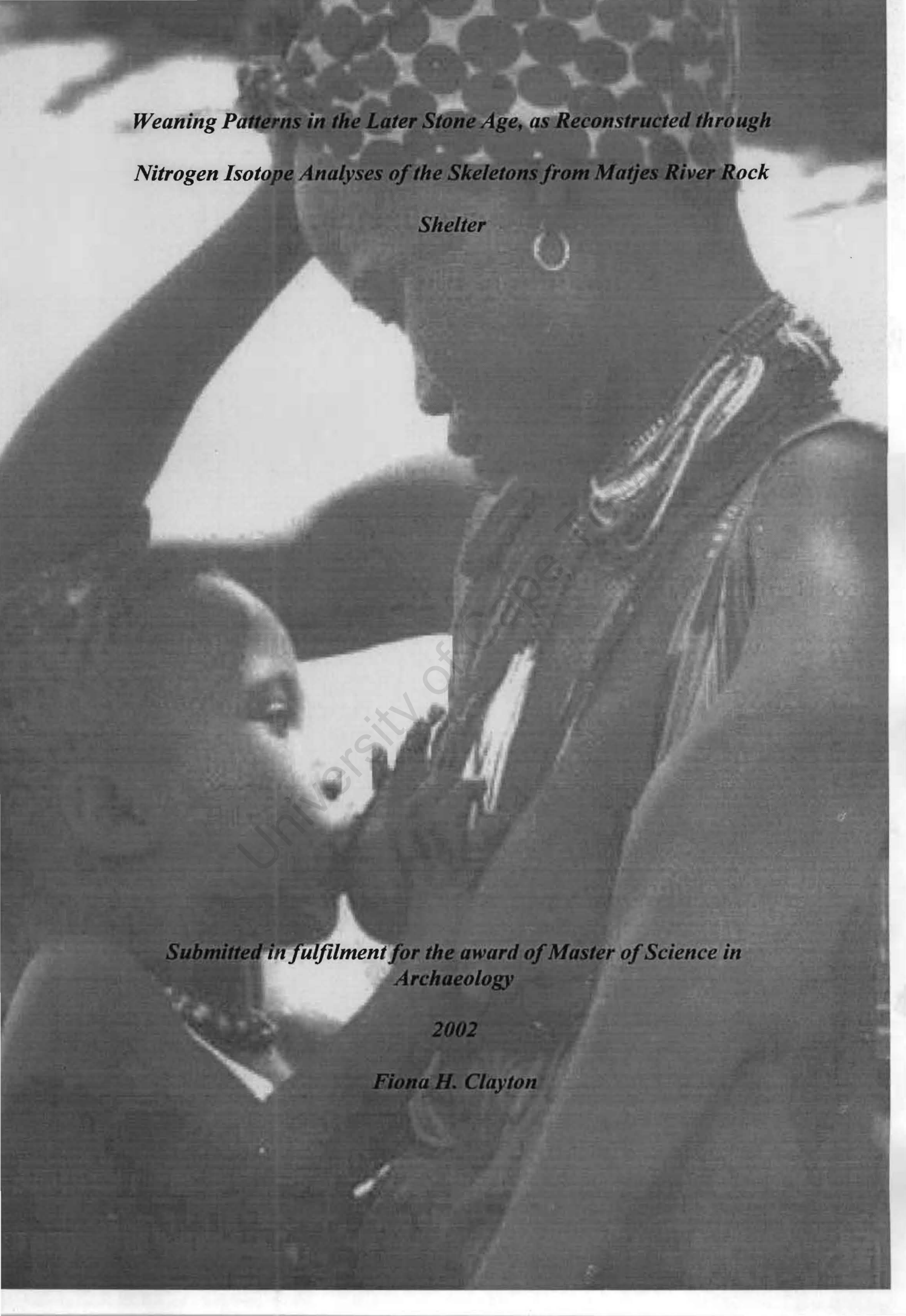


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*Weaning Patterns in the Later Stone Age, as Reconstructed through
Nitrogen Isotope Analyses of the Skeletons from Matjes River Rock
Shelter*

*Submitted in fulfilment for the award of Master of Science in
Archaeology*

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University of Cape Town

ABSTRACT

Stable nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$) isotope ratios have been measured in bone and dentine collagen from juvenile skeletons from Matjes River Rock Shelter, in order to establish a weaning curve for Southern African Later Stone Age hunter-gatherers.

$\delta^{15}\text{N}$ results for 33 individuals, from birth to 8.5 years old, show elevated values from birth to two years old. $\delta^{13}\text{C}$ values, too, are enriched; results are more tightly clustered than results for $\delta^{15}\text{N}$. Children at Matjes River Rock Shelter were breastfed for at least the first two years after birth, and were weaned sometime between two and four years old. A similar trend has been documented for recent Kalahari hunting and gathering people, with the interbirth spacing being approximately three years. This long interbirth spacing is thought to be the result of the biological effects of lactation on ovulation, the need to be mobile, infectious infertility, and naturally low fertility among !Kung women. Some of these factors are hard to investigate in prehistoric populations, yet we see a general agreement between the ethnography and the isotopic data. It therefore appears that the duration of breastfeeding in both communities is not determined primarily by the demands of the environment. The availability of suitable weaning foods may be an important issue.

Previous isotopic analyses of human skeletal remains from the southern Cape coast have focussed on reconstructing the diets of the adult population. This study has examined change in diet through infancy and childhood. It is the first confirmation of an extended period of breastfeeding not only in prehistoric Southern Africa, but also worldwide.

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Special thanks are due to Mary Leslie at the South African Heritage Resources Agency (SAHRA) for issuing me with the necessary permits. I also owe thanks to James Brink (H.O.D) and staff at the Florisbad Quaternary Research Department, National Museum, Bloemfontein, not only for allowing me access to the Matjes River Rock Shelter collection, but also for their hospitality during my visits. Mr. John Lanham and Mr. Ian Newton, at the Archaeometry Research Unit, University of Cape Town (UCT), deserve special mention. I appreciate their patience, assistance and advice during the course of analysis of the samples. Various staff members within the Department of Archaeology, UCT, have also helped to make my experience a good one.

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CHAPTER ONE

INTRODUCTION

Hunter-gatherers have lived in southern Africa from the late Pleistocene until the present. It is likely that the Later Stone Age people who lived here 20 000 years ago were the direct ancestors of the modern Bushmen.¹ Genetic and linguistic studies both confirm that twentieth century peoples, often referred to collectively as Khoisan², are the aboriginal inhabitants of southern Africa. Khoisan history is therefore closely connected with the history of the people of the Later Stone Age. Evidence for many aspects of their way of life is, however, most visible during the Holocene, the last 10000 years. It was only as recently as 2000 years ago that Khoe-speakers adopted a herding economy, and there was trade and interaction between hunters, herders and metal-working agriculturalists of the Early Iron Age after 2000 years ago. Ethnography and Later Stone Age archaeology in Southern Africa can be used to gain a long-term historical perspective on the hunting and gathering³ way of life.

¹ 'Bushman' or 'Bossiesman' was the name given to low-status people encountered by the Dutch settlers in the 1600s, and referred to those who collected their food off the land and had no domesticated animals. Today, while the hunters have no single name for themselves, they have come to prefer outsiders using the term 'Bushman' (Smith *et al.* 2000).

² 'Khoisan' encompasses a great deal of variability and was never used by the indigenous people themselves. Khoisan, or Khoesaaan, is a general term used by linguists for the click languages of southern Africa, and which physical anthropologists use to distinguish the aboriginal people of southern Africa from their black African farming neighbours (Deacon and Deacon 1999 and Smith *et al.* 2000).

³ Although problematic, the term 'hunter-gatherer' will be used interchangeably with forager in this thesis. 'Hunter-gatherer' was, in the past, a gender-biased term. The emphasis was placed on the importance of hunting, a predominantly male activity, even while gathering, a female activity, provided most of the family's nutrition, but was not given the same attention in the literature.

Occupation of the Southern Cape during the Holocene

There exists exceptionally rich archaeological evidence for Holocene human occupation along the western and southern Cape coast of South Africa. Many open-air shell middens and cave deposits have been, or are currently being excavated in these regions (see Kaplan 1993). The temperate climate and reliable sources of food along the Southern Cape seashore means that hunter-gatherers living here did not have to contend with seasonal food shortages or scarcity of food as documented in the Kalahari.

Sites along the southern Cape coast have yielded hundreds of fragmentary human skeletons have; unfortunately most have very little or no contextual information. With the application of radiocarbon dating, morphometric and bone chemistry studies, we can fit together the pieces of this archaeological puzzle. Sufficient detail is captured in the morphology and chemical composition of human skeletal remains to provide high-resolution information about an individual's life.

The Matjes River Rock Shelter is but one of many archaeological sites along the southern Cape coast. Much of the context of the rich archaeological deposits has been lost due to low-resolution excavations; this has made it difficult to answer some of the questions we would like to ask about the site. It is, however, possible to retrieve a good deal of information from the little-studied human remains recovered from the site.

History and background

The Matjes River Rock Shelter is situated in a temperate well-watered area, between Plettenberg Bay and the Tsitsikamma National Park, just east of the Keurbooms River mouth (Fig. 1.1). The site is on the western bank of the Matjes River mouth. The environment, with its high rainfall and rich resources, contrasts sharply with the inland regions occupied by hunter-gatherers in the nineteenth and twentieth centuries.

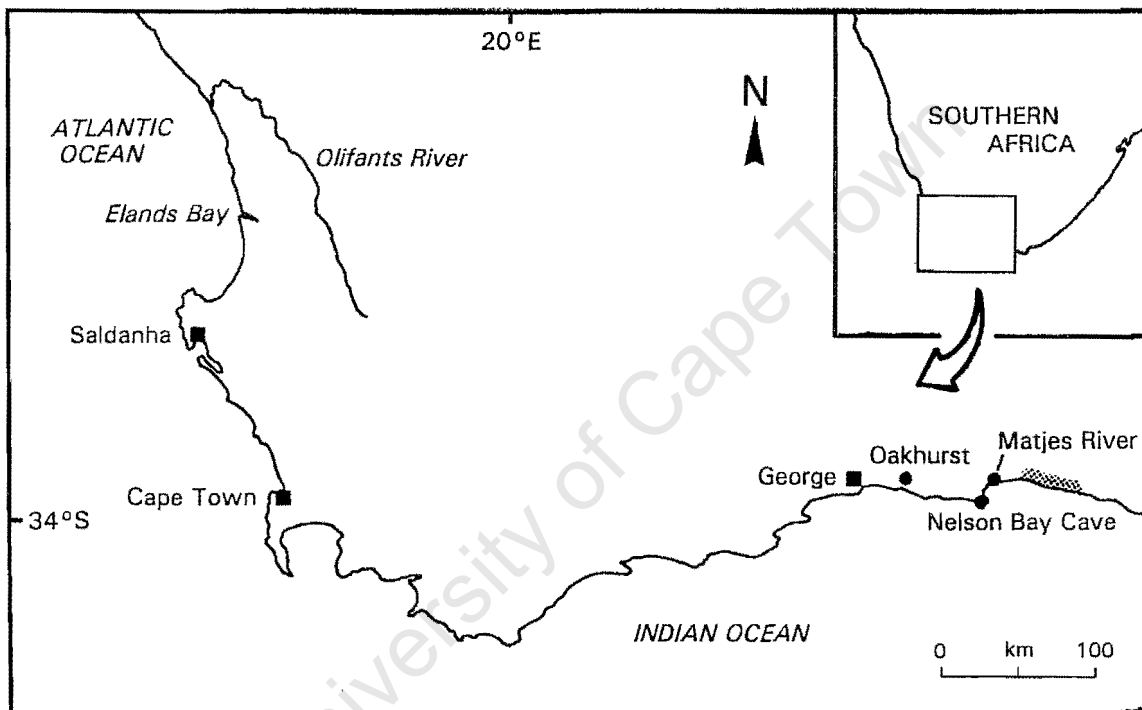


Figure 1.1: Map showing location of Matjes River Rock Shelter in relation to towns (■) and other excavated archaeological sites (●) in the area (adapted from Sealy 1997).

Matjes River Rock Shelter (Fig. 1.2) is an important archaeological and anthropological site. It is one of the deepest shell middens excavated along the Southern Cape coast. In 1928 Dr. T. F. Dreyer, affiliated with the National Museum, Bloemfontein, visited the shelter. Trained as a zoologist, and not an archaeologist, he carried out a pilot excavation in 1929 and found human skeletal remains throughout all layers of the deposit. He was primarily interested in obtaining human skeletons to

carry out racial typological studies, which were fashionable in the 1930s. Other archaeological evidence from Matjes River Rock Shelter appears to have been of secondary importance to Dreyer.

In 1952, just after the discovery of radiocarbon dating, Drs. A. C. Hoffman and A. J. D. Meiring launched another excavation project at the shelter. They carried out extensive excavations in the course of five expeditions. An extraordinary number of human skeletons, stone artefacts and bone tools were recovered. In 1953, through the influence of Hoffmann, the site was declared a National Monument.



Figure 1.2: Matjes River Rock Shelter, approximate location indicated by arrow (own photograph). The mouth of the Matjes River is visible in the foreground.

The Historical Monuments Council appointed one of the labourers who had assisted in the excavations as a guard during the summer. After his death, this practice was discontinued and the state of conservation of the site deteriorated. Deacon and Döckel set out in 1994 to rehabilitate Matjes River Rock Shelter and also to obtain additional information on the stratigraphy, dating and contents of the deposits (Döckel 1998).

Archaeology and antiquity of the site

The archaeological deposits at Matjes River Rock Shelter were about 11m deep. Louw (1960) recognised five stratigraphic layers, A to E, at the site. Radiocarbon dates range between approximately 3500 and 11 000 years BP; the most recent date was from the interface between Layers A and B. Two fragments of coarse pottery from Layer A indicated that surface deposits were less than 2000 years old. Layer A was relatively thin, varying in thickness from 0.3 to 2.4m. The post-2000 BP material, therefore, formed only a small proportion of the deposit at the site. We can say with some degree of certainty that the majority of the burials from the site are older than 2000 years.

Layer B consisted of 90% brown mussel (*Perna perna*) shell intermixed with unconsolidated ash. Few formal stone tools were recorded for this layer. Bone, stone, marine shell and ostrich eggshell ornaments were noted. Material of this type has been labelled as Post-Wilton at the nearby archaeological site, Nelson Bay Cave. Layer C, however, was rich in microlithic artefacts, assigned to the Wilton industry. Dates of between approximately 5500 and 7500 years BP were obtained for this layer. Work by Deacon and Döckel shows that the latter date is probably a good estimate of the beginning of deposition of Layer C. The upper date does not necessarily reflect the

end of the Wilton industry at Matjes River Rock Shelter. A gravestone, onto which two human figures were painted, was found associated with one of the graves.

Layer D was the thickest layer at about 5m. Louw (1960) initially assigned the lithic assemblage from this layer to the “Matjes River Rock Shelter variant of Smithfield A”. The stone tools recovered are typical of what would now be classified as Albany. Radiocarbon dates for this layer ranged between approximately 7500 (the Albany/Wilton interface) and 11 000 years BP. Layer D also yielded numerous shell and bone ornaments, as well as buck and other mammals.

Louw (1960) lists very few artefacts from Layer E, too small an assemblage to be assigned to any industry; this layer may in fact be the bottom of Layer D (Döckel 1998). Layer E is essentially a non-occupation horizon. The only notable find was the two human skulls, which could only have been intrusive from layer D. Although faunal remains were noted in all the layers, except Layer E, we cannot draw any definite conclusions regarding dietary preferences since the fauna was not well recorded, and much of it was discarded by the excavators.

Although excavations at the site were extensive, the lack of well-controlled excavations made the detail of the sequence difficult to interpret. This led Deacon and Döckel to undertake further excavations at the site in 1994, with the aim of gaining a better understanding of the site and correlating it with other sites in the vicinity. Their excavations, at the highest point of the deposit, extended from Louw’s Layers C through E. The younger deposits appear to have been lost due to slumping and/or erosion, at least in this part of the site.

Deacon and Döckel excavated two major stratigraphic divisions, the Top Shell Midden (TSM) and the Lower Shelly Loam (LSL). Within the two major divisions, Döckel recognised six members: EE, TSM-W, TSM-L, LSL-U, LSL-L, and LSL-C, in order from the top to the bottom of the excavation. TSM was a shell-rich deposit, which included the transition between the Wilton and Albany industries at 7400 ± 30 BP (Pta-6823); a date that is consistent with other well resolved sequences in the region. LSL included more loamy deposits with shell and ash layers. Excavation of these members exposed a number of primary occupation features such as hearths.

Analyses of the archaeological evidence revealed that Deacon and Döckel's TSM-W was the best match for Hoffmann and Meiring's Mytilus layer (Layer B) on the basis of shellfish species and abundance. The dates and artefacts, however, are equivalent to the Wilton layer (Layer C). TSM-L should correlate with Layer C on shellfish content, but is associated with an Albany rather than a Wilton industry and equates with Layer D on the artefactual content. The majority of the material excavated by Deacon and Döckel, from TSM-L to LSL-C, is associated with the Albany. At the base of the sequence, LSL-C, with a date of $10\ 660 \pm 280$ BP (Pta-6792), is essentially elastic rubble and yielded very little cultural material (Döckel 1998).

