing of weaning for these populations was possible because both deciduous 2nd molar crowns and roots were sampled. This was particularly useful for oxygen isotopes as problems with quality of preservation were far fewer. A flaw of this approach is that one is still sampling individuals who did not survive childhood. While most children are likely to die suddenly due to short illnesses, it is not possible to fully exclude those individuals who may have been chronically ill and therefore subject to a specialist dietary regimen. Two individuals with suspected congenital syphilis were analysed and their $\delta^{13}C$ and $\delta^{15}N$ values did not deviate significantly from sample means. However a continuing elevation in $\delta^{15}N$ in one individual's (BG477) deciduous 2nd molar root and rib samples indicate that this child may have been breast fed for a much longer period than is the norm for these populations, or received a higher than average amount of animal protein (for example milk). It is possible that this different dietary

practice may be the result of a special 'invalid' diet, alternately as the oxygen isotopes show that BG477 is an immigrant into the Black Gate population, this may have been the dietary norm in the area where this child was born. Sub sampling M1 enamel for oxygen isotopes could provide more detailed information on the weaning process in those infants who survived to adulthood. This would depend on the point at which oxygen is incorporated into the crystalline matrix of the enamel and requires further research to determine the viability of the suggested method.

Developing a model for breastfeeding and weaning

The statements made about the patterns of breastfeeding and weaning seen in these populations are drawn from interpretations of the observed data. Preliminary work has been carried out to develop a model for breastfeeding and weaning behaviour in order that statements can be made within a more quantitative framework. Such a model requires a number of assumptions, particularly as the model must relate to archaeological populations where very few specifics are known:

- A child is breastfed by a mother consuming a diet close to the female average of the population and drinking local water and weaned onto food that is close to the diet of the mother.
- Isotopic values for tissues formed *in utero* reflect those of the mother.
- Breastfeeding and weaning behaviour follows a general trend with no significant fluctuations i.e. the child is fully breastfed and then weaned rather than there being periods of little or no breastfeeding during the period when the child is nominally fully breastfed.
- The tissue sampled will reflect an average of all the isotopic inputs over the formation time with no weighting toward a particular period of tissue formation.
- That the isotopic value of periods of partial breastfeeding can be represented as an arbitrarily defined percentage of the full elevation associated with total breastfeeding.
- That the average elevation in $\delta^{15}N$ is 3‰ and in $\delta^{18}O$ is 0.7‰ and that individual levels of elevation vary only as a function of breastfeeding

and not for any other reason; e.g. due to variation in the mothers diet or growth.

The basis for the model then becomes a set of equations from which isotopic values can be derived:

	$\delta^{15}N$	$\delta^{18}O$
If mothers isotope value is (X)	11.5	17.3
Min expected elevation 1 trophic level (Y)	3.0	0.7
Full breastfeeding, F= X+ (Y *100%)	14.5	18.0
High partial breastfeeding, H= X+ (Y *75%)	13.7	17.8
Medium partial breastfeeding, M= X+ (Y *50%)	13.0	17.6
Low partial breastfeeding, L= X+ (Y *25%)	12.2	17.4
Token breastfeeding, T= X+ (Y *0%)	11.5	17.3

The values given for mothers above are the average values for female rib's ($\delta^{15}N$) and M3's ($\delta^{18}O$) from the Black Gate population. Token breastfeeding is not discussed further as it is highly unlikely to produce any elevation is isotopic values. A model can then be suggested for a particular schedule of breastfeeding and weaning behaviour.

How long fully breastfed?	say 7 months from birth
How long partially breastfed?	say 2 months at H, 2 at M and 1 at L
Age fully weaned	say at the end of 12 months

A table (table 7.1) and graph (figure 7.1) can then be created with the expected isotopic values in the child's body tissues:

Months from birth (approx)	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**
Expected $\delta^{15}N$ body tissue value	11.5	11.5	11.5	11.5	14.5	14.5	14.5	14.5
Expected $\delta^{18}O$ body tissue value	17.3	17.3	17.3	17.3	18.0	18.0	18.0	18.0
Months from birth (approx)	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Expected $\delta^{15}N$ body tissue value	14.5	14.5	14.5	13.7	13.7	13.0	13.0	12.2
Expected $\delta^{18}O$ body tissue value	18.0	18.0	18.0	17.8	17.8	17.6	17.6	17.4
Months from birth (approx)	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Expected $\delta^{15}N$ body tissue value	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Expected $\delta^{18}O$ body tissue value	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3
Months from birth (approx)	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
Expected $\delta^{15}N$ body tissue value	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Expected $\delta^{18}O$ body tissue value	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3
Months from birth (approx)	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
Expected $\delta^{15}N$ body tissue value	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Expected $\delta^{18}O$ body tissue value	17.3	17.3	17.3	17.3	17.3	17.3	17.3	17.3

Table 7.1: Expected nitrogen and oxygen isotopic values of body tissue for each month from birth if a child was fully breastfed for 7 months from birth, received a high level of breastfeeding for a further 2 months, a medium level of breastfeeding for 2 months and a low level of breastfeeding for one month, with weaning being complete by 12 months.