Human skeletal remains have been recorded from all layers at Matjes River Rock Shelter. Overall, the site has yielded approximately 120 human burials, both adult and juvenile, some of which have been radiocarbon dated. The dates range between ca. 2000 and 10 000 years BP (Protsch and Oberholzer 1975; Sealy and Pfeiffer 2000). The initial radiocarbon dates for human skeletal remains from Matjes River Rock Shelter, determined by Protsch and Oberholzer (1975), are not reliable, since bone

samples used in these determinations were not from single individuals, but rather mixtures of skeletal material from different skeletons. Approximately 25% of the adult skeletons have been isotopically analysed (Muller 2001, Sealy and Pfeiffer 2000) but no previous work has been carried out on the juveniles in the collection.

Layout and aims

Within the realm of dietary tracing studies, isotopic and perhaps trace element analyses of juvenile skeletons open up the possibility of characterising weaning practices through history. Breastfeeding and weaning are fundamental behavioural variables influencing both human fertility and population growth patterns. Various explanations/models have been proposed for the link between weaning age and interbirth intervals (detailed in Chapter Two). These issues are key to investigations of past demographic patterns and can be used as tools that complement archaeological investigations of prehistoric people.

Weaning is a gradual process through which infant diets are transformed from breastmilk to other foods. This transition is sometimes abrupt (see Chapter Two for the example of N^oisa), but more often, its duration is extended in comparison to sedentary, agricultural populations. Chapter Two is a synopsis of ethnographic information on breastfeeding practices, interbirth spacing and fertility in the recent past and present among primarily African foraging societies.

Chapter Three gives background information on stable light isotopic analysis. It presents an overview of the application of these methods to tracing human diets in different environments, and more importantly, determining weaning patterns. The

results of isotope-based weaning studies are summarised for various prehistoric and historic population groups worldwide. Chapter Four outlines the sampling strategy and gives a detailed account of the scientific methods employed to extract collagen from bone and dentine from both juvenile and adult human skeletons from the Matjes River Rock Shelter collection. The results of analyses are reported and interpreted in Chapter Five. Chapter Six contains the discussion and conclusions.

In this thesis, I will attempt to establish a weaning pattern for southern African hunter-gatherer children through stable light isotopic analysis. The skeletal material will be drawn from the extensive Later Stone Age collection recovered from the Matjes River Rock Shelter. The findings of this study will be compared to those from ethnographic studies of southern African hunter-gatherers. In so doing, I will investigate how applicable the ethnographically documented patterns are to hunter-gatherers in different historical and ecological settings.

CHAPTER TWO

LACTATION, WEANING, BIRTHSPACING AND DEMOGRAPHY

Introduction

Unlike the situation in modern societies, breastfeeding in prehistory was not an option, but rather compulsory. The lack of breastmilk substitutes, especially among hunter-gatherers, meant that prehistoric human infants had to be breastfed in order to survive. Scientists today are interested in the effects of breastfeeding on issues such as the causes of infant mortality, the duration of the process of weaning, and hence age at weaning in different societies around the world, with implications for birth spacing and the demographic structure of past communities.

Breastmilk - composition and benefits

Breastmilk is generally regarded as the best food for infants. Its importance in assuring the survival of infants is demonstrated in the history of infant feeding practices. Early attempts to find a suitable substitute focused on the source of nutrients and led to the use of milk from other mammals. Infants who were fed milk other than breastmilk in the first few weeks of life very rarely survived and wet nurses were essential in ensuring survival of infants whose mothers could not or would not nurse.

One of the first studies of the composition of human milk took place in 1885 and was carried out by AV Meigs. He found human milk to comprise 1% protein, 4.7% fat and 6.2% sugar (Barnes 1987). The composition of breastmilk varies among individuals

and is dependent on factors including stage of lactation, time of day, time into feeding, and maternal diet (Smith 1998). Overall, human milk has a low protein concentration compared with other milks; it has an unsaturated fatty acid component, and almost all of the carbohydrate present is lactose, a sugar. The initial discovery of these data led to the introduction of synthetic milk adapted (SMA) formula 30 years later (Barness 1987).

Later studies have revealed that the total quantity of nitrogen in human breastmilk is greater than initially thought, comprising not only protein-derived but also non-protein nitrogen. There is evidence that as much as 50% of total nitrogen in breastmilk may occur in the form of urea (Nóbrega 1996). High levels of total nitrogen and non-protein nitrogen occur in colostrum due to the increased presence of immunoglobulins, which play an important role in the protection against infections in newborn infants.

All human babies receive immunological coverage *in utero*. During pregnancy antibodies are passed via the placenta from mother to foetus. These proteins remain in the infant's circulatory system for a few weeks to months after birth. The antibodies, other proteins and immune cells in human milk offer breastfeeding infants extra protection. Human milk plays an active role in preventing disease in newborns. Breastfeeding thus mitigates infant morbidity and mortality. This is beneficial during the first few months of life when an infant's underdeveloped immune system cannot effectively respond to foreign organisms. A child's immune system is fully developed only at approximately five years of age (Newman 1995).

The use of human milk for infant feeding is beneficial to both mother and infant; besides the psychological advantages, the biological and health benefits are numerous. Infant feeding is classified into three categories, i.e. exclusive or complete breastfeeding: where the infant is fed on demand; partial breastfeeding: a mixed diet of breastmilk and supplementary foods; and exclusive or complete artificial feeding: milk other than human breastmilk.

Infants who are exclusively breastfed for the first six months of life suffer less often and less severely from many diseases. In general, these infants have a greater overall chance of survival than do infants on any other feeding regime. The type of feeding pattern has an impact on a wide range of diseases from acute diseases such as otitis media (inflammation in the middle ear), pneumonia, diarrhoea, cholera and meningitis to chronic conditions such as allergies, inflammatory bowel disease, diabetes, atherosclerosis and even cancer (Stuart-MacAdam 1995).

There are health benefits for the breastfeeding mother. One such benefit is the increase in levels of oxytocin during breastfeeding that results in more rapid uterine involution and less post-partum bleeding. Another consequence, which has some bearing on this project, is lactational amenorrhoea and the subsequent delayed resumption of ovulation. Hence the duration of breastfeeding influences interbirth spacing: exclusive breastfeeding offers 98% protection against pregnancy in the first six months after childbirth (Vitzthum 1994). The biological mechanism will be dealt with next.

Physiology of menstruation

Before looking at the role of hormones in the suppression of ovulation in lactating mothers, their respective roles have to be looked at within the menstrual cycle, which is under control of ovarian and pituitary hormones (for further details on the information to follow, see Ferin *et al.* 1993). These hormones trigger the development and maturation of the follicle in the ovary and the onset of menstruation itself. Gonadotropin Releasing Hormone (GnRH) is one such hormone that normally pulsates to a set rhythm. During a normal menstrual cycle GnRH is responsible for the release of pituitary hormones, namely Luteinising Hormone (LH) and Follicle-stimulating Hormone (FSH). Interaction of LH and FSH with oestrogens and progesterone from the ovaries regulates the menstrual cycle. Under normal circumstances, this cycle occurs every month from puberty until menopause, the end of a woman's reproductive life.

FSH stimulates the ovaries in order to begin the process of follicle development. This hormone triggers the growth of multiple ovarian follicles with one of these ova developing further than the rest, secreting increasing amounts of oestrogen (in the form of oestradiol) into the circulatory system. The release of oestrogen signals the other follicles to cease further development of ova. When oestradiol is released, there is a decrease in the general amount of oestrogen, and the pituitary no longer releases FSH. No further development of ova takes place. At approximately 14 days after the beginning of menses LH, which is necessary for the rupture of the follicle and subsequent ovulation, is secreted in large amounts.

Breastfeeding and the suppression of ovulation

A disruption in the rhythm of the release of these hormones clearly has an effect on the menstrual cycle. During breastfeeding, the normal pulsation of GnRH is disrupted, its function is impeded and the pulsation of FSH and LH becomes sporadic, confusing the signals normally sent to the follicles. The normal surge of LH levels just prior to ovulation does not occur in a breastfeeding woman, thus preventing ovulation.

Another pituitary hormone linked to lactational amenorrhoea is prolactin, also referred to as Leutotrophic Hormone (LTH). Produced throughout pregnancy as well as during lactation in response to physical stimulation of the nipple, the primary physiological role of prolactin is promoting milk production. Each time a baby suckles, the stimulation signals the hypothalamus to trigger the release of prolactin, thus sustaining milk production.

It is hypothesised that the stimulation of the nipple inhibits the release of dopamine, depressing the release of GnRH needed to trigger the pituitary gland to release FSH and LH. It however still has to be proven that the suckling stimulus impairs ovarian function. The action of prolactin is at most secondary to other hormonal pathways. There is no doubt that breastfeeding plays a major role in post-partum subfecundity.

Resumption of ovulation and return to fecundity

I will now turn to the factors influencing the time taken, after a woman has given birth, to resumption of fertility and return to fecundity. The rate is different within societies, due to personal choice, economic reasons, etc, but also differs between societies as a result of cultural and/or traditional views.

After childbirth there is a state of infertility in both breastfeeding and non-breastfeeding mothers. Breastfeeding suppresses ovarian activity resulting in amenorrhoea (i.e. the absence of menses) and infertility. This biological phenomenon is not population specific but is affected by factors including frequency of breastfeeds and the duration of feeding sessions. The likelihood of conception during lactation is thus related to infant feeding patterns. Infertility lasts for about six weeks in nonlactating mothers, while, as mentioned earlier, in lactating mothers the period of infertility is prolonged. Looking at modern populations, breastfeeding is a major force for birth control in much of the Third World. Deductions about its effect on population growth in the past can be made in order to gain an understanding of birth spacing in prehistory.

Factors that have been suggested to affect resumption of ovulation include the frequency and duration of suckling, continuation of night feeds, the introduction of supplementary foods, and maternal nutrition (see Frisch 1978). Infant feeding patterns play a vital role in the resumption of fertility, and the possibility of subsequent conception during lactation. By breastfeeding frequently and delaying the introduction of supplementary feeding, women extend the period of post-partum amenorrhoea. Although it is used as an indirect measure of ovarian function, the end of amenorrhoea does not necessarily mark a return to fertility. In the majority of lactating women, ovulation precedes first post-partum menses. However, the first ovulation after birth is rarely successful as it is sometimes accompanied by luteal dysfunction. Early “menstrual cycles” in breastfeeding women can be highly irregular, an indication of the presence of ovarian activity but without the restoration of fecundity (see Vitzthum 1994).

The study of breastfeeding as a method of child spacing is quite difficult to undertake in modern societies. Contraception is widely available to control birth interval. One group of women who breastfeed for extended periods of time and who do not use any method of artificial birth control is the Orthodox Jews. Rosner and Schulman (1990) surveyed Orthodox Jewish mothers about birth interval in relation to formula-feeding and breastfeeding experiences in the absence of birth control.

The average duration of amenorrhoea was 8.6 months, similar to the mean infant age when night feeds were stopped (8.2 months). This lends support to the theory that there is a strong correlation between night feeds and lactational amenorrhoea. Breastfeeding was stopped, on average, at 10.7 months (range from three to 36 months). The mean birth interval among breastfeeding mothers was 23.9 months, with a range from 12 to 52 months. Birth interval was calculated as length of time between the birth of the child in question and the birth of the next child. For mothers with formula-fed infants, on the other hand, the birth interval was only 15.8 months (Rosner and Schulman 1990). This provides good evidence for the correlation between breastfeeding and child spacing.

We must, however, bear in mind that the focus group of this study is a well-nourished, middle-class population and that differences in periods of lactational amenorrhoea and birth intervals are to be expected compared with subjects who are nutritionally marginal, from developing nations or from rural, low socio-economic populations. These and other factors come into play when we look at the mechanisms of population control among hunter-gatherers. Survival of hunting and gathering people depends greatly on the size of the population, as overpopulation will lead to over-

exploitation of food resources and consequently to food shortages. Child spacing, natural abortion and mortality, in addition to lower fertility due to nutritional deficiencies, all help to keep the population growth rate down (Hassan 1980, Hayden 1972).

Demography, population growth and regulation in prehistory

According to the Oxford English Dictionary (2002), demography is “that branch of anthropology which deals with the life-conditions of communities of people, as shown by statistics of births, deaths, diseases, etc.”. Essentially it is the study of populations and their size, growth rate and distribution. When looking at demography from an archaeological point of view, large inaccuracies are inevitable and the different techniques could result in varying conclusions.

Aspects of population growth are well documented in perhaps the most studied African hunter-gatherer society, the !Kung Bushmen (Lee 1968, 1972, 1980; Howell 1978, 1979). Bushman or San groups probably provide the best comparison when trying to answer questions regarding prehistoric hunter-gatherers of southern Africa. Hayden (1972) thinks that the relation between food supply and population density is the major driving force behind the maintenance of the carrying capacity of hunting and gathering societies. Factors like fertility, birth spacing, and reproductive systems are all closely connected to demography.

Nomadic hunter-gatherer societies, because of their mode of existence, do not encourage the accumulation of possessions that are not essential to everyday life. The nature of hunting and gathering societies, be they nomadic or semisedentary, is such

that most resources are shared and no person can amass resources, as this would mitigate the egalitarianism observed in these societies. When travelling, !Kung men carry all their belongings and any food they may have in skin bags hung on carrying-sticks. Children of about 3 to 6 years ride on their father's shoulders. On these long treks, the mother transports her worldly goods, sometimes including several ostrich eggshells filled with water, and any accumulated roots and berries. She also has to carry her young child if she has one. Having too many children dependent on the same mother would hinder mobility.

The manipulation of the birth interval is both natural (infertility during breastfeeding) and unnatural (infanticide). Schapera (1930) wrote about infanticide among the Bushmen as a means of mothers avoiding having to take care of two children with similar needs. He noted that mothers were determined not to have another child until the previous child was able to do without breastmilk and constant care. In the event of infanticide, the health of the infant was not taken into consideration, but rather the timing of the birth. Schapera (1930) gave evidence for this in noting that there were several people born into the group with physical defects, e.g. dwarfism.

Other biological factors, such as the timing of the onset of puberty, the effect of nutrition on fertility and natural abortion have, to varying degrees, some effect on population growth. The effects of these factors on each other and subsequently the net reproduction of a population are depicted in Figure 2.1 (Hassan 1980).

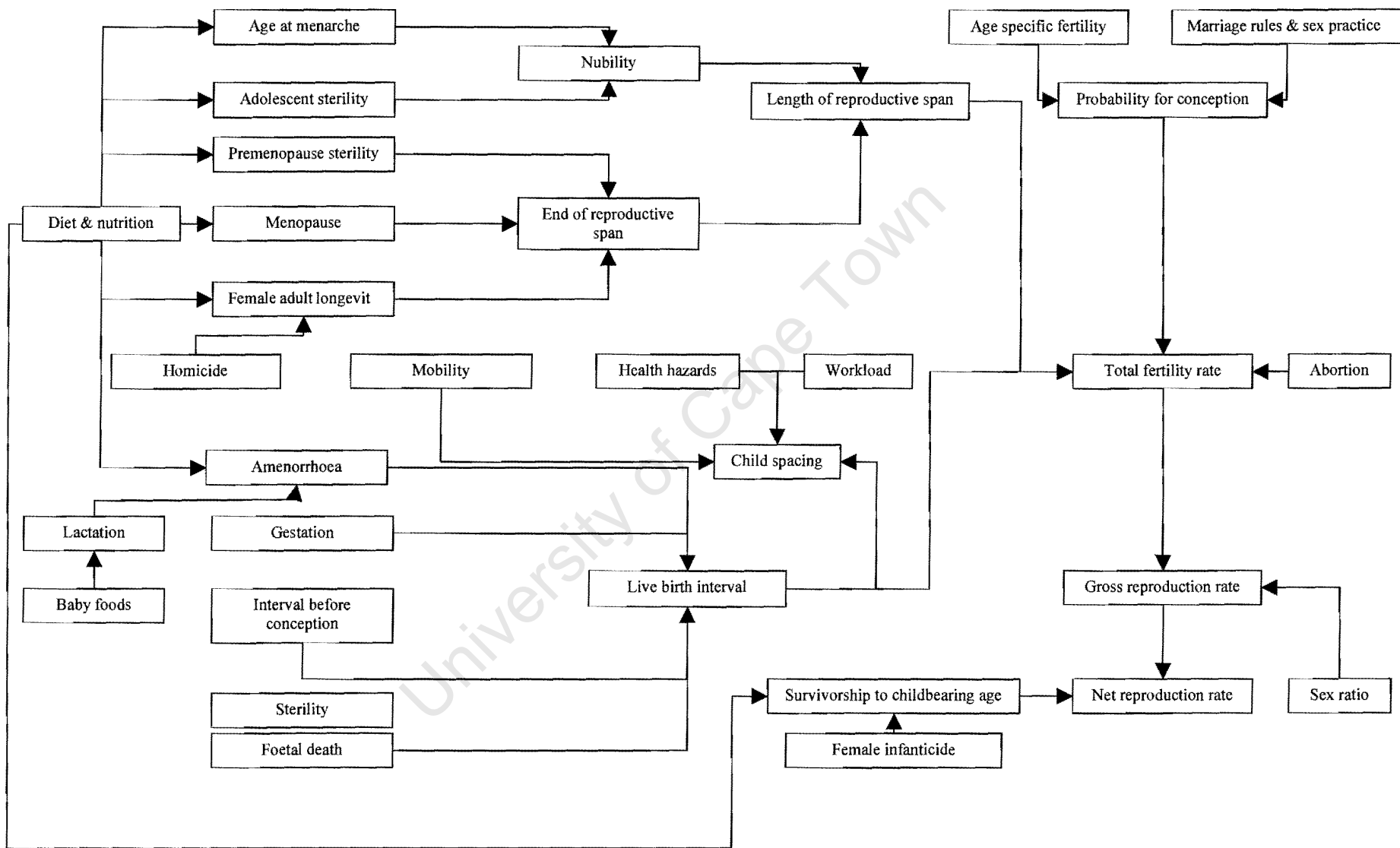


Figure 2.1: Biocultural determinants for net reproductive rate (from Hassan 1980).

The archaeological record indicates that large increases in human population coincided with the emergence of food production about 10 000 years ago. Reliance on agriculture came about because of the predictability and general reliability associated with plant and animal domestication. People were able to overcome the extreme fluctuations in the availability of wild nutritional resources, leading to an increase in the carrying capacity of the land, and ultimately an increase in birth rate, and perhaps also a decrease in death rate.

Hunting and gathering remained the primary mode of subsistence in southern Africa up to approximately 2000 years ago, when food production began to supplement, and in places replace, hunting and gathering. This shift in the modes of production invariably resulted in changes in lifestyles. One of the major changes, perhaps, was a shift towards more sedentary settlement patterns, at least among agriculturalists. Increase in population size is normally seen as societies become sedentary.

Table 2.1: Fertility in hunter-gatherers (adapted from Pennington 2001, Blurton Jones *et al.* 1992).

<i>Group</i>	<i>Lifestyle</i>	<i>Date</i>	<i>Number of women</i>	<i>Number of births</i>	<i>Total fertility rate *</i>
<i>Botswana</i>					
!Kung	Nomadic	1968	62	291	4.7
!Kung	Sedentary	1963 – 1973	166	179	4.3**
!Kung	Nomadic (Ngamiland)	1968	82	-	4.1
!Kung	Sedentary (Ghanzi)	1968	104	-	4.0
<i>Central African Republic</i>					
Aka Pygmy		1974-1984	34	-	6.2
<i>Democratic Republic of Congo</i>					
Mbuti Pygmy		1971	9	45	5.0

<i>Group</i>	<i>Lifestyle</i>	<i>Date</i>	<i>Number of women</i>	<i>Number of births</i>	<i>Total fertility rate *</i>
Efe Pygmy		1980-	89	228	2.6
<i>Tanzania</i>					
Hadza		1985	-	180	6.2
<i>Australia</i>					
Tiwi	Earlier sedentary	1952 – 1956	-	152	4.6**
Tiwi	Later sedentary	1957 – 1962	-	186	5.8**
<i>Philippines</i>					
Agta	Primarily Foragers	1950 – 1964	-	149	7.0**
Agta	Transition	1965 – 1979	-	137	6.5**
Agta	Peasants	1980 – 1994	-	169	7.6**
<i>Yukon</i>					
Kutchin	Nomadic	born before 1900	39	171	4.4
Kutchin	Sedentary	born after 1900	35	231	6.6
<i>Paraguay</i>					
Aché	Nomadic	born before 1959	167	587	8.0**
Aché	Reservation	1977-1989	-	291	8.5

* Cohort total fertility rate: measured from women who have already completed the reproductive span.

** Period fertility rate: estimated from a cross-sectional sample of women reproducing during the specified years. If fertility rates are unchanged through time, cohort fertility and period fertility rates are equal.

Table 2.1 summarises a number of studies of fertility among hunter-gatherers and people who were, until recently, hunting and gathering.

In the transition from a nomadic way of life to a sedentary one, the Kutchin settled into towns in the early 1900s, and their total fertility rate increased by 50% (Pennington 2001, Table 2.1). The Aché began settling on reservations sometime after

the 1950s, and their total fertility rate increased slightly, although it was initially high. Hill *et al.* (1987) showed that men's contribution to total Aché diet is highly significant. Quantitative observations in the 1980s indicated men provided more than 85% of total caloric intake, comprising approximately 77% meat and 8% honey. The total daily calorific intake exceeds 2700 calories per capita, making the Aché one of the best-fed foraging societies. This means that Aché women do not work as hard at foraging as, for example, !Kung women do and their free time is expended in high-quality childcare (Hill and Hurtando 1999). The high total fertility rate seen among the Aché (Table 2.1) can also be explained by the low percentage of sterility (3%) among women, the long reproductive span (from around age 20 to early 40s) and the shorter interbirth interval (approximately 38 months).

A high fertility rate during the foraging phase is also observed in the Agta. This population started moving away from foraging during the early Holocene, and modern Agta vary in the degree to which they rely upon hunting and gathering. The humid tropics may be rich in game, but poor in plant food and modern foragers are incipient horticulturalists exchanging with non-foraging people within or adjacent to the foragers' own collection ranges. Agta foragers have also for decades, possibly centuries, traded forest products (normally meat) for domesticated roots and cereal grains (among other non-food items). Women participate in hunting in regular and predictable fashion, contributing to the Agta diet. Although modern Agta consider themselves hunters, the regularity and reliability of fishing suggests that this is a basic source of food (Griffin 1984, Griffin and Griffin 1999).

The Northwest Coast area in the United States was home to hunter-gatherers who, like the Agta, subsisted primarily on a fishing economy. The high yielding, seasonally predictable resources presented the opportunity for specialised subsistence activities and aggregation of large population units (see Erlandson 1994). The archaeological evidence for this area includes permanent houses, large settlements and seasonal camps. The latter facilitated seasonal movement for the exploitation of salmon runs (Hassan 1979). The predictability of resources most likely accounts for the high density of this population ten times greater than that of the Pygmies.

The Aka Pygmies, together with the Hadza (to be discussed later), have a fertility rate at the upper end of the range for African hunter-gatherers. One of the possible contributing factors is the move to a more sedentary life. Hewlett *et al.* (1986) recorded that some Aka, the Bofi-Aka, had discarded components of their identity, moving away from a hunting and gathering way of life and taking up subsistence farming. This is in contrast to the Mbuti Pygmies who, although they exchange meat or labour for agricultural crops from villager neighbours, still depend on gathered foods. During peak season, honey provides more than 80% of calorific intake among the Mbuti (Ichikawa 1999).

Overall, the Aka Pygmies, according to Cavalli-Sforza (1986), have a potentially long reproductive span from just before 20 years old to 45 years old. The average interbirth interval is approximately 4.2 years. Turnbull (1986) mentions a sex taboo lasting for three years, the period between the birth and complete weaning of the child, which aids in explaining the long interbirth interval. This taboo has been reported for all groups of Pygmies (Cavalli-Sforza 1986). Although the Pygmies add food other than

milk (most likely moth caterpillars, snails and honey – see Bahuchet 1999) to the diets of infants fairly early, this should have little effect on the risk of pregnancy if the sex taboo is taken into account.

It is argued that sedentism led to improved ovarian function and higher fertility because of greater kilojoule intake. Buikstra *et al.* (1986) hypothesised that with the introduction of agriculture, mothers weaned their children onto alternate food sources at a younger age, and were thus able to give birth again in a shorter time interval. The ready availability of soft, palatable and digestible weaning food would have facilitated early weaning and a decrease in birth intervals (Pennington 1996). For some societies, however, fertility rates decrease after populations become sedentary, e.g. the !Kung (Table 2.1). This apparent decrease should be viewed in the context of health conditions. Pennington (2001) argues that the low fertility can best be explained by the increase in the incidences of sexually transmitted diseases (STDs) such as chlamydia and gonorrhoea. Lee (1980) noted that gonorrhoea was the major epidemic disease among the !Kung in the Dobe area, being introduced by men returning from the mines. STDs are responsible for low, and sometimes absence of fertility, causing birth rates to drop significantly. The low total fertility rate of 2.6 and the high primary sterility rate of 28% observed among the Efe Pygmies have been attributed to infectious infertility. The introduction of antibiotics to these areas reverses the negative effects STDs have on birth rates (Pennington 2001).

Why is the overall interbirth interval among hunter-gatherers relatively long in comparison to pastoralist and post-industrial societies? This can be answered from many different perspectives including economic, social, cultural and biological

aspects. In !Kung communities, women's roles are primarily two-fold: producers and reproducers. Since it is essentially the women in these societies who go out to gather, providing up to two-thirds of all food consumed by a camp (Lee 1972), practising some form of birth control would be beneficial to the entire band. Lee (1980:324) gives an overview of a !Kung adult woman's activities: subsistence work occupies two or three days of work per week. A woman walks from 3-20 km round trip on each workday, and on the return leg she carries loads of gathered food of between 7 and 15 kg.

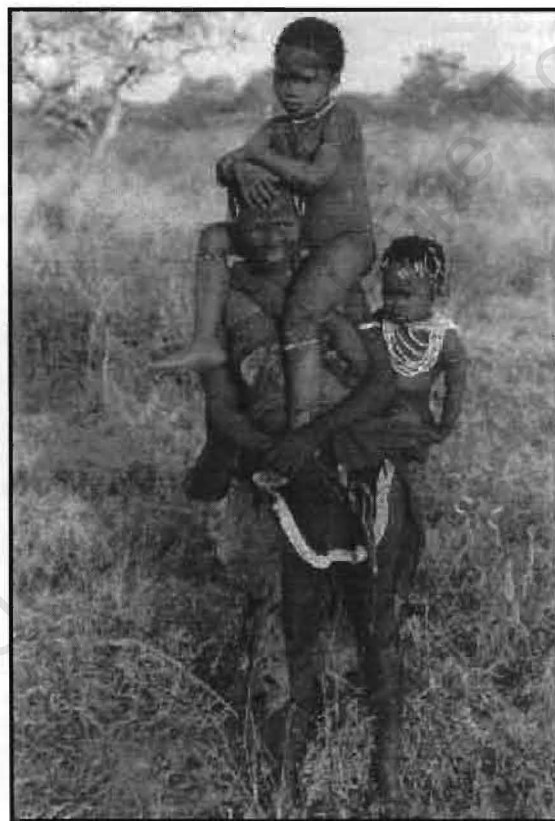


Figure 2.2: A Khuan//a woman carrying her two children (Marshall 1976).

On these trips a mother carries her baby in her kaross, and if she has an older child, she may carry him or her too on her shoulders (Figure 2.2; Marshall 1976). From this strenuous routine one can easily see why having many dependent children can impede

a woman from providing for her family. Thus several studies support the idea that long birth intervals optimise the fitness of the nomadic !Kung.

Producing and reproducing are both variables in population growth patterns and are highly dependent on each other in all societies, but especially among hunters and gatherers. Since the women are the most consistent contributors to food consumed by a camp, mobility is important to the well-being of a hunter-gatherer woman's family. If it is true that women are able to provide more efficiently for their families by spacing children far apart, hunter-gatherer women can focus their attention on one child at a time, and for a long period. This period of extended care, or long interbirth spacing (50 months) as well as a short reproductive span (from approximately 19 years to 34 years of age) among the Dobe !Kung was observed by Howell (1979). This translates into greater investment in a child and means a better chance of survival for the child.

Studies of modern !Kung populations indicate that early childhood mortality rates may decline dramatically among nomadic populations becoming sedentary. Child mortality decreased by nearly 75 percent among !Kung who became sedentary after the expansion of Herero and other farmers into their range from ca. 1950 (Howell 1979, Lee 1979). Being in such close proximity to farmers means increased access to milk and other high protein weaning foods which is most likely to be the cause of improvements in child survival.

The "Backload" model

Blurton Jones (1986) predicted that four-year interbirth intervals (IBIs) should produce more surviving offspring among !Kung women than shorter or longer IBIs.

Mothers who spaced their births more than four years would produce very few children while those producing more children, i.e. with shorter IBIs, would be more likely to lose infants to prenatal or early childhood mortality. The model was developed to predict the point at which the increased cost of the additional backload weight caused by shorter IBIs became greater than the gain in reproductive success in larger families. Stated differently, the weight, i.e. weight of both the child and the gathered foods, carried on foraging trips increased significantly as the IBI decreased from the normal four years. Using data provided by Howell (1979), Blurton Jones (1986) examined the rates of survival of pairs of !Kung children born to bush-living mothers by IBIs. Cases in which both children reached an age of ten years were classified as “successes”, and those in which either child died before ten years were regarded as “failures”. He found lower success rates associated with short IBIs and vice versa. Interpretation of these data showed that expected offspring yields increased as IBIs increased from two to four years, declined for IBIs of five years, peaked for IBIs of six years, and then declined again as IBIs rose to greater than six years. Blurton Jones concluded that IBIs of ca. four years optimise the fitness of !Kung women, providing evidence for the backload model as well as support for the belief that the !Kung have a naturally low fertility (Blurton Jones 1986).

Pennington and Harpending (1988) tested this model by examining sample groups similar to the one on which Blurton Jones (1986) had focused. One group consisted of post-reproductive !Kung living throughout Ngamiland district (which includes Dobe). The second group were post-reproductive !Kung settled on cattle ranches in the Ghanzi district. Pennington and Harpending expected child mortality rates to increase as family sizes increased and that women with a markedly high number of births

would have fewer surviving offspring than women with fewer births. Also, as per the Backload model, reproductive success was expected to peak among women giving birth to a total of four children in their lifetime. Neither of these predictions proved to be true. For both populations the survival rate of children born into large families was similar to that of those born into smaller ones, and therefore the number of offspring reaching reproductive age increased as family size increased (Pennington and Harpending 1988).

Lactation and reproductive function

Konner and Worthman (1980) present evidence for suppressed reproductive function in lactating !Kung women. The study reports a correlation between nursing patterns and the suppression of reproductive function. This work has been cited as explaining the long IBIs in !Kung.

Nursing patterns of 17 women were examined and the levels of oestradiol and progesterone were measured in 16 of the subjects. The women nursed about four times an hour with the interval between nursing bouts increasing with the age of the infant. No systematic observations were made at night. During interviews, 20 out of 21 nursing mothers with infants as old as three years reported that they were nursing at least once each night. The levels of oestradiol and progesterone increased with age of the child, indicating the gradual resumption of menstrual cycles. Taking into account nutritional infertility and prenatal infant mortality, Konner and Worthman (1980) suggested that the sum of these effects, including suppressed reproductive function, lengthens the birth interval to more than three years and solves the puzzle of !Kung birth spacing. A flaw in this study is that the authors did not report the ages of

children whose mothers were amenorrhoeic, and the duration of lactational suppression of fertility in !Kung was not clearly examined. Pennington (2001) states that, at best, the study correlates nursing behaviour with about two years of lactational infertility. This, by itself, is insufficient to account for the four-year IBI.

Nomadic and sedentary !Kung women – is there a difference in fertility?

Howell (1979) and Lee (1979) have investigated whether there is a difference between the fertility of nomadic versus sedentary !Kung women. The women were classified as “nomadic” or “sedentary” by the extent to which they were dependent on either bush or cattlepost foods.

Lee measured the mean time between births among women who had at least one completed birth interval for the duration of his fieldwork (1963-1973). He found that the active/ “more nomadic” women had IBIs of 44 months. The IBIs of the sedentary/ “less nomadic” women were eight months shorter. Lee concluded that there were higher birth rates among sedentary women due to relaxed constraints on reproduction. This comparison did not, however, include women with IBIs incomplete at the time of the study. Women with long IBIs were automatically excluded and therefore, the true IBI of both groups was underestimated. As a result the study may not conclusively show whether bush-living and cattlepost !Kung have different IBIs. Howell pointed out that birth rates may have increased simply because it is easier to raise children close to the cattleposts.

Howell (1979), on the other hand, found the differences between bush- versus cattlepost-dependent women to be small, if present at all. Classifying the women as

being either 'bush thin', 'bush fat', 'cattlepost thin', or 'cattlepost fat', she showed that the number of women giving birth 50 months later is similar in all four groups.

The Hadza – a comparable population of hunter-gatherers?

Blurton Jones *et al.* (1992) examined the demography of East African Hadza. During the past 60 years, and especially since the mid 1960s, various segments of the Hadza population have been encouraged to abandon foraging in favour of pastoralism. Some Hadza have managed to avoid settlement and retain their land. They continue to live as hunter-gatherers, and food is obtained relatively easily. Here, nutritional status is high by East African standards (Kaare and Woodburn 1999).

The Hadza of the southwest district of Tli'ika have a varied diet based mainly on wild resources (95% of food is obtained through hunting and gathering), primarily meat, honey, fruit and tubers. In their study Hawkes *et al.* (1997) noted that the relative importance of different foods varied greatly within and between seasons. Small quantities of maize, millet and tobacco were occasionally acquired as gifts or in exchange for dried meat.

Hadza living near farmers are exposed to alternate nutritional resources. In exchange for guarding crops against wild animals (which also affords excellent hunting opportunities), Hadza are allowed a share of the crop. Blurton Jones *et al.* (1992) pointed out that although Hadza territory had been encroached upon, with marked destruction of trees, berry bushes and wildlife, this had little effect on fertility and survivorship.