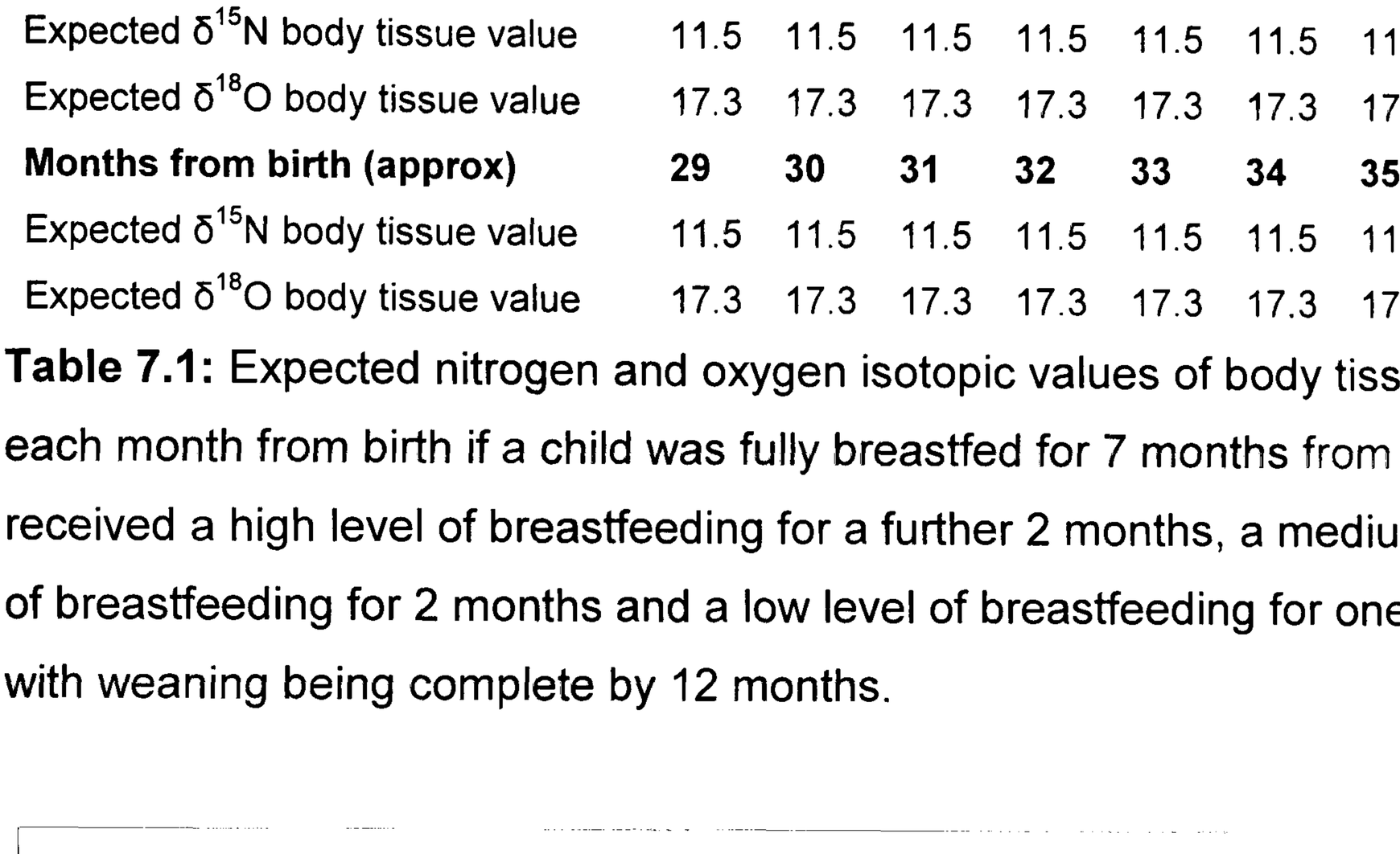

Figure 7.1: Graphical representation of the pattern of isotopic values for a child who was fully breastfed for 7 months from birth, received a high level of breastfeeding for a further 2 months, a medium level of breastfeeding for 2 months and a low level of breastfeeding for one month, with weaning being complete by 12 months.

We can then work out the expected value for a particular tissue type by averaging the values for each month of its formation period:

	Expected $\delta^{15}N$	Expected $\delta^{18}O$
dm2 crown formed in utero (-3) to 9 months	13.5	17.7
M1 crown formed from after birth to 2 years	12.7	17.6
dm2 root formed from 9 months to 3 years	11.7	17.3

This model can now be applied to real data to test the fit; the model can then be varied (by changing how many months a child spends in each state) to match the actual isotopic value of the individual. To gain an overview, the model is here applied to the average $\delta^{15}N$ values of the Black Gate dm2 crowns, M1's and dm2 roots:

	Expected $\delta^{15}N$	Actual mean $\delta^{15}N$
dm2 crown formed in utero (-3) to 9 months	13.5	13.3
M1 crown formed from after birth to 2 years	12.7	12.1
dm2 root formed from 9 months to 3 years	11.7	12.1

As we are dealing with average values, a 0.2‰ difference could be said to be acceptable, however the difference in values for the M1 and the dm2 root is greater than 0.2‰. We must now vary the model to try and make it fit the actual $\delta^{15}N$ values of the samples. A number of permutations, detailed in table 7.2 below, were tried, the output values for each one are listed below the breastfeeding-weaning schedule coded as follows:

(Number of months of breastfeeding [n[, level: full [F[, high [H], medium [M] low [L]) i.e. 7 months fully breastfed followed by 2 months high breastfeeding, 3 months medium breastfeeding and two months low breastfeeding meaning that the child was fully weaned at 14 months would be written (7F,2H,3M,2L)

	1 (7F,2H, 3M,2L)	2 (7F,1H, 3M,3L)	3 (6F,2H, 3M,3L)	4 (6F,2H, 4M,1L)	5 (6F,2H, 1M,1L)	6 (6F,2H, 1M,0L)
dm2 crown	13.5	13.4	13.3	13.3	13.3	13.3
M1 crown	12.8	12.7	12.7	12.7	12.5	12.5
dm2 root	11.8	11.7	11.7	11.7	11.6	11.5

Table 7.2: Average expected isotopic results for Black Gate dental tissues for different breastfeeding/weaning schedules.

Although it was possible to obtain an even closer match with dm2 crowns, it was not possible to obtain a closer match with M1's or dm2 roots. It is probable that this indicates that the isotopic values in these tissues do not reflect an even weighting of all the months of formation. For example, if we add weight to the first months of dm2 root formation by discounting the latter 6 months of formation (31-36 months) when the tips of the root are forming and the apex closing, we can obtain a model that fits more closely with the actual value (see figure 7.2):

	7 (6F,1H, 3M,8L)	actual mean $\delta^{15}N$
dm2 crown	13.3	13.3
M1 crown	12.6	12.1
dm2 root	11.9	12.1