The Blurton Jones *et al.* (1992) study reported on a suite of demographic measures including total population size and rate of change since 1967, and compared these data with that for surrounding non-Hadza and !Kung. In their discussion, they suggested that Hadza fertility is higher than !Kung fertility. Hadza total fertility rate averaged 6.2 compared to the !Kung rate of 4.7. The Hadza rate is similar to that of many traditional agricultural populations. In their comparison of the 1985 Hadza data with Howell's figures for the !Kung, Blurton Jones *et al.* (1992), showed that the age distribution of the Hadza population is significantly different from that of the !Kung (Table 2.2, Kolmogorov-Smirnov, $p < 0.01$). The Hadza population is younger, and also has a very much higher density and higher rate of increase.

Table 2.2: Percentage below each age point for Hadza and !Kung populations in 1985 and 1979, respectively (adapted from Blurton Jones *et al.* 1992).

<i>Age (year)</i>	<i>Hadza (1985)</i>	<i>!Kung (1979)</i>
5	15.9	11.8
10	27.7	21.9
15	39.1	31.5
20	48.6	40.6
25	57.2	49.2
30	64.0	57.2
35	70.7	64.5
40	76.2	71.2
45	80.7	77.3
50	84.4	82.8
55	88.2	87.6
60	91.2	91.6
65	94.6	94.9
70	97.4	97.3
70+	100	100

The explanation offered for the higher fertility in Hadza is that they have more food and do not have to work as hard as the !Kung to obtain it. Hawkes *et al.* (1997) offer the “Grandmother Hypothesis” as one of the explanations for increased fertility. Their

study focuses on the relationship between women's time allocation and children's nutritional welfare. The label "grandmother" in this instance is based on behavioural criteria, i.e. senior women who consistently feed, tend and support the children of younger women. Hawkes *et al.* (1997) documented the mother's role in provisioning weaned offspring, assessed the effect of a new baby on the mother's continuing support of those children, and described the grandmothers' complementary role in feeding them. Using statistical analysis on the observations made during the study, they illustrate that grandmothers offset the initial reduction in the amount of time a nursing mother spends foraging by foraging more when the new grandchild is youngest. The high returns from foraging by grandmothers and sharing also allow older women to support weaned children, enabling their adult daughters to allocate more effort and attention to the next baby. Having more food thus leads to shorter birth intervals and greater infant survival. Blurton Jones *et al.* (1992) also addressed the issue of mortality levels after infancy in the Hadza and conclude that these are comparable with those of !Kung. Blurton Jones *et al.* (1992) also claim that Hadza women have a longer span of reproduction in comparison to !Kung women.

Harpending (1994) offered another explanation for the lower fertility rates seen in !Kung. He suggested that infectious infertility in the !Kung is a better explanation even though their primary sterility rate (the fraction of women who have never produced a live birth) is low. Harpending claims that primary sterility rate is a poor measure of infectious infertility. Exposure to infection can begin well before a woman becomes fecund while exposure to pregnancy can hardly precede exposure to venereal infertility. The mean length of reproductive span is a better indicator, and Harpending notes the relatively short reproductive spans of !Kung women (19 to 34 years,

according to Howell 1979). He states that the prominent features of !Kung demography, like low fertility and apparent long birth intervals, can be explained as the effects of the same venereal infertility that has affected their neighbours around the Okavango Delta in Botswana. Blurton Jones *et al.* (1992) rejected the hypothesis that !Kung demography is significantly affected by venereal infertility. They claimed that venereal infertility does not have a substantial influence since the level of primary sterility is relatively low, about 10% reported for the !Kung by Howell (1979).

Kenya's Mukogodo – hunters in transition

The Mukogodo people inhabit north-central Kenya. Before the 1900s they lived in caves and had a diet consisting of wild animals, plants and honey, from both wild and man-made hives. The population totalled approximately 200. After the 1900s the Mukogodo began to keep cattle, sheep and goats, but honey continues to play an important role in their diet. Keeping livestock meant moving from caves to settlements. Since they are pastoralists, milk is available as a weaning food. This should enable mothers to nurse for shorter periods. However, children are not weaned until they are at least two years old.

Although Mukogodo women do not work as hard as !Kung women to collect food, they still have to gather firewood. This workload might be expected to have the same effect on the birth interval as foraging is thought have on !Kung women. Since pastoralist settlements are generally larger, mothers co-operate in childcare, relieving the foraging mother of the extra weight to carry. This would in theory eliminate the backload effect.

Cronk (1989) looked briefly at fertility rates in the Mukogodo population. He reported that Mukogodo women gave implausibly small numbers for infant and childhood deaths. Although the estimated total fertility rate of 6.9 is at the high end of the range for modern hunter-gatherers, Cronk concluded that this figure is not high enough to claim that Mukogodo fertility or child survivorship increased after the transition to pastoralism. This study is a good example of the limitations of demographic anthropology among small-scale populations, which include the under-reporting of births and deaths, difficulty in estimating the age of participants, and ensuring general accuracy of data.

Summary

The total fertility rates for the sample of nomadic hunter-gatherers in Table 2.1 range from 2.6 to 8.0. The highest birth rates occur among the Aché women of Paraguay who have an average of eight births. Post-reproductive Efe Pygmy women in the Democratic Republic of Congo gave birth to only 2.6 children in their lifetimes. At 6.2 the Hadza and the Aka Pygmy have the highest total fertility rate for African hunter-gatherers.

There is a statistically significant increase in the birth rates of the Agta, Kutchin, and Aché after they become sedentary. It therefore appears that these figures support the belief that hunter-gatherers have lower fertility than their settled, food-producing counterparts due to the limitations of foraging. The relaxation of these constraints should lower the age of reproduction, reduce birth spacing, and increase overall fertility.

Comparisons of birth rates in more nomadic !Kung with less nomadic have produced ambiguous results. Some authors have argued that there has been an increase in fertility among sedentary women who live near cattleposts. Others have observed no difference between the fertility rates in sedentary and nomadic women.

It has been proposed that fertility rates among contemporary hunting and gathering societies have been adversely affected by the introduction of sexually transmitted diseases (STDs). Lower fertility rates and shortened span of reproduction can be attributed to infectious infertility. Although some authors have rejected this theory, there has been an increase in the occurrence of STDs with the introduction of these diseases by men returning from the mines. This has also been observed with the migration of the Herero and other pastoralists to the Dobe region. Historically, the importance of STDs in fertility reduction is relatively unknown. STDs are, however, likely to be more of a problem in recent times, due to increased mobility and the marginal socio-economic status of former hunter-gatherers. The long interbirth interval in the past is more likely to have been because of the extended period of breastfeeding. This has been widely observed and documented, not only among the !Kung, but also in other hunting and gathering groups (e.g. Pygmies).

A first hand recollection of weaning is provided by N \neq isa, a !Kung woman whose memories of the various stages of her life were recorded by Marjorie Shostak (1990). N \neq isa recalls the abrupt and traumatic end to her nursing. Since the !Kung believe that a child should be completely weaned as soon as the mother realises she is pregnant again, N \neq isa experienced a difficult weaning when her mother fell pregnant. It is thought that the milk in the breast belongs to the foetus, and if the older child

continues to nurse, the health of either the nursing child or the foetus may be endangered. Late weaning (three to four years) makes it possible for some of the feelings associated with weaning to be remembered later in life. Schapera also recorded prolonged nursing among northwestern San groups as far back as 1930.

!Kung women believe that Bushman children should have strong legs, and a diet of mother's milk is the way to achieve this. They are also of the opinion that a child needs milk until it is at least three or four years old. Nomadic !Kung, not in regular contact with farmers, have no milk from cows or goats, neither do they have cereals on to which an infant can be weaned. Even if mothers supplement babies' diets by chewing tough meat, roots, and nuts and feeding the infant pre-masticated food (as observed by Marshall 1976), they cannot support two infants in this fashion. Neither thrives, and both may even die. It is therefore in the best interests of the infant for the mother to breastfeed the child for as long as possible, thereby lengthening the interbirth interval.

Drawing from the data available for hunting and gathering societies, it appears that foragers do in fact have extended interbirth spacings compared to settled, agriculturalist populations. Factors such as age of menarche and the age at cessation of fertility also contribute to the regulation of the birth rate. Among Bushmen women, age at menarche is approximately 16 years, with fertility decreasing between 35 and 40 years (Howell 1979). The reproductive spans in women from farming populations tend to be longer. Within the limits of demographic anthropological studies, the established evidence for extended interbirth spacing among hunting and gathering societies is sufficient to conclude that this pattern is most likely a general one. As

Figure 2.1 illustrates, the factors affecting the net reproductive rate are numerous, and more often than not linked, and cannot be examined individually.

We can work with the archaeological evidence to establish estimated interbirth spacings for past hunting and gathering societies, in order to gain a better understanding of demography in the past. Previous studies have employed chemical techniques in order to establish the age at weaning, with implications for interbirth intervals for societies in different temporal, spatial and ecological settings. The scientific background to these studies, and an overview of the literature on determination of weaning age will be addressed in the following chapter.

University of Cape Town

CHAPTER THREE

SKELETAL TISSUES, STABLE ISOTOPES AND DIETARY TRACING

Introduction

In the living body, the skeletal system consists of bone, cartilage, and other connective tissues that are alive and respond to their environment. Therefore their cells need nutrients and oxygen in order to function. Our skeletons serve as records of age, traumatic injury, habitual muscular usage and also nutritional and health status. In a similar fashion, teeth contain information about diet and health, and play an important function in palaeoanthropological and palaeodietary studies.

Growth and composition of bone and teeth

Growth of bone

Formation of the skeleton begins early in foetal life (Scheuer 2000, Solomon 1992). During foetal development, bone forms, or ossifies, in two ways. The long bones develop from cartilage (endochondral bone development), while bones of the cranium and vertebral column develop from a non-cartilage connective tissue (intramembranous bone development). Bone tissue may be compact or cancellous (also known as trabecular or spongy) bone. Compact bone is very dense and is found in the diaphyses of long-bones, and near the surfaces of other bony elements. Cancellous bone is found within the epiphyses of long-bones, in vertebrae, etc.

As a bone develops, it increases in length and width, but its shape also alters to accommodate the changing stresses placed upon it during growth. Remodelling

involves the resorption of bone formed at an earlier stage and its replacement with new bone. It serves to repair bone by the elimination of microscopic damage but does not necessarily alter overall size and shape. It is episodic and occurs throughout life. Rates of remodelling vary according to age and type of bone (i.e. compact or cancellous). Compact bones turn over more slowly and contain tissue laid down over a long period. Cancellous bone comprises a greater proportion of tissue from the later stages in life.

Organic and inorganic components of bone

Bone is a complex tissue with three components: water, an organic matrix, and an inorganic mineral fraction closely bound to the organic phase. The organic component makes up approximately 20-25% of the dry weight of bone. Bone producing cells, or osteoblasts, secrete collagen, which accounts for 90% of the organic phase. Approximately 5% of the organic phase comprises noncollagenous proteins, and less than 5% is a combination of lipids and carbohydrates (Boskey and Posner 1984). The source of carbon and nitrogen incorporated into bone collagen is a complex issue and is being debated. It seems, however, that carbohydrate, protein, and lipids can all provide carbon for tissue synthesis, while only protein can supply nitrogen. Collagen has a characteristic spectrum of some 20 different amino acids. Each collagen chain comprises approximately 1000 amino acid residues, over 30% of which are glycine. The atom-to-atom ratio of carbon to nitrogen (C:N) in modern and well-preserved collagen is about 3.2 (DeNiro 1985, Ambrose 1993).

The inorganic component makes up approximately 70% of the dry weight of bone. 95% of the mineral phase is comprised of a complex calcium phosphate in the form of

hydroxyapatite (commonly referred to as apatite), and approximates the formula $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$. Apatite crystallises around collagen; it forms the hard matrix of bone and contains carbon in the form of carbonate ions. Carbonate in bone apatite occurs in two forms: adsorbed carbonate occurs on the crystal surface, and structural carbonate is substituted in the phosphate position in the crystalline structure (Lee-Thorp 1989). Bone carbonate is chemically and isotopically equilibrated with blood CO_2 , which is in turn derived from the oxidation of glucose and fats.

Growth and composition of teeth

All teeth follow a basic, predictable pattern of growth: formation, calcification, completion of the crown, eruption and completion of the roots, with negligible variation in timing between and within various populations (F. Grine pers comm.). Deciduous teeth begin to form at about six weeks *in utero*, and the last permanent tooth does not reach completion until early adult life (Hillson 1986). The development and maturation of both sets of teeth span almost the entire juvenile life. Teeth are therefore one of the most accurate indicators of age at death, especially in juveniles.

By birth, all the teeth of the deciduous dentition and the first permanent molars have started to mineralise. By about three years old, the deciduous dentition has fully erupted and the roots have completely formed (see Fig. 3.1 and Table 3.1), and between the ages of two and four years, mineralisation in the premolars and second molars has started. The third molars begin to form between six and 12 years of age (Hillson 1986, Scheuer 2000, van Beek 1983).

Table 3.1: Chronology of deciduous and permanent dentition (adapted from van Beek 1983 for teeth sampled for this thesis).

<i>Tooth</i>	<i>Initial calcification</i>	<i>Completion of crown</i>	<i>Completion of roots</i>
<i>Deciduous dentition</i>			
Maxillary/mandibular canine	5 months <i>in utero</i>	9 months*	2.5 – 3 years*
Maxillary/mandibular first molar	5 months <i>in utero</i>	6 months	2 – 2.5 years
Maxillary/mandibular second molar	6 months <i>in utero</i>	10 – 12 months	3 years
<i>Permanent dentition</i>			
Maxillary second incisor	10 – 12 months	4 – 5 years	11 years
Mandibular second incisor	3 – 4 months	4 – 5 years	10 years
Maxillary canine	4 – 5 months	6 – 7 years	13 – 15 years
Mandibular canine	4 – 5 months	6 – 7 years	12 – 14 years
Maxillary first premolar	18 – 21 months	5 – 6 years	12 – 13 years
Mandibular first premolar	21 – 24 months	5 – 6 years	12 – 13 years
Maxillary first molar	Birth or slightly before	2.5 – 3 years	9 – 10 years
Mandibular first molar	Birth or slightly before	2.5 – 3 years	9 – 10 years
Maxillary second molar	2.5 – 3 years	7 – 8 years	14 – 16 years
Mandibular second molar	2.5 – 3 years	7 – 8 years	15 – 16 years
Maxillary third molar	7 – 9 years	12 – 16 years	18 – 25 years
Mandibular third molar	8 – 10 years	12 – 16 years	18 – 25 years

* indicates months and years after birth

The chemical make-up of teeth and bones is similar, but they differ in their respective histories of formation. The dental hard tissues, namely enamel, dentine, and cementum lack a blood supply and are not continually turned over, as is bone. Enamel, which forms in childhood, is composed mainly of hydroxyapatite, with very little protein. Dentine is composed of about 75% inorganic material (primarily hydroxyapatite) and between 17.5 and 18.5 weight percent collagen (Hillson 1986). Dentine is formed mostly during childhood in a progressive manner from the crown towards the root. It is not modified much after deposition, although small quantities of

secondary dentine are deposited in adulthood. Damage caused by attrition or caries results in the deposition of tertiary dentine.

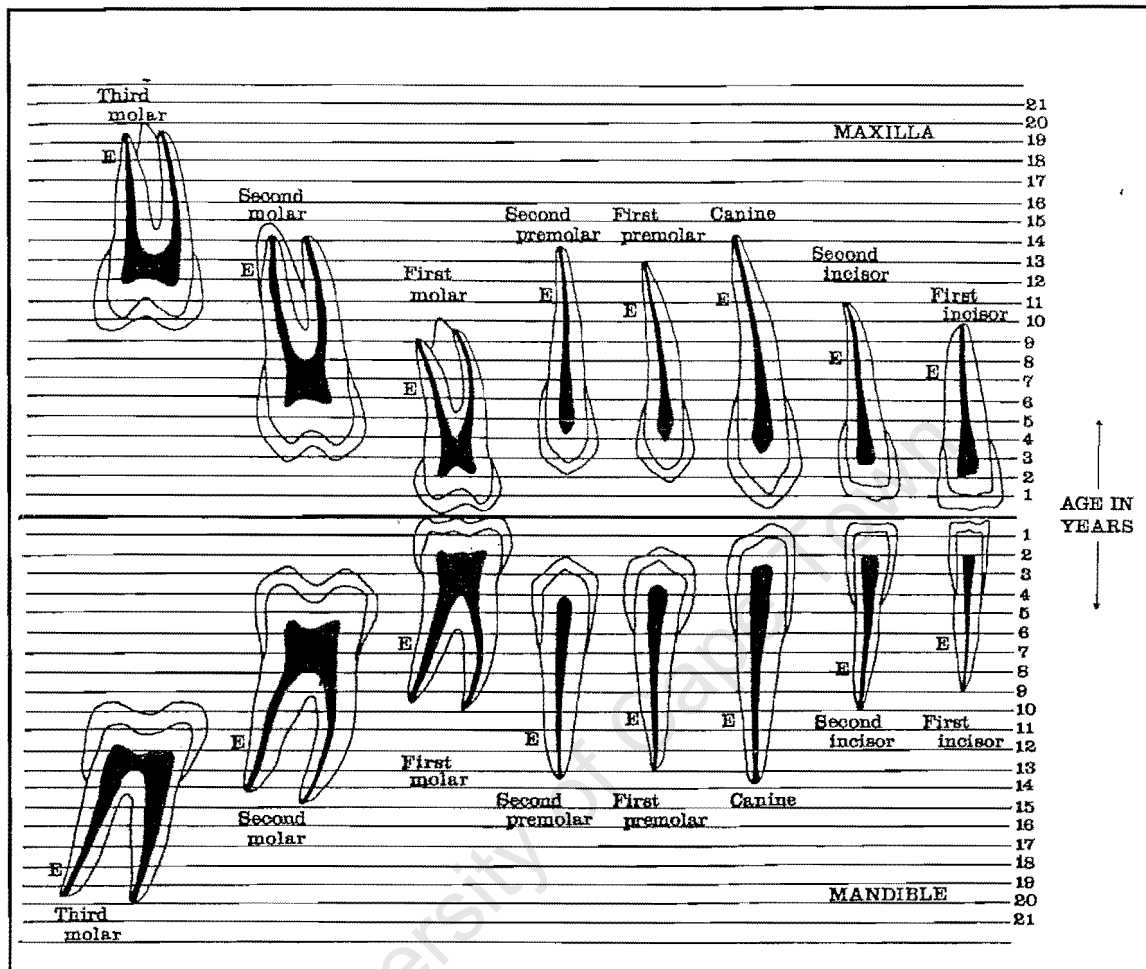


Figure 3.1: Chronology of the development of the permanent teeth. E denotes approximate age at eruption (from Mays 1998).