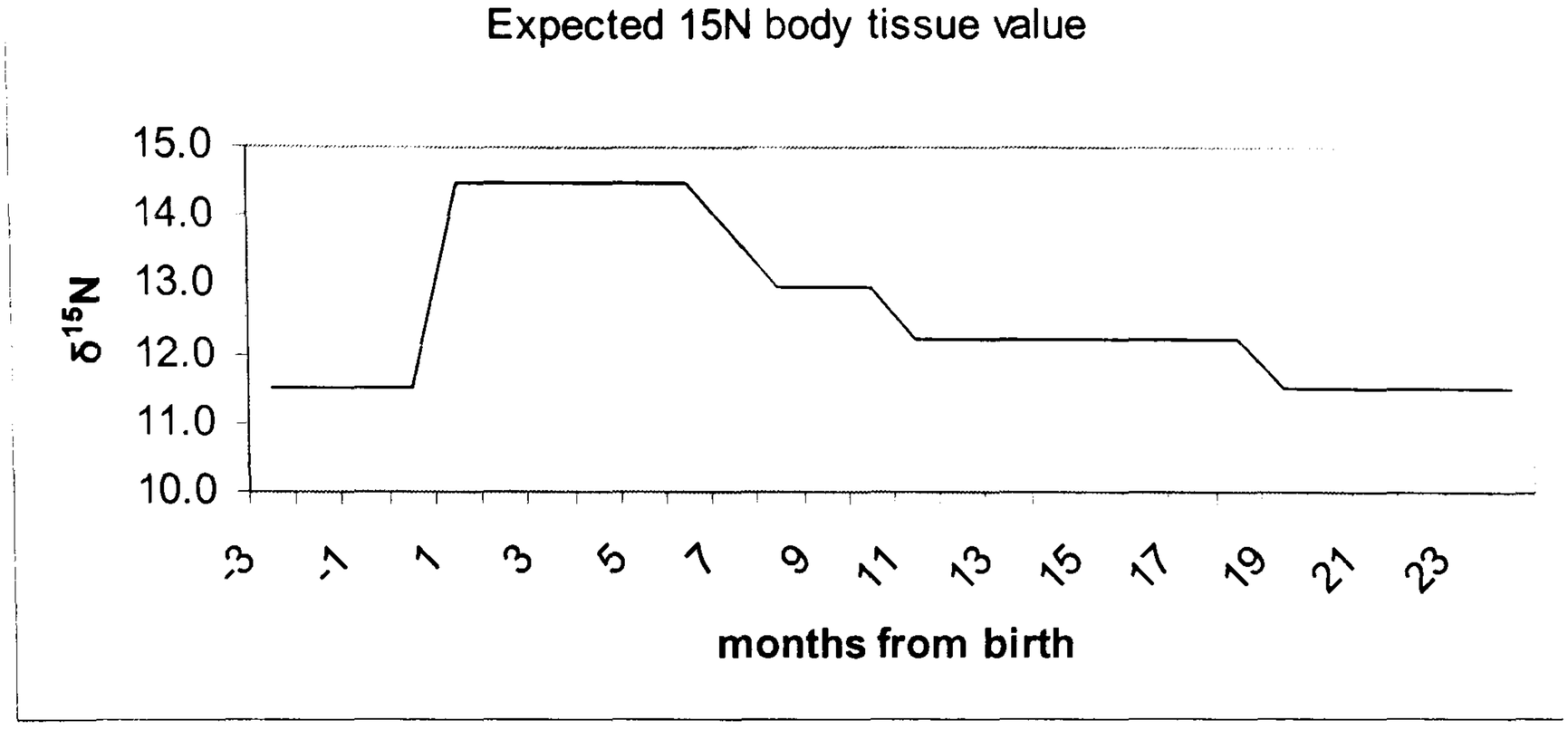

Figure 7.2: Graphical representation of the breastfeeding/weaning schedule most closely matching the actual values of the Black Gate dm2 crown and root average values.

It is currently not possible to fit the model to all three material types, this requires a greater knowledge of the formation patterns of individual tissue types, in particular an identification of the developmental period which has the most tissue laid down. It would then be possible to weight averages gained from the model to favour these periods.

Caveats

This model assumes that the level of enrichment I have used for each type of breastfeeding behaviour is constant, this wouldn't be the case and graphical representation of a real life breastfeeding-weaning schedule would depict a smooth curve rather than a stepped line. It is also possible to have slightly different permutations which output the same expected values. At this early stage, such a model can only give general indications of the broad pattern of breastfeeding and weaning schedules, particularly with the assumptions given and the difficulty is assigning the correct weighting to each developmental period during a tissues formation.

Further developments

This model requires further development to make it truly useful. In the future, a number of adjustments could be made. These include:

- Sub-dividing the levels of breastfeeding and time-slices further could help to increase the accuracy of predicted values.
- Researching the developmental rates of tissue formation to ensure the correct weighting is given to each time slice. For example, if 60% of the tissue sample forms in months 2 to 7 of a 12 month formation period and only 5% forms in months 10 to 12, then a greater weighting must be given to months 2 to 7 than 10 to 12.
- Extending the model to take account of other tissue types, for example ribs.
- Testing the model against individual tissue values (for the children) rather than the population averages.
- Looking at the possible causes of variation in the adult female isotopic values, and developing methods of compensating for this.
- Testing the model against isotope signatures that look unusual and seeing if the model can be made to account for this.
- Using samples that represent smaller time-slices so that the model can be refined and increased in accuracy.

What does the model indicate about the robustness of assumptions made in the thesis?

The strongest conclusion indicated by the development of this model is that there may be a number of different breastfeeding and weaning schedules that can give rise to the same isotopic value. When combined with an unknown level of individual variation, an absolute cut off point for breastfeeding is therefore almost impossible to determine, particularly without a greater knowledge of how teeth form. A low level of breast feeding could have persisted for some time. It does however indicate that intensity of breastfeeding can be detected by the variations in the elevation of juvenile tooth values over adult rib values and that those who received full breast feeding can be differentiated over those who received partial breastfeeding.

Following weaning, most individuals exhibit lowered $\delta^{15}N$ values in their M2's compared with all other sample types from the same skeleton. This

difference is in the order of 0.5‰, however it is not statistically significant. The lack of statistical significance may be explained by the small samples sizes and wide range of variation observed between individuals from these sites. It is most plausible that this difference is caused by physiological factors experienced during growth, discussed more fully below. However if this is not the case then it appears that most children did not receive as much of their protein from animal sources as their older siblings and adult contemporaries. There is some historical evidence that bread was the staple food for young children: the baker of Ælfric's *Colloquy* claims that bread makes men strong and so 'the little ones will not shun me', and bread was all the children at the monastery of Abingdon had to eat when Queen Edith came to visit them (Hagen, 1992: 94). It may be that young children ate a different diet as it was perceived to be better for them, or it may be that they were denied larger amounts of animal protein until they were older and played a fuller role in adult society. By the time the M3 was forming, most children were eating the same or similar foods to those they would consume once they were adults. There is a greater level of variation in the $\delta^{15}N$ values for M3's when compared with teeth, but this may be explained by the shorter formation time (approximately 3 to 4 years) compared with collagen turnover time in bone (5 to 20 years).

Are depleted $\delta^{15}N$ values in M2's a consequence of normal growth?

It was suggested above that the average 0.5‰ depletion of $\delta^{15}N$ in permanent 2nd molars may be an artefact of growth, and that, although this phenomenon is not statistically significant in these samples, its occurrence in 66% of individuals for whom a full sample set was taken warrants some discussion of its possible causes. As was noted in chapter 3, this depletion has been observed in material formed in the 3 to 9 years age range in other populations, from the Middle Neolithic site of Västerbjers on Gotland (Eriksson, 2004), to pre- and highly-agricultural sites in the Ohio Valley (Schurr and Powell, 2005), and medieval England (Fuller, et al., 2003). There is also a slight depletion in $\delta^{15}N$ values in children aged 4 to 9 years from the 19th century Prospect Hill cemetery, Canada. However the sample size (11 juveniles aged between 4 and 9) is too small for these results to be

statistically significant. This problem of small sample size dogs all other published studies, perhaps because this age category of individuals is seen as having nothing interesting to add to the field of palaeodiet. Tamsin O'Connell has also observed a 3-5‰ depletion in hair samples from 4 to 9 year olds in Pakistan (2005, pers. comm.) and suggests that this is a metabolic effect. The range of depletion for the populations studied here is 0.1 to 2.1‰, an amount that is consistently smaller, where it does occur, than that observed by O'Connell in hair. This may be due to the longer formation time of teeth versus hair, or it may be explainable in part by dietary differences, any further deliberations on this aspect of ^{15}N metabolism must await further research and the publication of more data. If we do accept the hypothesis that depletion of ^{15}N in children between 3 and 9 years of age has a physiological aetiology, a possible explanation of the mechanism by which this occurs must be offered.

A similar level of depletion to that seen in children between 3 and 9 years of age has been observed by Fuller *et al.* in the hair of pregnant women (2004). As the $\delta^{15}N$ values of dietary nitrogen and urea nitrogen are significantly lower than maternal tissues, the authors suggest that the 0.3 to 1.1‰ depletion in $\delta^{15}N$ values of maternal tissues may be due to increased utilization of these nitrogen sources for tissue synthesis during pregnancy. However the mechanism by which maternal tissues become depleted in ^{15}N during pregnancy is likely to be complex, and has not yet been fully elucidated. Feeding experiments on llamas and goats indicated that while there were no statistically significant differences in $\delta^{15}N$ between diet and total excreta for adult mammals at steady state, this may not hold true for those mammals in periods of growth, diet change and thermal or nutritional stress (Sponheimer, et al., 2003). In these cases fractionation between intake and excreta $\delta^{15}N$, and therefore body tissues may occur. Fuller *et al* (2004) suggest two metabolic pathways that may lead to lower $\delta^{15}N$ values. In times of increased nutritional demand such as pregnancy, dietary amino acids can be preferentially routed away from oxidation and excretion towards sites of tissue synthesis:

Since $\delta^{15}N$ values increase in a relative step-wise fashion as one moves up the food chain (the trophic level effect), dietary $\delta^{15}N$ values results in a reduction in the 'normal' or steady state diet to body trophic level fraction by approximately 0.5-1‰. Second, this decrease in maternal hair $\delta^{15}N$ values could also be influenced by increased urea salvage by microflora in the colon. Since human urine is ^{15}N-depleted compared to body tissues, with $\delta^{15}N$ values ranging from 3-5‰, the return of this isotopically light nitrogen to the metabolic pool for protein synthesis could potentially result in a decrease in maternal $\delta^{15}N$ values during gestation (Fuller, et al., 2004).