Stable isotopes

Introduction

Atoms of a chemical element with the same number of protons, but different numbers of neutrons are known as isotopes. Unlike radioactive isotopes, stable isotopes do not transmute into other elements. Biologically important elements such as hydrogen (H), carbon (C), nitrogen (N), sulphur (S), and oxygen (O) occur in different isotopic forms. For example, carbon occurs as ^{12}C , ^{13}C and ^{14}C with relative abundances of

98.9%, 1.1%, and $10^{-10}\%$, respectively. The alteration of the ratio of isotopes is known as fractionation, and occurs when different isotopes of the same element are separated out due to differentiation caused by physical and chemical reactions. These variations are predictable and occur in a patterned way in nature (Ehleringer and Rundel 1989).

The isotopic composition of a sample is determined by measuring the ratio of the two stable isotopes present in the sample. It has been established that measuring the absolute isotopic composition is not as reliable and/or convenient as measuring isotopic differences between a sample and a given standard. While obtaining high precision in absolute isotopic composition of a sample is not difficult over the short term, it is very difficult over the long term. However, by measuring the differences between a defined standard and sample it is possible to achieve high precision and repeatability over both short- and long-term periods. This differential approach also allows miniscule differences in the isotopic composition of two samples to be accurately and reliably determined (Ehleringer and Rundel 1989). By convention isotopic composition of a sample is expressed in the delta (δ) notation, compared to a standard:

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

where $\delta X_{\text{standard}}$ is the isotope ratio in delta units relative to a standard, and R_{sample} and R_{standard} are the absolute ratios of, for example, ^{15}N to ^{14}N of the sample and standard respectively. Multiplying by 1000 allows the values to be expressed in parts per thousand (‰), or per mil (Ehleringer and Rundel 1989). For nitrogen isotopes, the

international standard is atmospheric nitrogen. The standard for carbon isotopes is a Peedee Belemnite marine carbonate fossil, referred to as PDB.

Nitrogen isotopes

More than 99% of the known nitrogen on or near the Earth's surface is present as N_2 or as dissolved N_2 in the ocean. As nitrogen occurs in various oxidation states and in gaseous, dissolved, and solid forms (N_2 , NO_3^- , NO_2^- , NH_3 , NH_4^+), nitrogen is a highly suitable element for the search for natural variations in its isotopic composition. Nitrogen consists of two stable isotopes namely ^{14}N and ^{15}N . Atmospheric nitrogen is composed of 99.64% ^{14}N and 0.36% ^{15}N . Naturally-occurring changes to the ratio of these isotopes, 0.00363, are detected only in the last digit of this number (Hoefs 1997). For nitrogen isotope ratio measurements, atmospheric N_2 is used as the standard. By definition, therefore, the $\delta^{15}N$ value of air is zero. In order to understand the nitrogen isotope distribution in the marine and terrestrial environments, it is necessary to take a brief look at the biological nitrogen cycle.

Nitrogen isotope distribution in the terrestrial environment

Microorganisms drive the major conversions in the nitrogen cycle. These conversions are divided into fixation, nitrification and denitrification (Fig. 3.2). Since most nitrogen occurs as N_2 , it must first be fixed; that is the N-N bonds must be broken and new bonds formed to oxygen or hydrogen to form inorganic compounds that plants can use. Fixation depends mainly on nitrogen-fixing organisms, i.e. aquatic blue/green algae (both freshwater and marine) and the bacterial nodules on terrestrial plant roots. This process results in synthesised tissue with $\delta^{15}N$ values close to zero (i.e. the $\delta^{15}N$ value of atmospheric N_2).

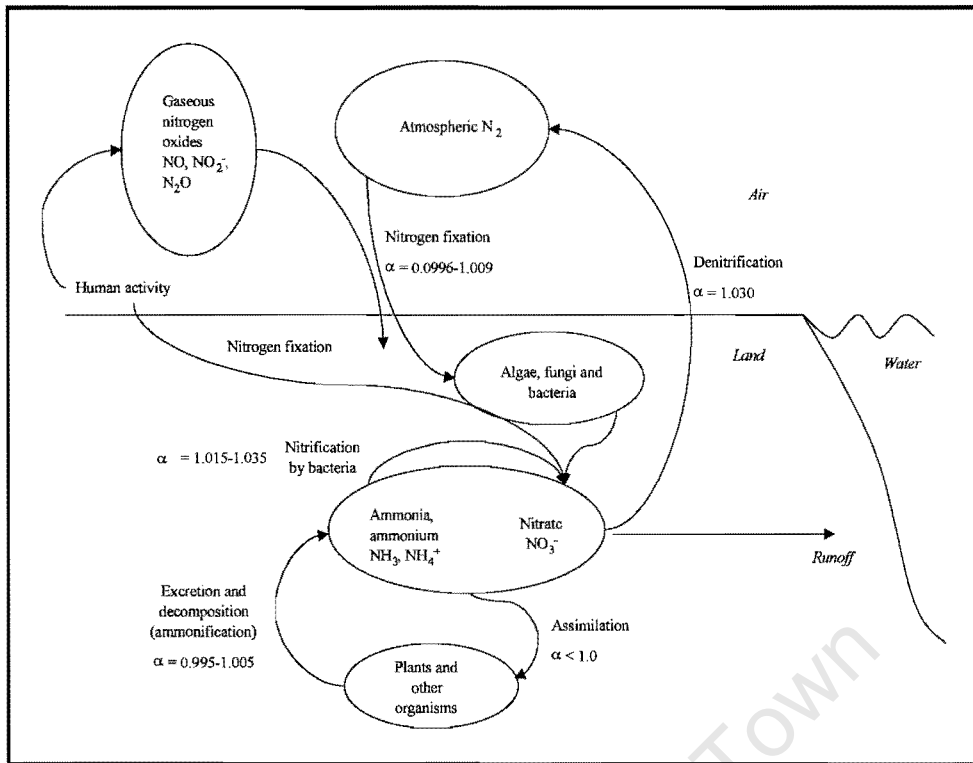


Figure 3.2: The terrestrial nitrogen cycle showing α values for the main processes, where $\alpha = 1 + (\text{initial pool } \delta^{15}\text{N} - \text{product pool } \delta^{15}\text{N}) \times 10^{-3}$; if α is greater than 1, then the product is depleted in ^{15}N relative to the source (adapted from Marion 1987).

Nitrification includes the conversion of recently-fixed nitrogen to nitrates and the bacterial breakdown of complex nitrogen molecules in organic matter following the death of organisms, resulting in the production of nitrates. These nitrates, with higher $\delta^{15}\text{N}$ values, can be used directly by non-nitrogen fixing plants. This is partly the reason for these plants having slightly more positive $\delta^{15}\text{N}$ values in comparison to N_2 -fixing plants. At the end of the cycle, denitrifying bacteria convert the inorganic forms of nitrogen in the soil back to inert N_2 gas. Thus the nitrogen cycle is necessary to make atmospheric nitrogen accessible to plants, animals and humans (Virginia and Delwiche 1982). A similar cycle exists in aquatic ecosystems, where cyanobacteria fix nitrogen.

Plants

Some plants, such as legumes, have the ability to fix nitrogen from air. Since the $\delta^{15}\text{N}$ value of atmospheric nitrogen is approximately 0‰, leguminous plants have $\delta^{15}\text{N}$ values close to zero. Other plants, i.e. non-nitrogen fixing plants take up nitrogen from the soil, and have greater $\delta^{15}\text{N}$ values than leguminous plants because the $\delta^{15}\text{N}$ value of soils are slightly positive (see Hopkins *et al.* 1992 for studies in soil nitrogen). Taking fractionation into account, these plants typically have values around 3‰ (Handley *et al.* 1998, Hoefs 1997).

Animals

Plants form the basis of the terrestrial foodchain. Most animals are dependent on plant material for survival, assimilating nitrogen from plants into their tissues. The $\delta^{15}\text{N}$ values in herbivore collagen are increased relative to the animal's diet by about 3-4‰. Nitrogen is used to synthesise tissues and also excreted in various forms of waste products. The isotopic compositions of the assimilated nitrogen and excreted nitrogen, however, differ. The form in which mammals commonly excrete nitrogen is urea, which accounts for approximately 76% of the nitrogen in urine. Since urinary urea has considerably less ^{15}N than the animal's diet, ^{15}N is retained in the animal's body so that its tissues are enriched in the heavier nitrogen isotope (Ambrose 1991). This results in the tissues of herbivores having more positive $^{15}\text{N}/^{14}\text{N}$ ratios than that in the plants upon which they feed. Herbivores that consume legumes will have lower $\delta^{15}\text{N}$ values than their non-leguminous plant-eating counterparts (Schoeninger and Moore 1992).

Organisms from higher trophic levels are further enriched in the heavier isotope, as the $\delta^{15}\text{N}$ value increases with each trophic level. The bone collagen of animals is generally enriched in ^{15}N by 3-4‰ with respect to the diet of the animal (DeNiro and Epstein 1981, Minagawa and Wada 1984, Schwarcz and Schoeninger 1991). Therefore, a further trophic level shift is seen in carnivores, which generally have $\delta^{15}\text{N}$ values between 7-9‰ (Ambrose 1991, Schoeninger *et al.* 1983, Sealy *et al.* 1987). The range of $\delta^{15}\text{N}$ values in humans depends on the relative percentages of animal- and plant-based food sources in the diet. These values are also dependent on climate as will be discussed later.

Water-stressed environments

The ranges of $\delta^{15}\text{N}$ values mentioned above are for well-watered regions. Nitrogen isotope values are however influenced by climate in arid areas. In most environments the net effect of nitrification and denitrification processes is to increase soil $\delta^{15}\text{N}$ values. Soil dryness and high temperatures inhibit soil nitrogen fixation. Thus in hot and arid environments the input of atmospheric N_2 should be low, and the soil $\delta^{15}\text{N}$ values should be high. A possible explanation for this phenomenon is the evaporative loss of ammonia from the soil, which is depleted in ^{15}N with respect to nitrate, ammonia ions and organic nitrogen species (Ambrose 1991, Schwarcz *et al.* 1999).

Higher than expected $\delta^{15}\text{N}$ values in bone collagen have been noted in areas where animals are water-stressed (Heaton *et al.* 1986, Sealy *et al.* 1987, Ambrose 1991, Schwarcz *et al.* 1999). Ambrose (1991), for example, reports that $\delta^{15}\text{N}$ values for bushbuck range from +4.4‰ in montane forest to +10.4‰ in open savanna in the Rift Valley area. In areas of low rainfall (less than 400mm per annum) terrestrial animals

suffering from water stress undergo changes in their nitrogen metabolism. These stressed animals excrete more urea, which is depleted in ^{15}N , resulting in higher $\delta^{15}\text{N}$ values in the animal's tissues. Because of this change in nitrogen metabolism, the animal appears to move up several trophic levels in the foodchain (Ambrose 1991).

Pate *et al.* (1998) have shown that the linear relationship between bone collagen $\delta^{15}\text{N}$ values and mean annual rainfall observed in Southern Africa, does not apply in South Australia. In both cases, there seems to be a critical mean annual rainfall value that is required before obvious bone collagen $\delta^{15}\text{N}$ enrichment occurs in herbivores and associated carnivores. In Southern Africa, this critical mean annual rainfall value is 400mm, but in south Australia significant bone collagen $\delta^{15}\text{N}$ enrichment does not occur until the 200-250mm rainfall zone.

Pate *et al.* (1998) reported bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values from a range of modern marsupial and eutherian mammals at four sites along the eastern border of South Australia. Collection sites included Mount Gambier, Karte, Plumbago and Innamincka. Mean annual rainfall ranges from 700-800mm at Mount Gambier to 150-175mm at Innamincka. The results for this study showed the expected enrichment of bone collagen $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ as the mean annual rainfall decreased, but only at the 200-250mm mean annual rainfall zone at the inland Plumbago site.

Table 3.2: Isotopic values for herbivores from regions with different rainfall patterns (Pate *et al.* 1998).

<i>Collection site location</i>	<i>Mean annual rainfall (mm)</i>	<i>Marsupial herbivores</i>	<i>Eutherian herbivores</i>	<i>(‰)</i>
Mount Gambier	700-800	6.3 ± 0.8	8.3 ± 1.5	$\delta^{15}\text{N}$
		-24.8 ± 0.8	-23.2 ± 1.2	$\delta^{13}\text{C}$

<i>Collection site location</i>	<i>Mean annual rainfall (mm)</i>	<i>Marsupial herbivores</i>	<i>Eutherian herbivores</i>	<i>(‰)</i>
Karte	300-400	6.3 ± 0.5	7.7 ± 0.4	δ ¹⁵ N
		-21.6 ± 0.7	-21.8 ± 0.8	δ ¹³ C
Plumbago	200-250	11.1 ± 1.0	13.4 ± 1.1	δ ¹⁵ N
		-17.6 ± 2.4	-18.9 ± 2.2	δ ¹³ C
Innamincka	150-175	12.6 ± 1.2	12.2 ± 1.2	δ ¹⁵ N
		-15.4 ± 1.2	-16.8 ± 1.5	δ ¹³ C

Nitrogen isotopes in the marine environment

Since marine resources have some bearing on this study, it is necessary to look at nitrogen isotopes in the marine system.

Approximately 70% of the earth's surface is covered by open oceans. The pool of nitrogen cycling in the ocean is larger than the terrestrial one. There is a difference in nutrient content between open oceans and near-shores, with nutrient content increasing towards shores. Nitrogen is an important element in marine systems as it is one of the limiting factors in phytoplankton production (Sprenst 1987, Probyn 1992). N₂ can be biologically reduced by N₂-fixing cyanobacteria and phytoplankton (i.e. diazotrophs). The formation of nitrate from ammonium is catalysed through a nitrite intermediate by two groups of bacteria: one group oxidizes ammonium to nitrite; the second oxidizes nitrite to nitrate (Falkowski 1997). Nitrate containing the lighter isotope is preferentially taken up by the phytoplankton. This means that phytoplankton is typically depleted in ¹⁵N relative to the nitrate substrate used for growth and the remaining nitrate pool becomes progressively enriched in ¹⁵N (Holmes 1996).

It appears that the rate of nitrate formation is so slow, and the denitrification in the ocean so rapid, that nitrogen is in short supply. Since denitrification favours ^{14}N , the lighter nitrogen isotope, to be converted into di-nitrogen (N_2), the oceans are enriched in the heavier ^{15}N . Thus denitrification is the principal mechanism keeping marine nitrogen at higher $\delta^{15}\text{N}$ values than atmospheric nitrogen (Hoefs 1997).

Another reason for the enrichment of $\delta^{15}\text{N}$ at higher trophic levels for marine systems is that when compared to the terrestrial one, the marine system has many more trophic levels. Since the 3‰ stepwise enrichment also applies to the marine system, marine animals near the top of the food chain, e.g. seals and sea lions, are markedly more positive than are terrestrial carnivores (except those from very arid areas) (see Fig. 3.3 below) (Sealy 1989, Richards and Hedges 1999). Human activity also affects levels of nitrogen in both the marine and atmospheric systems. The addition of artificial fertilizer to the soil is the main contributor to increased nitrogen levels. According to Pollard and Wilson (2001), approximately 40% of the nitrogen entering the soil each year is directly a result of human activity. Some of this influx is carried away by river flow and into the groundwater (terrestrial run-off), affecting its isotopic composition.