It is also possible that a low protein diet may have a similar effect. Sponheimer *et al.* found that diet-hair fractionation of $\delta^{15}N$ was 2.3‰ greater in herbivores on high protein diets than in those on a protein-deficient diet (2003). They suggested that this may be caused by those animals excreting more ^{15}N-depleted urine compared with ^{15}N-enriched faeces when in a steady state, or by an excess of dietary protein. This second explanation is unlikely to be plausible for the populations in the current study, even those individuals who are depleted in ^{15}N relative to later forming teeth and rib samples display a sufficient elevation over the faunal $\delta^{15}N$ values to surmise that the majority of their dietary protein was being derived from animal sources, rather than partially from animal protein and partially from the bread and cereal products which documentary sources suggest was an Anglo-Saxon staple.

There have been a number of studies on protein requirements in human nutrition, all of which indicate that the body has different needs when in different states. In a study of severely malnourished children, Badaloo *et al.* (1999) found that during the period of catch-up growth, children on a standard infant formula, high in protein had significantly greater deposition of lean tissue and higher rates of urea production, hydrolysis and salvage of urea-nitrogen than those on a recommended dietary regimen low in protein. In the high protein group, urea utilization relative to urea production was significantly less than the low protein group. In adults there is great deal of variation in urea kinetics, both in healthy individuals (Child, et al., 1997) and in those who are fasting (Hibbert, et al., 1995). Factors affecting variation include the proportion of protein and energy in the diet, and the amount of

adipose tissue on the body. However, across all this adult disparity, urea production varies by less than 15% (Badaloo, et al., 1999). Hibbert, *et al.* (1995) suggest that approximately 26% of urea-nitrogen produced is retained in the metabolic pool by healthy, non-fasting adults. The relationships between diet, urea and nitrogen that have been characterised for adults do not apply in childhood, possibly because of the demands associated with growth (Badaloo, et al., 1999). During periods of catch-up growth, the salvage of urea-nitrogen is increased (ibid.), however urea-nitrogen kinetics of healthy children experiencing a normal growth pattern have not yet been fully characterised. A single study on prepubertal Chilean schoolboys found that a very high proportion of the salvage nitrogen derived from urea hydrolysis was maintained within the metabolic pool, on average, about 43% of urea-nitrogen was salvaged for further metabolic interaction (Bickerton, et al., 1996).

Urea hydrolysis improves the quality of the dietary protein supply by enabling an increased supply of nitrogen rich lysine and other essential amino acids (Millward, et al., 2000). In their study of undernourished male infants, Millward *et al.* suggest that there may be transfer of nitrogen from urea to lysine and other amino acids, indicating that urea hydrolysis can be of nutritional significance through the provision of essential amino acids synthesised *de novo* by intestinal microflora. These studies would suggest that both healthy children, and those experiencing catch-up growth have a greater tendency to recycle urea-nitrogen than healthy adults, which, as urea-nitrogen is depleted in ^{15}N, would lead to lower $\delta^{15}N$ values in their body tissues.

The social implications of these findings

Mothers and infants

The following hypotheses were made in chapter 2: that most children would be breast fed, and that weaning would have been over an extended period, but was likely to have been completed well before the age of two. It was suggested that after this period children's bulk nutrient intake would have

been similar to the rest of the household and that they were unlikely to have eaten substantially different foods.

The results of the stable isotope analyses have indicated that the majority of children were breast fed: both those who survived into adulthood, and those who did not. It is probable that other than a small elite, most mothers would have breast fed their own children. Weaning behaviour was varied both within and between populations, with those individuals buried in the Black Gate cemetery being weaned earlier and more rapidly than those buried in North Lincolnshire. This is particularly interesting given the diverse origins of the cemetery's contributing population, discussed below. Black Gate yielded 20 juveniles who had their dm2 crowns sampled for oxygen isotopes, 8 of these were not born locally[27]. The high proportion of young immigrants in the cemetery makes the uniformity of weaning behaviour in this population is even more striking. One explanation for this pattern may be the working lives of women. If most women, including mothers spent much of their working day outside the home, for example in agricultural labour, an extended period of breast feeding and weaning may not have been possible. Younger infants are easier to take out of the home, for example in a sling than older babies, or mothers of such children may have been more likely to remain at home. Perhaps when a child was felt to be old enough, they were left in the care of older siblings, relatives or other members of the community while the mother worked outside the home. This would immediately restrict the baby's access to the breast, perhaps to a morning and evening feed, and encourage a relatively rapid period of weaning, between the ages of 9 and 12 months.

Breast feeding and weaning behaviour in North Lincolnshire seems to follow a different pattern. Again 20 juveniles have oxygen isotope results for their dm2 crowns, but only 5 of these were immigrants. There is slightly less diversity in the origins of the children in these cemeteries, but a much greater

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[27] Infants were categorised as being born locally if the $\delta^{18}O$ in their dm2 crown was between 17.35 and 18.58, this range includes a 1‰ elevation for full breast feeding, the lower value reflecting infants who were not breast fed. An infant was assumed to have been at least partially breast fed if there was a minimum of a 0.2‰ elevation in the $\delta^{18}O$ of the dm2 crown when compared with the dm2 root. Infants for whom there was no root value available were assumed to have been breast fed.

diversity in their parents weaning behaviour. It is possible that 7 infants were either not breast fed at all, or weaned extremely early, this may indicate a higher maternal mortality for the North Lincolnshire population, or may indicate different breast feeding practices in other areas: 4 of the 7 were not born in North Lincolnshire. As discussed in chapter 5, breast feeding was of greater duration in North Lincolnshire, but not as intensive. It is likely that supplemental foods were introduced to babies at a younger age, but a final cessation of breastfeeding did not occur until they were between 1 and 2 years of age. This may indicate a different pattern of labour for women in this area, different feeding patterns or differing attitudes as to what age a child could be left in the care of someone other than its mother (necessitating less breast feeding). Certainly the $\delta^{18}O$ values indicate that children were receiving less of their drinking water through breast milk than those at Black Gate. Towards the end of the weaning period, it is likely that only 1 or 2 small feeds a day would have come from the breast.

Children

If further research substantiates the hypothesis that the depletion in $\delta^{15}N$ seen in M2's has a physiological basis, we may conclude that in these populations there was no substantial difference in bulk dietary protein source between children of 3 years and older and adults. This conclusion would indicate that there is no isotopically detectable specialised 'childhood diet' for most individuals in this period. If this is the case, the results imply that children did not occupy a special dietary niche. They were neither specially treated nor neglected but ate the same foods as their adult contemporaries. It is not possible to determine whether animal protein came from meat or milk, as milk is enriched by an average of 3.6‰ over diet (Steele and Daniel, 1978), in the same range as, as that expected between diet and other animal tissues (Ambrose, 1993). This leaves open the possibility that while the bulk protein source may not differ between children and adults the details of dietary intake may still vary. More research into this area is likely to prove fruitful.

Migration and mobility

As discussed in chapters 4 and 5, there is a great deal of variability in the $\delta^{18}O$ values of individuals buried in both Black Gate and North Lincolnshire. Drinking water values vary in Britain on an east-west gradient, but not north-south. The average range for δ18O in drinking water in the region encompassing both Newcastle and North Lincolnshire is -7 to -8‰, a range which also covers most of east and central Britain. All the drinking water 'bands' from east to west can also be found in Europe, including that encompassing the study area. This means that oxygen isotope analysis provides suggestions rather than substantiated determinations as to whether or not an individual is likely to have been born and spent their childhood in the area where they died. It is assumed that if an individual's teeth $\delta^{18}O$ values match that expected for their burial region that they originated locally, but this cannot be proved conclusively because they could still have migrated parallel to the isotenors. Oxygen isotopes on their own are therefore not a suitable tool for determining local mobility patterns. A suggestion of a more specific area of origin can by achieved by combining oxygen and strontium and perhaps lead isotopes, although research on strontium isotopes also has methodological problems associated with it (see for example Budd, et al., 2004). It is however possible to identify individuals who spent part of their childhood in an area far enough away from their burial region for the drinking water to have a different $\delta^{18}O$ range (see figure 7.3). The term migration is used as individuals would have had to spend at least 2 years in an area for the change to show up in their tooth $\delta^{18}O$ values.

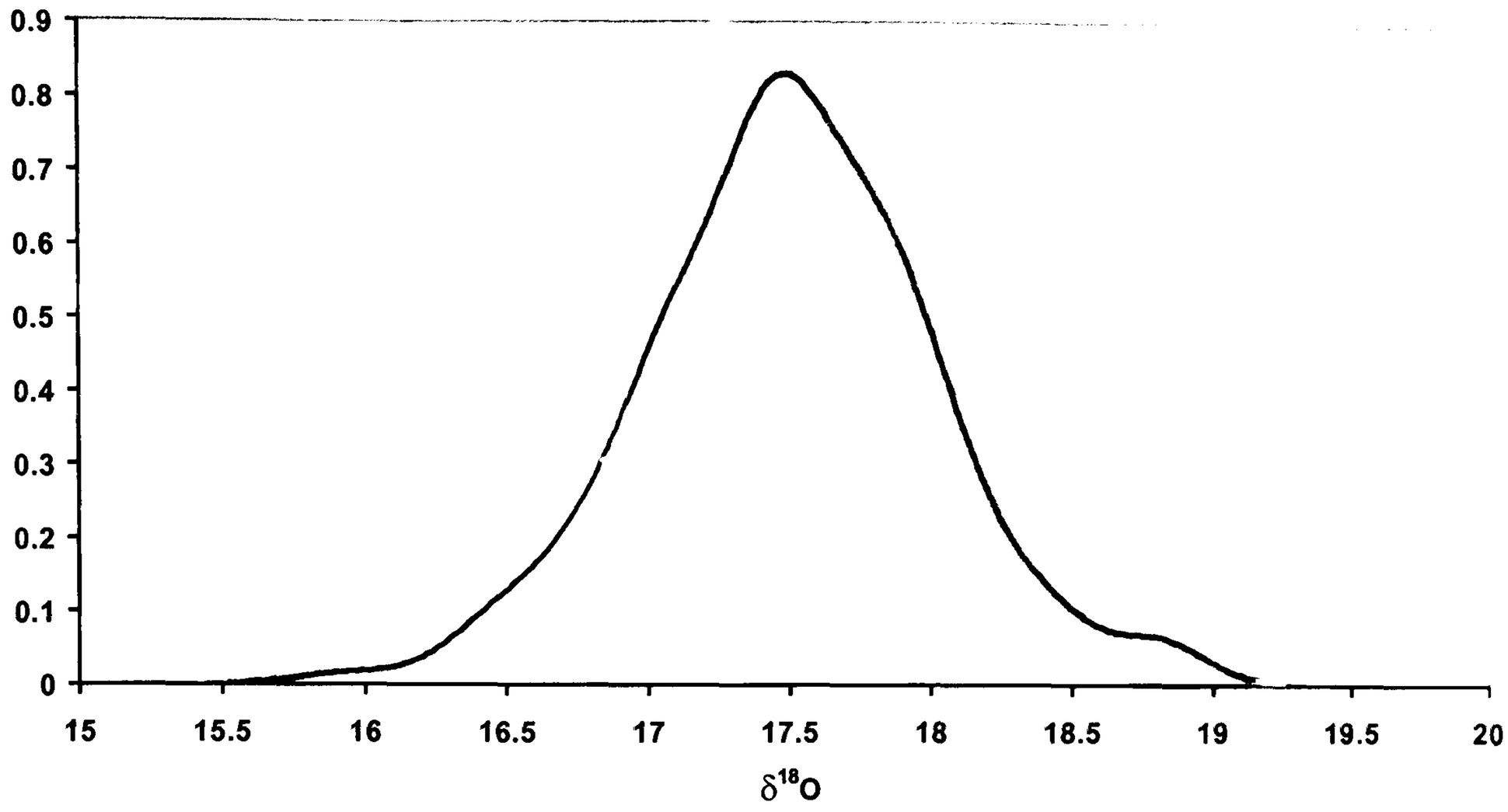

Figure 7.3: Kernel density plot for permanent tooth enamel $\delta^{18}O$ values for all samples preserving a biogenic signal. Each coloured section of the line indicates the group of teeth judged to have come from a colder region than the study area (blue), the same region as the study area (green) and a warmer region than the study area (orange).

The range of $\delta^{18}O$ values for Black Gate M2's and M3's is 2.51‰ and for North Lincolnshire is 3.37‰. This level of variation is higher than that expected for a sedentary population: White et al (1998, 2004) found a range of intrapopulational variability of 2‰ in Mesoamerican control samples judged to be local. However she stresses that these values, derived from adult bone phosphate, could include high status individuals consuming imported foods high in water content, or individuals who had moved recently from other nearby microenvironments. Others have suggested that the level of variation to be expected in a stationary population may be as little as 1‰ (Longinelli, 1984). Individuals from Nubia, also judged to be local, had a far greater range of $\delta^{18}O$ values (6‰), however this is a population living in an extreme environment whose only drinking water source was the Nile (White, et al., 2004). The time period covered by the samples was in the order of 1000 years and reflects the increasing aridity of the regions, with most of the variation in $\delta^{18}O$ values being caused by this climatic shift. White et al.

suggest that other factors, for example loss of water through perspiration, seasonality and the effects of pregnancy, lactation and weaning, may be contributing to the isotopic variation seen in the population, but in order to determine how much variability each factor was causing further, and more refined, sampling would be necessary.