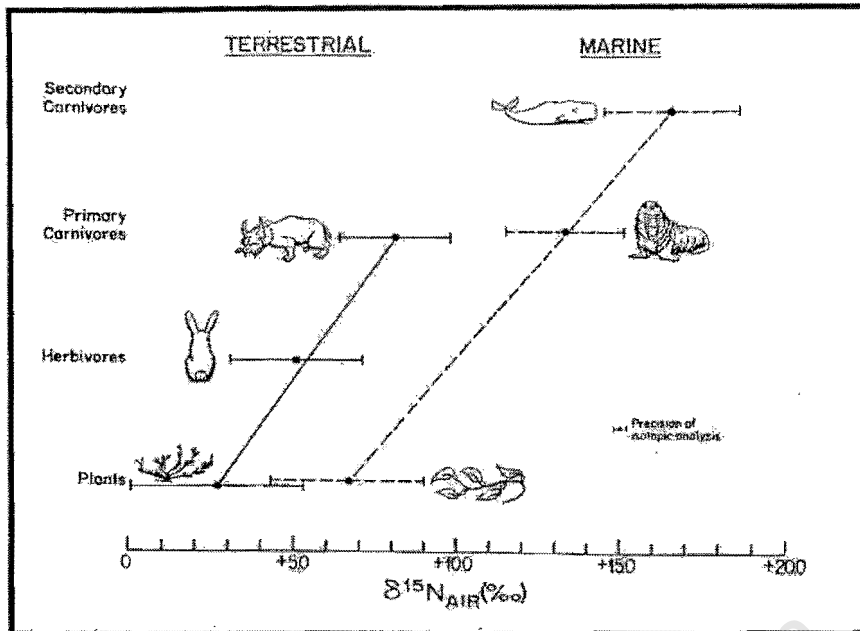


Figure 3.3: Organisms along a foodchain in both terrestrial and marine environments (from Schoeninger and DeNiro 1984). This is the “typical” situation and it should be noted that there are exceptions as in the case of arid environments and coral reefs.

In all areas receiving low rainfall, less than 400mm per annum, nitrogen isotope ratios are a potentially unreliable marine/terrestrial indicator (this will be discussed later). In low rainfall areas, carbon and/or strontium ($^{87}\text{Sr}/^{86}\text{Sr}$) isotope measurements are better tools for identifying the marine component in prehistoric diets (see Sealy 1989).

Table 3.3, adapted from Richards and Hedges (1999) is a compilation of the $\delta^{15}\text{N}$ values of modern and archaeological marine fauna from locations around the world.

Table 3.3: Average $\delta^{15}\text{N}$ values of modern and archaeological marine fauna from around the world (Richards and Hedges 1999).

<i>Class of fauna</i>	<i>Material§</i>	$\delta^{15}\text{N}$ (‰)	<i>N</i>	<i>Location</i>
Sea lions	C	18.0 ± 1.5	22	California and Peru
Seals	C	17.0 ± 2.1	13	California, Northwest Europe, and an unknown location

<i>Class of fauna</i>	<i>Material</i> §	$\delta^{15}N$ (‰)	<i>N</i>	<i>Location</i>
Whales (1)	C	16.5 ± 0.8	5	Alaska and California
Dolphins/porpoises	C	15.7 ± 0.9	12	California
Fish (1)	C	12.8 ± 2.1	3	Southern California
Fish (1)	M	14.5 ± 2.8	9	George Banks, South Africa
Whales (2)	C	13.7 ± 1.3	12	Alaska, California, South Africa
Fish (2)	C	13.4 ± 0.9	21	Southern California and Ecuador
Fish (2)	M	12.6 ± 1.9	45	George Banks and an unknown location
Cephalopods	M	12.6 ± 2.3	5	Ecuador and George Banks
Walrus	C	12.3 ± 0.2	3	Alaska and Northwest England
Fish (3)	M	11.5 ± 1.9	11	British Columbia and George Banks
Crustaceans	M	10.7 ± 2.3	14	George Banks, Ecuador, and South Africa
Shellfish	M	8.8 ± 1.3	45	Ecuador, George Banks, and South Africa and an unknown location

* Whales (1) consume mainly molluscs, arthropods and plankton, Whales (2) consume primarily fish. Fish (1) are piscivores, Fish (2) have an unknown diet, and Fish (3) are planktivores.

§ C = bone collagen, M = flesh

Carbon isotopes

Carbon in the terrestrial environment

Carbon isotopes are less important in this thesis than nitrogen isotopes, so coverage of this topic will be less detailed. Carbon isotopes are used in conjunction with nitrogen isotope measurements in human bone collagen to differentiate marine and terrestrial diet, and also to investigate the contribution of C₃ and C₄ plant foods to diet.

Plants

Nearly all natural reactions involving carbon discriminate among the three carbon isotopes ^{14}C , ^{13}C and ^{12}C . The degree of discrimination is characteristic of the particular reaction. All plants fractionate carbon during photosynthesis. Different photosynthetic pathways cause distinct changes in the carbon isotope ratios that filter through the food chain, resulting in different ratios for diets based on plants following different photosynthetic pathways.

Three photosynthetic pathways exist in the world. They are commonly referred to as the C_3 (Calvin-Benson), C_4 (Hatch-Slack) and CAM (Crassulacean Acid Metabolism) pathways. C_3 and C_4 pathways are named for the numbers of carbon atoms in the initial products of fixation. Terrestrial plants fix carbon from atmospheric carbon dioxide (CO_2). There is a differential fractionation of carbon isotopes during CO_2 fixation by C_3 , C_4 and CAM plants, which is important in dietary studies. Because the heavier ^{13}C isotope is strongly discriminated against during C_3 photosynthesis, these plants have low $\delta^{13}\text{C}$ values, averaging -26.5‰ . Tropical grasses employ the C_4 photosynthetic pathway and have higher $\delta^{13}\text{C}$ values, averaging -12.5‰ .

These average values can however vary due to environmental conditions, for example the $\delta^{13}\text{C}$ values of C_3 plants may vary from -22‰ to -34‰ (Bender 1971, Smith and Epstein 1971, Heaton 1999) compared with C_4 plants which may vary from -9‰ to -16‰ (van der Merwe and Tschauer 1999). The $\delta^{13}\text{C}$ values of modern plants have undoubtedly been influenced by changes in $^{13}\text{C}/^{12}\text{C}$ composition of atmospheric CO_2 due to human activity over the past 200 years, so $\delta^{13}\text{C}$ values for plants were slightly more positive in the past (Marion and McElroy 1991). The CAM pathway is found in

succulents such as cactus, and these plants have the ability to switch between C₃ and C₄ photosynthesis. The $\delta^{13}\text{C}$ values thus fall anywhere in the range for C₃ and C₄ plants.

'Typical' C₃ plants are trees, most shrubs and grasses in temperate environments, including wheat, oats, barley, rice and most 'vegetables'. Millet, maize, sugarcane and sorghum are C₄, as are most wild grasses in summer rainfall areas (van der Merwe and Tschauner 1999).

Animals

The carbon isotope ratios in plants are passed on through the food chain with some secondary fractionation, so that $\delta^{13}\text{C}$ values of the tissues of consumers reflect the C₃- or C₄-based nature of the diet. When animals eat plants, enrichment in ¹³C of about +5‰ occurs during the formation of collagen (Fig. 3.4). In savannahs with C₃ trees and shrubs and C₄ grasses, browsers (C₃ plant-eaters) have average collagen values of -21.5‰, while pure grazers average -7.5‰. Mixed feeders fall somewhere in between the averages for browsers and grazers. For apatite, the enrichment is greater, at about +12‰ (Lee-Thorp *et al.* 1989, Lee-Thorp and van der Merwe 1987) to +14‰ (Cerling and Harris 1999). The collagen of carnivores is enriched further by approximately 2‰, but their apatite values are similar to those of their herbivorous prey (Lee-Thorp *et al.* 1989, Lee-Thorp and van der Merwe 1987).

Carbon in the marine environment

Patterning in carbon isotopes in the marine system is complex. There is a constant exchange between dissolved CO₂, bicarbonate and carbonate ions, with associated

isotopic fractionation (see Johnston and Kennedy 1998). Photosynthesis of dissolved CO_2 by phytoplankton results in less fractionation than in C_3 plants. Marine plants and plankton therefore have $\delta^{13}\text{C}$ values that are between the values of terrestrial C_3 and C_4 plants (Chisholm *et al.* 1982). Global variations can, however, be quite large, and are correlated with sea temperature and therefore dissolved CO_2 content. Marine organisms have values ranging from closer to C_3 plants at one extreme to those of C_4 plants at the other. According to Sealy (2001), a reasonable estimate of mean $\delta^{13}\text{C}$ for marine animals from temperate oceans is around -16‰ . Marine animals tend to be more important in human diets than marine plants.

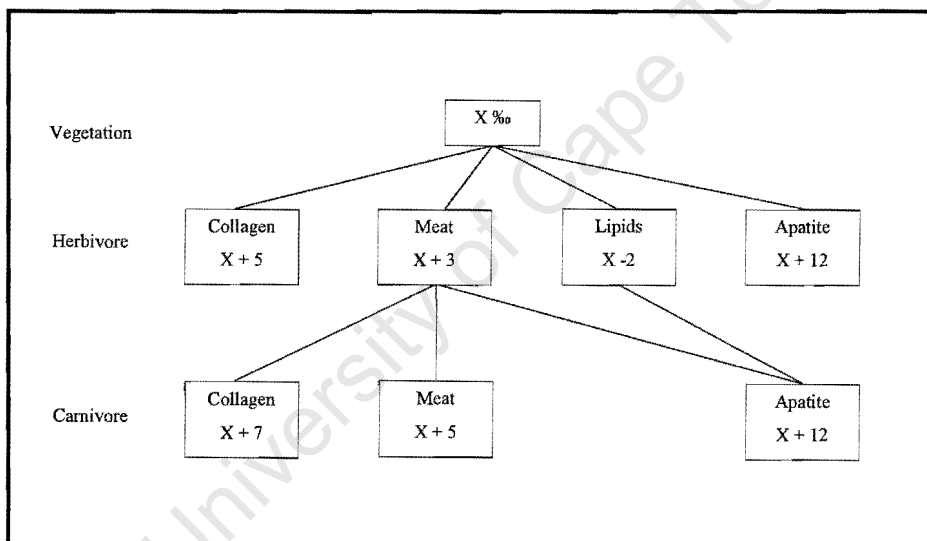


Figure 3.4: $\delta^{13}\text{C}$ values in a terrestrial foodweb (after Lee-Thorp *et al.* 1989).

In coastal areas where land vegetation is C_3 , the $^{13}\text{C}/^{12}\text{C}$ measurements of human bone collagen inform us about the proportions of marine and terrestrial foods people consumed (Tauber 1981, Sealy and van der Merwe 1985, Sealy 1996).

Nitrogen and carbon metabolism

Nitrogen isotope ratios are one of several methods of tracing and reconstructing diets. This is possible because nitrogen in the body and in the diet is present almost exclusively as protein and the amino acids from which protein is synthesised. It is also present in nucleic acids, ammonia and urea, but about 98% of nitrogen is found in protein and amino acids. The only exception to this is human breastmilk in which about 20% of the nitrogen is present in a form other than protein (Schoeller 1999). Thus the nitrogen found in bone collagen comes from protein in the diet, and collagen $\delta^{15}\text{N}$ values inform us about the origins of dietary protein.

The products of protein denaturation are absorbed and transported to the liver. Amino acids in excess of the requirement are catabolised -chemically broken down- producing ammonia, of which most is converted to urea. About 88% of total nitrogen excretion is found in urine. Other routes of nitrogen output include defaecation, milk production in lactating females, minor losses due to sweat, sloughage of skin and growth of hair and nails (Schoeller 1999).

Given the diverse sources of carbon in the diet, the metabolism of carbon is much more complicated than nitrogen metabolism. Carbon isotopic composition of these different biochemical fractions present variations within one diet, e.g. lipids are ^{13}C -depleted relative to carbohydrates, and amino acids are usually ^{13}C -enriched relative to carbohydrates. The difference between carbon isotopic abundances in collagen and in carbonate hydroxyapatite within one individual also relates to trophic level. Herbivores primarily consume carbohydrates whereas carnivores have diets rich in amino acids and lipids. The difference between carbon isotopic abundance in collagen

and in carbonate hydroxyapatite of one individual is therefore greater for herbivores than for carnivores and intermediate omnivores (Lee-Thorp *et al.* 1989).

Krueger and Sullivan (1984) suggested that bone carbonate might be used as a measure of the carbon isotope ratio of the carbohydrate component of the diets, whereas the same ratio of collagen would reflect the amino acid source (see also Lee-Thorp and van der Merwe 1987, Ambrose and Norr 1993, Tieszen and Fagre 1993). Recent controlled diet studies of pigs, however, show that a significant proportion of the carbon in bone collagen can derive from dietary carbohydrates (Howland *et al.* 2002).

Isotopes in humans

$\delta^{15}\text{N}$ values for humans with varying diets

Many studies report $\delta^{15}\text{N}$ values in humans, showing great variation in people eating varied diets in different parts of the world. In Table 3.4, mean values for adults range from $+8.5 \pm 0.5\text{‰}$ for terrestrial-based diets (Richards *et al.* 1998) to $+18.6 \pm 1.3\text{‰}$ in British Columbia (Schwarcz 1991). Schoeninger *et al.* (1983) have reported values of approximately $+20\text{‰}$ for North American salmon fishers. At the Dakhleh Oasis, where rainfall is essentially zero, elevated $\delta^{15}\text{N}$ values ($17.6 \pm 1.3\text{‰}$) have been reported. This elevation in nitrogen isotope ratios has been observed in other arid environments. Since $\delta^{15}\text{N}$ analysis can only be performed on organic tissue (e.g. collagen and dentine), these studies are limited to sites where there is good preservation and nearly all studies have been on bone collagen.

According to Schoeninger *et al.* (1983) $\delta^{15}\text{N}_{\text{collagen}}$ values below 10‰ indicate a diet comprising little or no marine resources and values above 10‰ result from marine food, while the most enriched values are as a result of a large dietary marine component. However, at this time $\delta^{15}\text{N}$ values had not been measured for low trophic level marine food sources, for example shellfish. Published mean values for shellfish range from approximately 6.0 to 11.0‰ (Sealy *et al.* 1987, Bustamente and Branch 1996, Richards and Hedges 1999, Muller 2001). The samples at the bottom of the range are the filter feeders or grazers (e.g. black mussels, genus *Choromytilus*) and the detritus feeders (e.g. limpets, genus *Patella* and abalone, genus *Haliotis*).

For populations placing more emphasis on shellfish than on fish, lower $\delta^{15}\text{N}$ values are expected. Richards and Hedges (1999) compared their data on humans from the English Late Mesolithic period to those obtained by Schoeninger *et al.* (1983) for Danish Mesolithic period people. Both populations lived on the coast and used large quantities of marine foods. The Danish $\delta^{15}\text{N}$ values were lower, about 14‰, and suggest that the source of marine protein consumed at these sites was at a slightly lower average trophic level.

The nitrogen isotopic values for diets including marine foods vary depending on the type of marine resources incorporated into the diet. The average values for populations with a reliance on marine resources, represented in Table 3.4, range from $9.5 \pm 0.9\text{‰}$ to $18.6 \pm 1.3\text{‰}$. The high $\delta^{15}\text{N}$ values suggest the inclusion of marine carnivores, like seals, into the diet; however, planktivorous whales will not contribute to elevated $\delta^{15}\text{N}$ values.

Values for populations eating terrestrial diets in well-watered areas range from $8.5 \pm 0.5\text{‰}$ to $9.3 \pm 1.3\text{‰}$ (Richards *et al.* 1998). Isotopic analyses of six skeletons from the Scottish Oronsay middens yielded an average $\delta^{15}\text{N}$ value of $15.5 \pm 0.9\text{‰}$, suggesting that people here were eating not only shellfish, but also fish and marine mammals. It is suggested that one individual was moving between sites which offered either marine or terrestrial foods thus resulting in isotopic values indicative of a mixed diet (Richards and Mellars 1998; Table 3.4, Fig. 3.5).

Table 3.4: An overview of average $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values for humans with varying diets.

<i>Locality and source</i>	<i>N</i>	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)
<i>Terrestrial-based diet</i>			
Neolithic Portugal (Lubell <i>et al.</i> 1994)	12	9.1 ± 1.3	-19.3 ± 1.4
Late Iron Age/ Early Roman era, Poundbury Camp, England (Richards <i>et al.</i> 1998)	13	8.5 ± 0.5	-19.9 ± 0.5
Lower status burials, Poundbury Camp, England (Richards <i>et al.</i> 1998)	21	9.3 ± 1.3	-19.5 ± 0.5
<i>Marine- and terrestrial-based diet</i>			
CNGII, Oronsay, Scotland (Richards and Mellars 1998)	1	14.6	-15.8
Cnoc Coig, Oronsay, Scotland (Richards and Mellars 1998)	6	15.5 ± 0.9	-12.6 ± 0.7
<i>Diets including marine foods</i>			
British Columbia (Schwarcz 1991)	29	18.6 ± 1.3	-12.7 ± 2.3
Mesolithic Portugal (Lubell <i>et al.</i> 1994)	11	12.1 ± 1.6	-16.8 ± 1.3
Afetna, Saipan - coastal lagoonal environment (McGovern-Wilson and Quinn 1996)	10	9.5 ± 0.9	-18.7 ± 0.8
Coastal LSA hunter-gatherers, southern Cape, South Africa (Sealy and Pfeiffer 2000)	80	13.1 ± 2.3	-13.8 ± 1.5

<i>Locality and source</i>	<i>N</i>	$\delta^{15}\text{N}$ (‰)	$\delta^{13}\text{C}$ (‰)
<i>Terrestrial-based diet in an arid environment</i>			
Dakhleh Oasis, Egypt (Schwarcz <i>et al.</i> 1999)	71	17.6 ± 1.3	unknown

In South Africa, there have been a number of dietary tracing/reconstruction studies, many of which focus on the indigenous populations who lived in the Holocene. These studies concentrate mainly on the coastal population, but there have been studies of inland populations who were, to some extent, involved in food production. $\delta^{15}\text{N}$ values are affected by not only the amounts of marine foods consumed, but also the type, i.e. high trophic versus low trophic level foods.