Samples analysed in the current study are from a temperate region, and span a period of four hundred years at the most, during which time climate (as discussed below) was stable. The levels of variation seen here are therefore outside what can be considered a normal range. However the standard interpretation of the $\delta^{18}O$ values in these populations, as discussed below, leads to levels of childhood migration of 75% or higher. If correct, this is indicative of an extremely mobile population in the early medieval period characterised by the migration of large sections of society over a number of centuries. A degree of migration is expected in this period, characterised by migrations from the Scandinavian countries and trade both within the British Isles and with the continent, although the extent of these activities is unclear (Hadley, 2000, Hinton, 1990). Variables affecting the interpretations are discussed, but without extensive work on more populations from temperate Europe which are felt to be static, it is difficult to be certain how indicative these $\delta^{18}O$ data are of a mobile population.

Oxygen is derived from both the content of food and drinking water. It is possible that if there was a high level of imported foodstuffs with high water content, or drink, then this might affect isotopic values. Although it is impossible to totally discount this as a factor, any imported foodstuffs are likely to have arrived either in dry form (e.g. cereal grains, flour) or on the hoof and would therefore have a minimal impact on total ingested water. It is also unlikely that drink was imported on a large scale, the most common drink was ale (Hagen, 1992), which was not always brewed with hops and often had poor keeping qualities, meaning it was difficult to transport any distance. In addition, the amount drunk meant that new batches were brewed on a monthly basis, reducing the likelihood that this low status drink would have been imported great distances (Hagen, 1995). Although other

drinks, such as wine mead and other alcoholic beverages could have been imported, their expense and high status (*ibid.)* mean it is again unlikely that they would have formed a large part of total ingested water.

As the source of drinking water is not known for these populations, it is possible that this might represent another factor in the observed variation in $\delta^{18}O$ signals in teeth analysed. Water drunk from different sources, for example rivers, wells and ponds will reflect the isotopic value of their source water, with varying levels of fractionation caused by evaporation (Hunt, et al., 2005). The isotopic maps and values used in the interpretation of this study are derived from both meteoric, surface and groundwater (Darling and Talbot, 2003, 2003) and therefore represent the range of values seen in a particular region throughout the seasons. Unless a tooth was formed over a number of years when the climate differed significantly from the average, this difference is unlikely to show up in the $\delta^{18}O$ values. In addition water available for consumption in these populations was unlikely to have derived from an area with a significantly different isotopic composition. Although the sources of the Tyne (the North and South Tyne rivers) are on the Scottish Border, north of Keilder Water, and in Cumbria, on Alston Moor, these are areas with water isotope values in the same range as the Black Gate region. The sources of the Humber (the rivers Ouse, Trent, Ancholme and Hull) are distributed throughout the Yorkshire Dales, the North York Moors, Staffordshire, North Lincolnshire and the Yorkshire Wolds. Some of these sources do pass through an area of slightly more depleted oxygen isotope values in drinking water, however as the Humber is a tidal river whose water is brackish and sediment rich, it is unlikely that individuals would drink water from the Humber and therefore any depletion in $\delta^{18}O$ in the river water is unlikely to affect isotopic values in their teeth. It is likely that most drinking water would have been obtained from local surface run off captured in wells and springs (Hagen, 1995) and individuals' $\delta^{18}O$ values would therefore be expected to reflect local rainfall values.

There are no currently published studies for expected levels of variations for humans living in the British Isles in this period in sedentary populations. The

Black Gate and North Lincolnshire samples all derive from estuarine locations and therefore might be expected to exhibit a higher degree of movement due to proximity to both rivers and the sea. Travel by water was easier in this period, particularly for trade, than travel overland where the transportation of both goods and people is more difficult. As there is currently no settlement associated with the Black Gate Cemetery, it is not possible to determine the nature of the subsistence pattern of cemetery population. There have been suggestions that the cemetery served a trading community, or perhaps a lay community serving a monastery, either of which may have been characterised by a high degree of inward migration (Merrony, et al., 1996). The cemetery at St Peter's, Barton upon Humber appears to have served a local settlement from the 5th century through to the 20th. This level of stability in cemetery use could be used to suggest a similar level of stability in the contributing population; however the early medieval practice of sending children away for the purposes of fosterage, as child oblates, slaves and apprentices should not be discounted. What is unknown is the extent to which these activities would have been a factor in the lives of most children in this period.

The time span of these two cemeteries encompasses a period of large scale political upheaval in England, from the Scandinavian migrations to the Norman Conquest and beyond. An additional factor, which could be taken into account if known, is the extent to which changes in social and political structures which England experienced at this time affected population movement. Whatever the actual level of mobility in these populations, they are located in positions where movement would not have been as difficult as for inland populations. Drinking water corrections are therefore discussed below without reference to expected levels of intrapopulational variability, although variation in oxygen signature due to differing water sources cannot be fully discounted.

Only 12 of the 48 adults with biogenic $\delta^{18}O$ values have values that indicate they spent their whole childhood in the drinking water area encompassing Black Gate and North Lincolnshire. The remaining individuals spent time in

one or more areas before travelling to the place in which they were buried. By comparing the values of M2's and M3's it is possible to detect individuals who migrated at least once, and at least twice between the ages of 3 and 13. At Black Gate, equal numbers of individual migrated at least once, and at least twice during their childhoods. In North Lincolnshire, more individuals migrated at least twice than at least once in their childhood. It is possible that there was a higher degree of mobility amongst those individuals settling in North Lincolnshire, as indicated by the range of $\delta^{18}O$ seen in M2's and M3's. In both areas, individuals were immigrating both from more enriched, (warmer) and more depleted (colder) $\delta^{18}O$ regions; this can be seen by the roughly equal sized tails in figure 7.3. Both cemeteries are in estuarine locations and are therefore easily accessible by river and sea meaning that individuals could have immigrated to these areas from both Britain and abroad. This pattern of movement would be far easier than travel over land, enabling greater distances to be covered over a shorter time. Further research is needed to determine whether there is a greater degree of $\delta^{18}O$ variability amongst estuarine and costal populations than inland populations in this period, and whether this indicates an increased level of mobility in littoral communities.

Why then might individuals be migrating, both in childhood and in adulthood in this period? Children may have moved from one area to another both as an individual (less likely), and as part of a larger family or community group (more likely). As individuals, children may be sent to live in a household away from their natal home for many reasons, for example through the practices of fostering, hostage giving, and as training, for example in an army or religious house (Crawford, 1999). Children would also have migrated with adults as part of a family group for trading expeditions, and as is indicated by Icelandic Sagas, such expeditions may have remained in an area for a number of years before returning to their home settlement (1961). As part of this system of trade children and adults would have been sold, and moved to other areas, as slaves. An individual could enter into slavery either as punishment for breaking the law, in return for food in times of famine, by being sold into slavery or through capture in war (Crawford, 1999). Indeed, a

primary source of slaves for the Anglo-Saxons was the *Wealas* or Welsh, a word that was also Anglo-Saxon for slave (Lacey and Danziger, 1999). Finally families and communities may simply have migrated to another area where they thought they might improve their quality of life.

One must also ask whether individuals were likely to have moved from their birth place as children younger than 3 years. Most demographic migration models predict that the people most likely to migrate are young adults and their dependent offspring. This would necessarily include young children who were not yet weaned. Data on migration in modern rural Bangladesh indicates that young children (below the age of five) move when their parents do (ICDDR, 2005). In such a case we are not tracking the independent migration of young children, but rather the movement of their parents or carers.