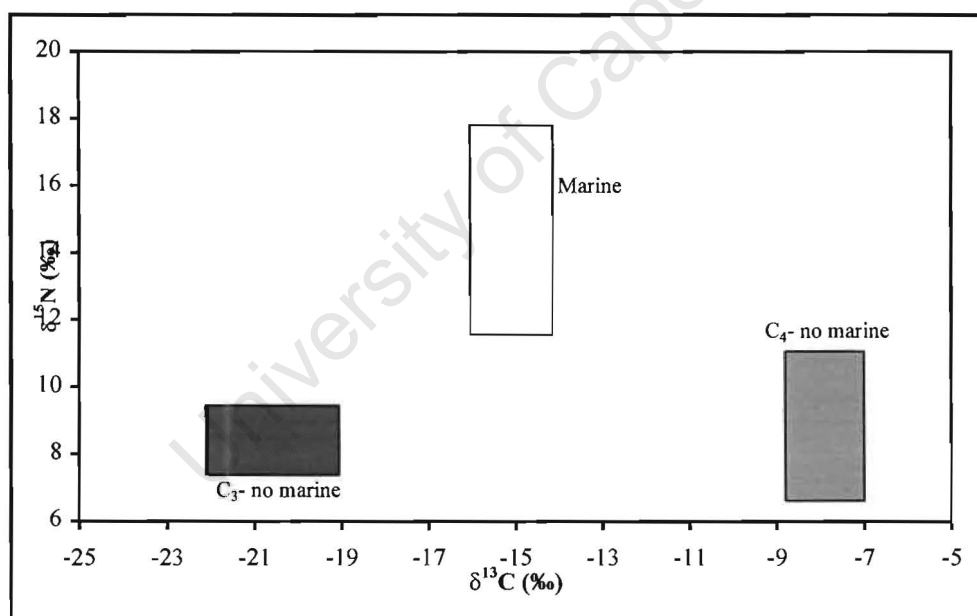


Figure 3.5: Model of expected values in human bone collagen from preagricultural populations with a predominantly C₃ diet and using no marine foods, populations using marked amounts of marine foods, and populations using little or no marine foods, but with access to C₄ foods, such as maize (from Schoeninger and Moore 1992).

$\delta^{13}\text{C}$ values for humans with varying diets

van der Merwe and Vogel (1978) carried out one of the earliest dietary tracing studies using carbon isotopes. The carbon isotope record of human skeletons from the North American Eastern Woodlands, particularly the Lower Illinois Valley, provided insight into the appearance and increased reliance on maize in this area. The woodland has essentially no indigenous C_4 plants, thus it provides an ideal situation for determining the significance of a C_4 plant like maize using carbon isotopes. Throughout the Archaic, Early Woodland and Middle Woodland periods, skeletal $\delta^{13}\text{C}$ values for this region averaged -21.5‰ , a value identical to that of C_3 herbivores, indicating that maize was not eaten. After 800 AD, the carbon isotope ratios rapidly changed, reaching -10‰ after 1000 AD, much later than archaeologists had expected. This value indicates that 75% of the carbon in bone collagen was derived from C_4 plants, in this case maize. Subsequent studies have documented regional variations in the introduction and spread of maize.

In prehistoric Ontario, before 700 AD, isotopic values for human bone collagen are around -20.5‰ showing that there was no maize in the diet. After 700 AD, isotopic values become less negative, a trend that accelerates after 1000 AD, with values peaking between 1300 and 1400 AD (Katzenberg *et al.* 1995).

Isotopic analyses of Mesoamerican populations show a variable pattern of C_4 plant (mostly maize) consumption. $\delta^{13}\text{C}$ values from Lamanai and Pactibun, Belize, indicate that prehistoric Mayans placed less emphasis on maize than did some other Mesoamerican groups (e.g. Tehuacan) (White and Schwarcz 1989, White *et al.* 1993). Preclassic populations (1200 BC to 300 AD) have a mean $\delta^{13}\text{C}$ value of $-12.4 \pm 0.3\text{‰}$,

suggesting strong reliance on maize. Late and Terminal Classic groups have increasingly negative $\delta^{13}\text{C}$ values at Lamanai and less negative values at Pactibun, indicating a respective decrease and increase in maize reliance (see also van der Merwe *et al.* 2000). $\delta^{13}\text{C}$ values for Postclassic and Historic period skeletons have $\delta^{13}\text{C}$ values of $-9.3 \pm 0.8\text{‰}$ and $-9.9 \pm 0.9\text{‰}$, respectively. White and Schwarcz (1989) interpret this pattern as representing a doubling of maize consumption in less than a century.

In coastal areas where no C_4 plants are consumed, carbon isotopic ratios provide an important means of assessing the relative importance of marine and terrestrial foods. In Mesolithic and post-Mesolithic Danish populations, generally less negative values (-11 to -15‰) indicate a reliance on seafood (Schoeninger *et al.* 1983, Richards and Hedges 1999). The values are similar to those of populations known to have been dependent on marine food sources (e.g. Greenland Inuit). An abrupt shift in dietary preferences is documented in Mesolithic and Neolithic populations in Portugal (Lubell *et al.* 1994). Beginning in the Mesolithic and intensifying into the Neolithic, the Portuguese diet changed towards one that was more terrestrial. Values for the samples from coastal and near-coastal sites range from -15.3‰ to -20.4‰ . The less negative values are mainly Mesolithic and the more negative values are Neolithic (see Table 3.4).

Fig. 3.6 is a diagrammatised representation of four theoretical extreme dietary types.

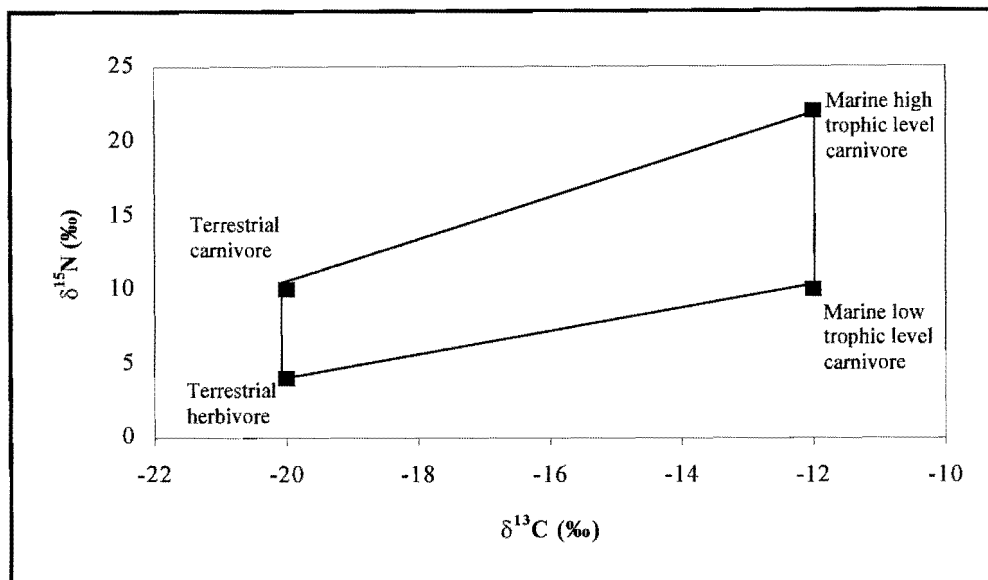


Figure 3.6: Four (theoretical) extreme dietary types, and their associated bone collagen stable nitrogen and carbon isotope values (adapted from Richards and Hedges 1999).

Previous isotopic work on the Matjes River collection

The southern Cape region, where the Matjes River Rock Shelter is located, is a temperate region, receiving year-round rainfall of between 600 to more than 1200mm per annum. Thus, the problem of increased $\delta^{15}\text{N}$ values due to aridity does not apply. Sealy (1996) reported $\delta^{15}\text{N}$ values of approximately 5‰ for archaeological animal bones from the Late Pleistocene and Holocene levels of Nelson Bay Cave, some 20km from Matjes River Rock Shelter in the same climatic zone. Buffalo (*Syncerus caffer*) gave a mean value of $4.6 \pm 1.0\text{‰}$, $n = 20$ and bloubok (*Hippotragus leucophaeus*) yielded an average of $5.9 \pm 1.2\text{‰}$, $n = 8$. Muller's (2001) results for modern mussels, *Perna perna* ($7.6 \pm 1.3\text{‰}$, $n = 32$) and archaeological seals ($16.8 \pm 1.7\text{‰}$, $n = 9$) show that $\delta^{15}\text{N}$ in the marine system is typical.

$\delta^{15}\text{N}_{\text{collagen}}$ values for 33 adult human skeletons from Matjes River Rock Shelter ranged from 6.8 to 17.7‰. Mean $\delta^{15}\text{N}$ was $13.0 \pm 2.2\text{‰}$, while the mean $\delta^{13}\text{C}$ was $-13.4 \pm 2.2\text{‰}$ (range -17.6 to -5.6‰) (Sealy and Pfeiffer 2000, Muller 2001). The

similarity in the standard deviations for nitrogen and carbon indicate that enriched carbon isotope values for the adults in the population were the result of marine foods, even though the environment surrounding the Matjes River Rock Shelter included some C₄ vegetation (Vogel *et al.* 1978). This pattern is also observed in the rest of the southern Cape region.

$\delta^{15}\text{N}$ values for individuals from the Matjes River Rock Shelter are significantly lower than those of skeletons from the Robberg Peninsula, approximately 15km away. This means that there was a difference in the economies of these two communities and it implies that LSA hunter-gatherers in the southern Cape may have been more territorial than archaeologists have generally realised. The elevation in $\delta^{15}\text{N}$ values at Robberg may be due to the inclusion of larger quantities of carnivorous fish and/or seal in the diet. Faunal analysis from Nelson Bay Cave, on the Robberg Peninsula, has shown large quantities of seal bones. Due to the nature of the excavation and also slumping of the unexcavated deposit of the mid-to-late Holocene at Matjes River Rock Shelter, the importance of seals or other marine mammals there remains unknown (Döckel 1998, Sealy and Pfeiffer 2000, Muller 2001).

Weaning and stable light isotopes

The use of nitrogen isotopes to determine weaning age is based on the fact that these ratios reflect trophic level differences, such that the higher an organism is in a foodchain, the more positive its $\delta^{15}\text{N}$ value will be. The weaning effect has also been observed in mammals other than humans (see Lee *et al.* 1991, Jenkins *et al.* 2000, Polischuk *et al.* 2001).

Fogel *et al.* (1989) pioneered the study of the use of stable isotopes of nitrogen for determining weaning age. For a breastfeeding child, the only source of dietary nitrogen comes from the mother's milk, thus isotopic composition of the child's collagen will be related to that of breastmilk. All animals are enriched in ^{15}N with respect to their diet by about 3‰ because they excrete urea (waste nitrogen), which is depleted in ^{15}N . Breastfeeding infants are feeding off their mothers' tissues and their bone collagen is correspondingly enriched, as shown by Fogel *et al.* (1989).

Fogel and colleagues (1989) showed that $^{15}\text{N}/^{14}\text{N}$ ratios could be used to detect the consumption and/or loss of breastmilk in the diet. In this study fingernail clippings from lactating mothers and their nursing infants were collected. From the isotopic analysis it was shown that the $\delta^{15}\text{N}$ values for newborn infants approximated the mother's value. Values for infants of about three months of age were enriched in comparison to their mother's. Older infants, i.e. those who were completely weaned, showed $\delta^{15}\text{N}$ values similar to those of the mother. This trophic level effect has been used to estimate the age of weaning in populations through time (see overlays for comparison between studies).

Fogel *et al.* (1989) also investigated the possibility for differences in age at weaning in pre-agricultural and agricultural populations. Bone samples from 13 adults and 34 children were analysed from pre-agricultural sites of the Tennessee Valley. The skeletal remains came from three Middle and Late Archaic period sites (5500 to 2000 BC). The mode of subsistence was hunting and gathering, with no evidence for maize horticulture. The Sully site in South Dakota is a protohistoric site dating to between 1650 and 1700 AD. The population relied on a mixed subsistence economy, involving

hunting and gathering as well as horticulture, with corn being one of the principal crops. In addition to these dietary resources, there was also a substantial reliance on bison meat (Tuross and Fogel 1994).

At the Sully site women breastfed their infants for one year without introducing any significant alternate protein source (see Fig. 3.7).

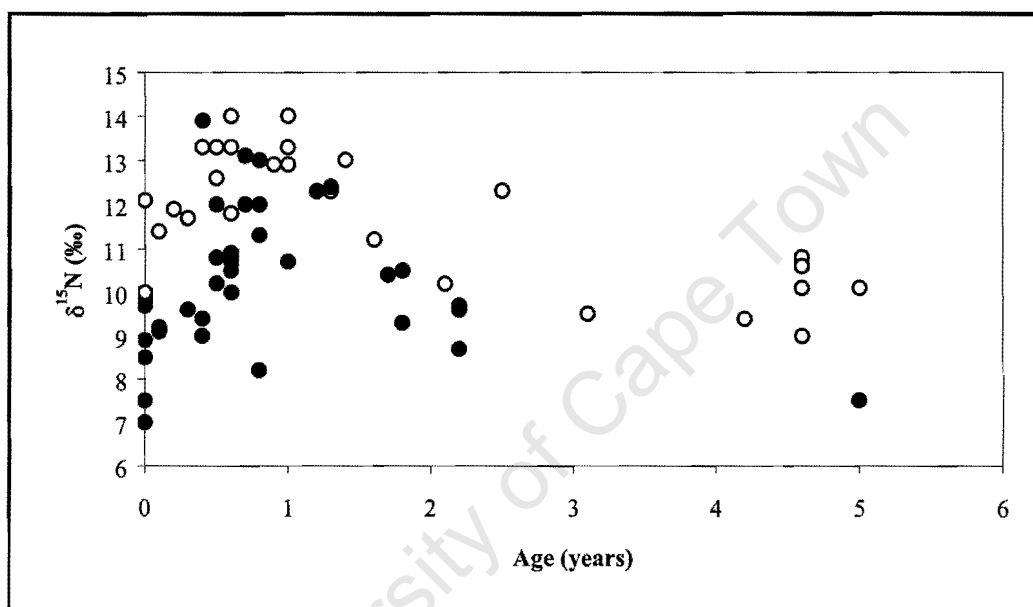


Figure 3.7: $\delta^{15}\text{N}$ values for bone collagen plotted against age for infants from the Sully (○) and Tennessee Valley (●) sites (Fogel *et al.* 1989, Tuross and Fogel 1994).

The $\delta^{15}\text{N}$ of bone collagen from both sites decline sharply at 18 to 20 months, indicating the introduction of alternate food sources. The pattern of change in $\delta^{15}\text{N}$ for these two populations is indistinguishable from each other. If maize had been used in large amounts as a weaning food, the $\delta^{15}\text{N}$ values for infant collagen would be less positive than the fully breastfed infant. The $\delta^{15}\text{N}$ values infants at about two years old from the Tennessee Valley is not very different to the adult mean of $8.2 \pm 0.8\text{‰}$ ($n = 13$), which suggests that these infants were weaned onto a diet similar to that of the adults. For infants between two and five years at the Sully site, $\delta^{15}\text{N}$ values fall below

that of the adult population ($11.1 \pm 0.5\text{‰}$, $n = 8$). The decline to a value less than that of the adults suggests that children were, on average, eating less meat than their elders. The results from the Sully and Tennessee Valley sites are contrary to the hypothesis that weaning occurs earlier in agricultural than in non-agricultural populations.

Angel was a late prehistoric Middle Mississippian civic and ceremonial centre along the Ohio River in southern Indiana, inhabited between about 1200 to 1450AD by maize agriculturalists. Here, breastmilk provided most of the dietary nitrogen until sometime during the second year of life (Fig. 3.8) (Schurr 1998).