The evidence discussed above is based on a comparison of the drinking water area of young children aged between 3 and 6, their drinking water area between 9 and 13 and the area in which they were buried. This makes the unsubstantiated assumption that children were less likely to migrate before the age of 6 and that any differences seen in the M1 are an artefact of breast feeding. Re-examining the $\delta^{18}O$ values of M1's indicates that there were 12 individuals whose M1 $\delta^{18}O$ was the same as or lower than their M2 values. In 3 cases (BG499, BG534 and BH1305), the values are so similar that we may suggest that these individuals received little or no breast feeding as infants. The remaining 9 cases have lower $\delta^{18}O$ in their M1's than in their M2's, indicating that these individuals must have moved from their birth place before their M2's began to form. There were a further 6 individuals whose $\delta^{18}O$ value was more than 1‰ greater in their M1 than their M2. As 1‰ is the suggested maximum elevation in $\delta^{18}O$ caused by breast feeding, it is likely that these people also moved to a different area as infants or young children. Of the 15 individuals who migrated to different areas as young children, 6 were likely to have migrated at least twice. As discussed above, 13 of the 40 juveniles sampled also originated from outside their burial area. It must therefore be concluded that children were just as likely to migrate as

older members of early medieval society, and probably for as wide or wider a range of reasons as adults (also see comments above). Multiple stable isotope determinations of such individuals may further elucidate the degree of migration in such communities and identify more specifically the areas from which they were moving.

As $\delta^{18}O$ values are affected by climatic variables (Siegenthaler and Oeschger, 1980), it is pertinent to establish that such variations are not significantly affecting the $\delta^{18}O$ values of the samples studied here. Samples from both sites date to between the 8th and 12th centuries AD, a range that lies within the medieval warm period. This period was characterised by warm summers and mild wet winters, much like today, although there was also a short cold spell around 900AD (Hass, 1996). However even a mean annual temperature decrease of 0.5°C would reduce drinking water $\delta^{18}O$ by no more than about 0.2‰ compared to the same areas today (Budd, et al., 2004).

A study on climate variation in France carried out using human tooth enamel from the last 1700 years found a large variation in $\delta^{18}O$ in the teeth (Daux, et al., 2005). The samples were all taken from an area of Lorraine from individuals who lived in a rural habitat and populations traditionally very sedentary. However as with the exception of 10 individuals whose birth place was known from chronicles, it was not possible to rule out the inclusion of incomers with non-regional $\delta^{18}O$ signals in their teeth. It is also pertinent to note that some permanent first molars were included in the sample, which could mean that a breast feeding signal was included in the analyses; it is not possible to establish whether or not this was the case as the tooth type is not given in the results. The large variations seen in the samples are correlated with a period of climate change from the 'Medieval Warm Period' to the 'Little Ice Age', with the largest variability being seen during the Little Ice Age (particularly during the 16th to 18th centuries). Despite this the mean $\delta^{18}O$ for both periods is the same; the authors attribute this to a higher level of summer precipitation in the Little Ice Age, inflating meteoric oxygen ratios. The range for these samples across the full time period is 4‰, far greater than any variation seen in the current study but principally attributable to the

time period covered by the Little Ice Age (range = 4‰, n=26). The range in the Medieval Warm Period (defined by the authors as the 10th to 14th centuries AD) was2.5‰ (n=14), as was the range for samples dated to between the 8th and 12th centuries AD (n=13), the period covered in this study. This is identical to the range seen in the Black Gate population, but lower than that seen for North Lincolnshire; however there are two outliers at the extremes of the data range. It is not impossible that these two individuals are immigrants into the community; this would give an immigration rate of 15% a figure which is not unreasonable in a sedentary population. Without these two individuals the range of $\delta^{18}O$ values seen in individuals dated to the 8th to 12th centuries is 1‰, the isotopic range previously predicted for a sedentary population (Longinelli, 1984). It is impossible to exclude migration as the major source of variation in the Longinelli data. Historical data indicate that up to 10% of individuals may migrate per year in the young adult age categories (see, for example, the Bangladesh data (ICDDR) where age-specific out-migration rates peak above 10% per annum).

It is therefore unlikely that any of the variations in $\delta^{18}O$ values in the current samples are caused by climate change. Indeed, even in skeletal apatite samples with a greater variability in $\delta^{18}O$, this will often still correlate to the drinking water value of the source area. Iacumin and Longinelli (2002) examined fox bone and tooth phosphate from a number of locations representing different climatic and environmental conditions and found very homogenous results fox samples from particular areas; samples fit a straight line whose equation can be used for paleoclimatological studies either in Arctic or in temperate regions. Samples from Wales did have a larger range (0.7‰), explained by the different elevations of the collecting sites, however, the $\delta^{18}O$ values in skeletal apatite for these samples still corrected to the same drinking water range.

As teeth are sampled from crown to CEJ, oxygen isotope ratios represent a mean of seasonal variations over the 2 to 4 year period over which the tooth formed. It is therefore also unlikely that variations are caused by seasonal fluctuations in $\delta^{18}O$, as seen in hypsodont teeth (Fricke and O'Neil, 1996,

Sharma, et al., 2004). Given that most causes of variability in $\delta^{18}O$ signal can in the current study be discounted to a greater or lesser degree, the conclusion drawn from this data must be that there was an extremely high level of migration in these two populations. If we take into account that variations in oxygen isotopes cannot detect migration from areas with the same $\delta^{18}O$ values as the sample areas, then levels of migration could approach 100%. Even if it was common in early medieval England to send children away from the natal home for one or more periods, and the social and political change caused large scale population movements, the levels of migration seen in these populations are extremely high. It is therefore possible that there are other causes of variability in $\delta^{18}O$ ratios not discussed within this thesis which future research will highlight.

Chapter conclusions

This research adds to the growing body of isotopic studies of palaeodiet and migration in the British Isles. It differs in that the diet and migration patterns of children are specifically addressed. The varied nature of childhood diet from breastfeeding through weaning, childhood and adulthood has been highlighted within the general trends discovered. Despite the estuarine location of the cemeteries under study, there is no detectable consumption of marine protein in these populations. Rather individuals consumed a largely terrestrial diet, containing plenty of animal protein, possibly with the inclusion of some fresh water resources. Two different breast feeding and weaning patterns were evident, corresponding with the two study areas. The breastfeeding model develops indicates that the general pattern at Black Gate, was exclusive breastfeeding of babies until they were approximately 6 months old, followed by a period when the intensity of breastfeeding was reduced over the course of four months full weaning occurred later: a low level of breastfeeding seems to have been maintained for a further 8 months before breastfeeding ceased completely. As was pointed out above, this model is embryonic an it is probable that a number of breastfeeding regimens could produce the same data. The model was not tested against the North Lincolnshire population however comparison of the raw data indicates that, children were exclusively breast fed for a much shorter period, and were

receiving supplemental food well before the completion of the deciduous 2nd molar crown. Again, full weaning occurred much later: children would often be receiving some breast milk until they were approximately 2 years old.

Young children, between the ages of 3 and 6 years are depleted in ^{15}N relative to their values as older children and adults. The recycling of ^{15}N depleted urea for tissue synthesis is the most likely cause of this growth related effect. There does not appear to be any diet-related variation in isotopes between adults and children in this population. As samples forming at different ages were taken from the same individuals, we may assert that most people ate an isotopically similar diet throughout childhood to adulthood.

Oxygen isotopic analysis has revealed the varied nature of migration and mobility patterns for the populations studied. Both areas contained cemetery populations with a low proportion of individuals who could be said to have spent their lives in one area. Both adults and children were migrating one or more times in their lives, and in some cases, spending only a few years in a new area before migrating again. That babies and children were as mobile as adults indicates that their presence was not a limiting factor in the mobility of families and communities; rather they may have provided at least part of the impetus for the migration patterns seen in this study. These interpretations of the oxygen data are made in the absence of an adequate alternative explanation for the levels of variation seen in these populations. As discussed above such high levels of mobility are not out of the question, but more robust interpretation of the data must await further research on the nature of $\delta^{18}O$ variability within human tissues.

Chapter 8: Conclusions

The wider research context

This research has been carried out at a time of blossoming interest both in the use of isotopes to answer archaeological questions, and in the archaeology of children. The question asked in this case was whether or not children had a special place in early medieval society (either embraced or ignored) that was reflected in the bulk food resources that they had access too. Stable isotope analysis is an ideal tool to address this question: $\delta^{13}C$ and $\delta^{15}N$ values can indicate the presence of marine food in the diet and indicate protein source, while $\delta^{18}O$ identifies the any migrants into the sample, who may affect dietary signals.

The two groups of populations studied were geographically separate, but both lived in similar environmental conditions, and might therefore be expected to consume similar diets. This is indeed the case, in particular though both groups were in estuarine locations with access to both open water and the sea, there was little to no consumption of marine protein. It is possible that freshwater fish were consumed, but there are currently no large freshwater samples analysed for these areas and time period with which to compare the human isotope signals. Within this broadly similar dietary pattern there is a great deal of individual variation evident both in bulk amounts of protein and the pattern of isotope values seen over childhood, and into adult life. This may in part be due to the potentially high levels of migration evident for both populations, as indicated by the $\delta^{18}O$ data. The standard interpretations indicate that only 25% of the sampled individuals spent all their childhood in an area with the same isotopic drinking water range as their place of burial, the remainder may have migrated one or more times before death. As the areas of origin range from the west coast of Ireland to central Europe, there may be a great variety of both dietary practices and the isotopic signals of food sources. That migration could occur at any age in the population analysed (see chapter 7 for a discussion of individual and group migration) reveals the mobile nature of early medieval

life in general and childhood in particular. Young children were most likely to migrate as part of family groups; however older children could conceivably have migrated away from their natal families, either of their own volition, or through arrangements made by their kin. We must therefore conclude that children were active participants in the societies of early medieval Europe. However before such interpretations may be made with real confidence, much more research is required in the future to thoroughly quantify variations in $\delta^{18}O$ in human tissues and their relationship to migration.

Although there is a great deal of individual dietary variation, it does not seem that bulk diet, and in particular the levels of protein available, differed greatly between adults and children. Once children were weaned, the largest source of carbon and nitrogen isotopic variation was not caused by alterations in diet, but by the requirements of growth. These requirements may lead children between the ages 3 and 8 to recycle urea nitrogen in order to promote tissue growth. The results of this research therefore indicate that the diet of early medieval children was characterised by as great a level of access to protein as that of their adult contemporaries. If children did occupy a separate place in society, this was not reflected in their bulk diet.

Before weaning, children were dependent on a lactating woman (in most cases this was probably the mother) for the majority of their dietary requirements. A number of different breast feeding patterns were detected in this research, which can give an insight into the lives of both mother and infant. Duration and intensity of breast feeding reflects not only the requirements of the nutritee, but the cultural and social environment of the nutritor. Early medieval women breast fed their children with varying degrees of intensity and duration, reflecting the demands placed on them by other members of the family, their communities, and their role in economic production.

Future research directions

A number of questions arose during the course of this investigation which merit further research in the future. The continuing difficulty of identifying

freshwater protein consumption in this period and region could be mediated both by a programme of analysing fresh water faunal remains and by extending the use of sulphur isotopes. The use of triple rather than dual isotope determinations and the routine inclusion of freshwater samples in studies would help to locate individuals within their food webs with greater precision. Oxygen isotope analysis has revealed the high levels of mobility of these populations, and accurate assessments of their dietary intake during childhood are hindered by an incomplete knowledge of how stable isotope ratios in food sources vary across Europe. Research on stable isotope variation in pan-European faunal material from this period would greatly enhance interpretations of palaeodiet for populations containing immigrants from a number of regions. Such data may help to differentiate dietary differences due to status from those due to migration. Multiple stable isotope determinations would also be of use in determining the childhood abodes of migrating individuals. The combination of oxygen with strontium, and possibly sulphur and hydrogen could help to narrow down the geological and environmental area in which an individual lived. This would be particularly useful in areas where water $\delta^{18}O$ forms large bands with little variation, but the underlying geology is more varied.

The high level of variation in breast feeding and weaning practices for the two populations studied prove the utility of this technique in investigating societal attitudes to infants and their carers. Intensity and duration of breast feeding may alter both with period and geographical area. Events which caused intense population flux, such as the spread of agriculture, the Black Death and the industrial revolution may affect birth spacing, breast feeding patterns and infant mortality. The method used in this study involved sub-sampling deciduous 2nd molars from juveniles, and permanent 1st molar crowns from adults. This limited the amount of information that could be gained from those individuals who survived childhood. A study is currently under way to assess the efficacy of studying sub samples of permanent 1st molar enamel to track fluctuations in $\delta^{18}O$ over short periods of up to 3 months. If oxygen is incorporated into the phosphate component of the enamel in a continuous process during tooth formation, it will be possible to track duration and

intensity of breast feeding in surviving adults. Such microscopic sampling techniques would also enable highly detailed 'travel biographies' to be constructed through out the period of enamel formation in permanent teeth. Furthermore by sampling enamel below the perinatal line, it may be possible to establish degree of isotopic fractionation of oxygen as it crosses the placental barrier and hence the area of residence of the gestating mother. This could have implications for travel patterns of migrating communities i.e., were pregnant women more likely to migrate before or after the birth of their babies? It could also provide explanations for differences in breast feeding patterns for groups of individuals who all grew up in the same region: the migrating mother could have retained the cultural behaviours of her area of origin in caring for her child rather than adopting the practices of her new community.

Finally, the depletion observed in $\delta^{15}N$ values in permanent 2nd molars requires further research to ascertain its precise aetiology and full duration. Analysing 2nd molar roots would provide a bridge between the crown values and the 3rd molar values, sub sectioning of these roots could provide further information on the duration of this depletion. A much greater sample size is necessary to fully characterise the nature of this depletion and the causes of variation from the pattern. Hair and urine samples from modern healthy children with a well characterised diet would also eliminate any effects caused by past dietary variation. Ideally a longitudinal study should be carried out to characterise ^{15}N variation in individuals over a number of years. Once the mechanisms and nature of ^{15}N variation in growing children are fully elucidated it will be possible to identify the effects of dietary variation, particularly protein stress, had on past individuals.

Final conclusions

Stable isotopes have characterised the bulk dietary intake of early medieval populations and have demonstrated how diet may change over an individual's lifetime. Age of weaning in these populations was highly variable and contingent on the circumstances of the mother and child. Post-weaning, most individuals studied consumed a diet based largely on terrestrial protein

with little to no input from marine resources. This research has also discovered the mobile nature of early medieval communities; in particular, individuals (both adults and children), families and larger groups may have migrated one or more times in a generation. In conclusion, children were an integral part of the communities in which they lived, and had access to the same dietary resources as adults.

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