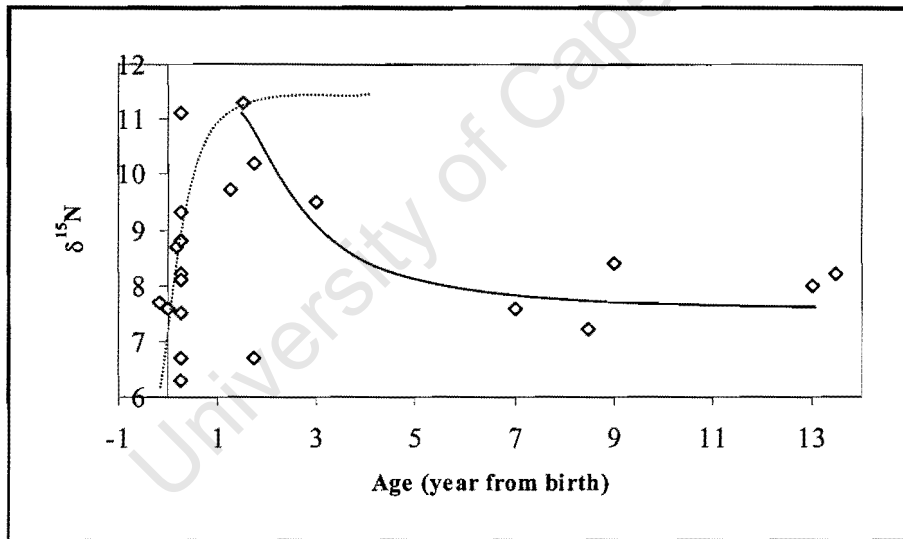


Figure 3.8: $\delta^{15}\text{N}$ values for the Angel juveniles and expected trends for nursing (---) and weaning (—) (after Schurr 1997).

Several infants of about two years old from the Angel site showed relatively positive $\delta^{13}\text{C}$ values along with relatively low $\delta^{15}\text{N}$ values, thus it appears that infants of this age consumed diets supplemented with significant amounts of maize. The isotope ratios at Angel site show no evidence for relatively early weaning or dietary supplementation (Schurr 1997, 1998).

MacPherson, a proto-historic village located in what is now Ontario, Canada, was inhabited during the 16th century by an Iroquoian tribe with similar subsistence activities to those at Angel. However, $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ results show that this population consumed less C_4 plant food (maize). For the infant sample, Katzenberg (1993) separated individuals who may have been breastfeeding from those who were being, or had been, weaned. Age two years was chosen as the cut-off as the ethnohistory for the area indicates that children of Ontario Iroquois were weaned between the ages of two and three years. Individuals in the birth to two years category ($n = 11$) yielded a mean $\delta^{15}\text{N}$ of $13.5 \pm 0.8\text{‰}$, while those two years and older ($n = 19$) had a mean value of $11.8 \pm 1.0\text{‰}$ (see Fig. 3.9). In some instances infants have both the highest $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values.



Figure 3.9: $\delta^{15}\text{N}$ plotted against age for juveniles from MacPherson, a protohistoric Amerindian village (Katzenberg 1993).

Prospect Hill was a Methodist cemetery in Newmarket, Ontario and was used between 1824 and 1879 AD. Once again, at this site infants showed elevated $\delta^{15}\text{N}$ values relative to children and adults in the sample. The $\delta^{15}\text{N}$ values at Prospect Hill

reach a maximum just after the first year of life. No adult has a $\delta^{15}\text{N}$ value greater than 13.8‰, while in the birth to two year age range, values range from 13.4 to 16.5‰ (Fig. 3.10) (Katzenberg 1993, Katzenberg and Pfeiffer 1995).

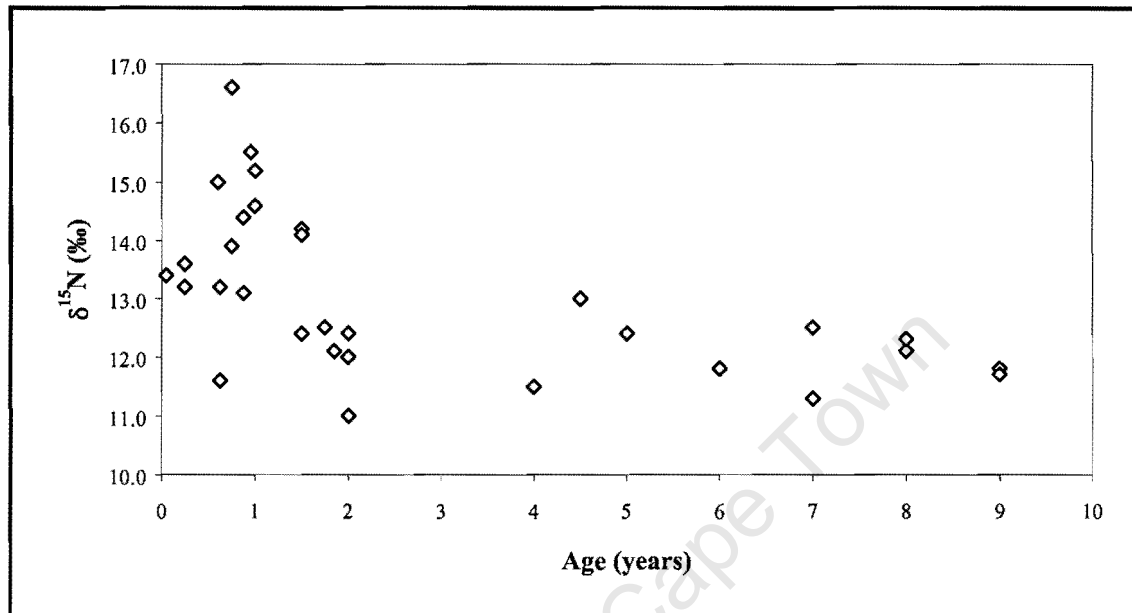


Figure 3.10: $\delta^{15}\text{N}$ plotted against age for the Prospect Hill juveniles (reproduced from Katzenberg 1993).

Another series of 19th century Canadian skeletons comes from the St. Thomas Anglican churchyard in Belleville, Ontario. The large number of infant skeletons from this site ($n = 149$), together with parish records, made this collection especially suitable for a weaning pattern study. Rib samples for 60 individuals between birth and three years were analysed for stable nitrogen isotopes only. Analyses revealed that nursing was carried out for about 14 months (Herring *et al.* 1998; Fig. 3.11).

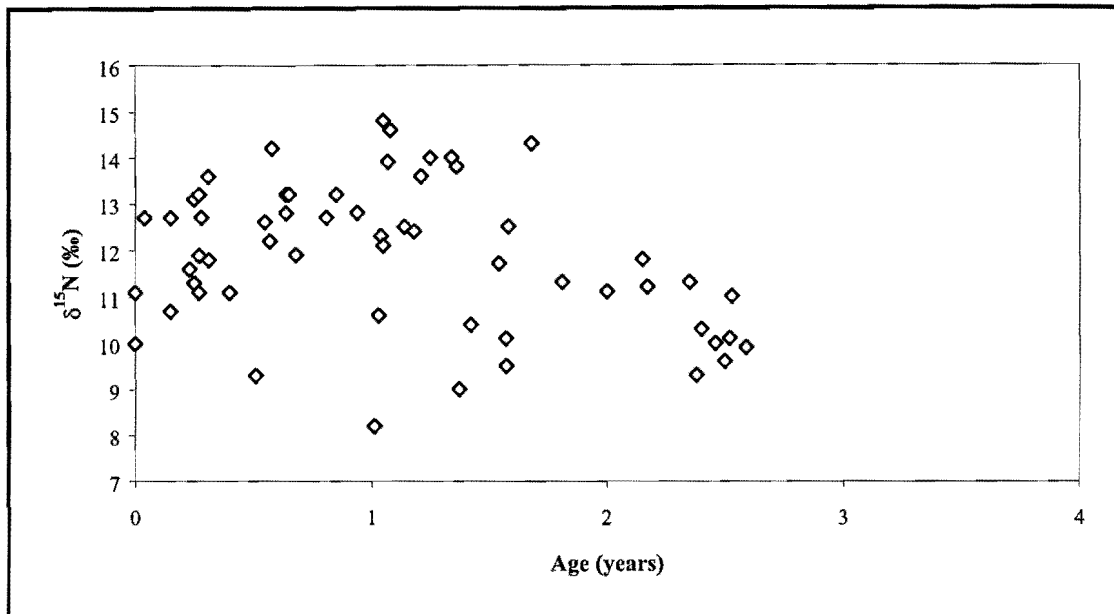


Figure 3.11: $\delta^{15}\text{N}$ plotted against age for the St. Thomas Anglican churchyard (Herring *et al.* 1998).

The site of Kaminaljuyú, an important Prehispanic state in highland Guatemala, is the focus of the Wright and Schwarcz (1998, 1999) studies. Settled in Early Preclassic times, Kaminaljuyú became a large stratified community by approximately 400 BC. The skeletons span Middle Preclassic through Late Postclassic occupations, ca. 700 BC to 1500 AD. Ancient diet at the site was based on the cultivation of maize, squash and beans and a variety of other fruits and vegetables.

Wright and Schwarcz (1999) outline a record of dietary change in the $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ composition of dentine collagen from the same three teeth from each skeleton (a first permanent molar, M1; a premolar, P; and a third molar, M3). These teeth have little developmental overlap and show childhood diet at different ages. The $\delta^{15}\text{N}$ values in the M1 should be greater than in P and M3, which develop in later childhood. $\delta^{13}\text{C}$ values should increase from M1 to P and M3, due to the introduction of solid foods and a decrease in $\delta^{18}\text{O}$ values should be observed, as a result of a reduced intake of ^{18}O -rich breastmilk (Wright and Schwarcz 1998).

Oxygen in body water is enriched in the heavy isotope ^{18}O relative to drinking water largely due to the preferential expiration of H_2^{16}O vapour. Human breastmilk is formed from the body water pool and, thus, is heavier in $\delta^{18}\text{O}$ than the water imbibed by lactating mothers. It is safe to assume that the $\delta^{18}\text{O}$ value of a breastfed infant would be higher than that of an infant who isn't (Bryant and Froelich 1995). Dental enamel provides the opportunity to obtain information regarding two different aspects of the childhood nutritional transition: the introduction of solid foods, or supplementation, and the replacement of mother's milk with alternative sources of water, i.e. weaning. Wright and Schwarcz (1998, 1999) developed this method in their study.

The difference in $\delta^{15}\text{N}$ between early and late developing teeth should be between two and three per mil, in accordance with the trophic level effect. The authors argued that the first molars showed higher dentine $\delta^{15}\text{N}$ than teeth developing at older ages (Table 3.5). This statement is debatable since these values show high standard deviations from the mean. Wright and Schwarcz (1999) attribute the smaller than expected difference to the introduction of solid proteins to the infant diet before the completion of the M1. Because of the low number of teeth that yielded reliable $\delta^{15}\text{N}$ values, they based this statement on the $\delta^{13}\text{C}$ values obtained from the enamel.

Table 3.5: Isotopic results from analysis of permanent tooth dentine and enamel from individuals at Kaminaljuyú (Wright and Schwarcz 1999).

	‰	<i>M1</i>	<i>P</i>	<i>M3</i>
Dentine	$\delta^{15}\text{N}$	9.85 ± 1.69	9.24 ± 2.05	7.96 ± 0.98
	$\delta^{13}\text{C}$	-9.92 ± 0.92	-9.98 ± 1.00	-9.63 ± 0.98
Enamel	$\delta^{13}\text{C}$	-3.41 ± 1.38	-2.91 ± 1.26	-2.47 ± 1.12
	$\delta^{18}\text{O}$	-4.28 ± 0.76	-4.51 ± 0.95	-5.38 ± 0.68

Wright and Schwarcz (1998) argued that the enamel of teeth that developed at older ages was more enriched in ^{13}C and more depleted in ^{18}O than in teeth that developed earlier. The mean $\delta^{13}\text{C}$ values change from first molars to premolars, indicating a change after two years of age, when premolars begin to mineralise. Again, the standard deviations are large. Later developing teeth in some individuals have more positive enamel $\delta^{13}\text{C}$. The opposite trend is seen in other individuals. The latter pattern may reflect a move to an isotopically lighter diet in later childhood. The alternate reason offered for the decline in $\delta^{13}\text{C}$ is that it represents a trophic level effect in carbon metabolism; infants consumed solids of similar isotopic composition to the adult diet. These observations are rather generalised and the variation in the results could be due to behavioural differences between individuals, or possible metabolic “noise”. Changes in infant feeding practices through time can be ruled out as a possible explanation for the variation seen in this sample since all but one skeleton date from the same phase. $\delta^{18}\text{O}$ values changed significantly only between the first and third molars, suggesting that breastfeeding continued during the formation of the premolar. The data indicate that a few individuals were consuming substantial amounts of water soon after two years of age but most skeletons provide evidence for breastfeeding up to the age of six years.

Wright and Schwarcz (1998) conclude that mothers at Kaminaljuyú began to supplement breastmilk with solid foods by at least the end of the child’s first year of life. Although solid foods had been introduced early, before the mineralisation of premolars, it appears that breastmilk accounted for a large portion of liquids imbibed by many Kaminaljuyú children up to the age of five or six years.

Fuller *et al.* (2001) investigated the age of weaning at the medieval village site of Wharram Percy, Yorkshire, England. The site, St. Martin's church and churchyard, yielded 687 articulated human skeletons, the remains of peasants who lived at Wharram Percy or farmsteads in the parish. Nearly half of the skeletons (327) consist of individuals under the age of 18, making this collection an excellent one for looking at weaning behaviour in the past.

Ribs and tooth samples were analysed and from the results it was concluded that the adult diet was a relatively uniform C₃ diet, with little input of marine- or C₄-based foods. When comparing the average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of juvenile and adult collagen, infants, as expected, showed elevated $\delta^{15}\text{N}$ values (by 3‰) in the first year of life but decreased to within adult range by two years old. This means that solid foods must have been introduced around one year old, with children fully weaned by two years (see Fig. 3.12). These results are in accordance with medieval literature that advised children should be weaned by the age of two years (see Mays 2002, Richards *et al.* 2002).

These findings were confirmed by the analysis of dentine collagen. Fuller *et al.* (2001) looked at intra-tooth variability using both the enamel and dentine from a single tooth. To investigate variation within dentine collagen, they sampled the crown, neck and root of second deciduous molars.

The crowns of these molar are complete between 10 months and one year after birth while the roots are complete between 2.5 and three years after birth. They report an enrichment of 1‰ in $\delta^{13}\text{C}$ and 3‰ in $\delta^{15}\text{N}$ when comparing the crown and root

dentine. This is what is expected considering the difference in age at completion of these tooth parts.

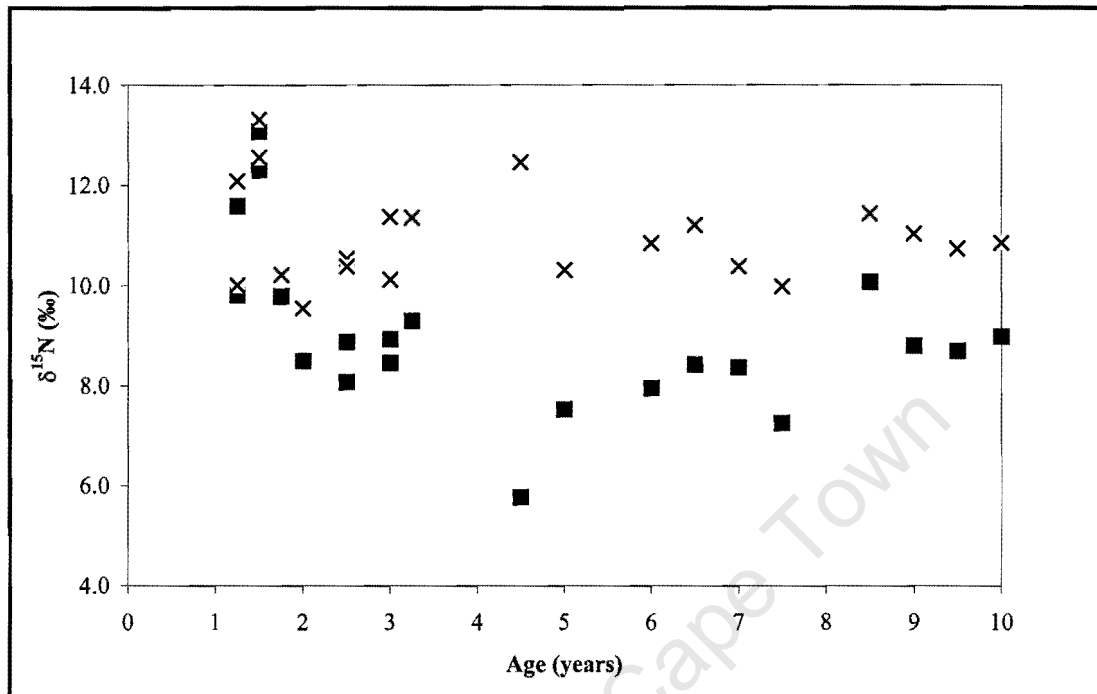


Figure 3.12: $\delta^{15}\text{N}$ values for rib collagen (■) and dentine collagen from whole molars (×) from the same individuals plotted against estimated age at death at Wharram Percy (reproduced from Fuller *et al.* 2001).

The enrichment of crown compared with root collagen is evidence that deciduous dentine preserves information about time and rate of weaning. Since growth rates for teeth are better established than those for bone, this method provides a more accurate measurement of the weaning period and dietary changes within individuals.

Rib and humeral samples of infants and juveniles from a Romano-Christian cemetery at the Dakhleh Oasis, Egypt were analysed in order to investigate the influence of Roman ideas regarding weaning (Dupras *et al.* 2001). Documentary sources indicate that infants were breastfed for up to three years in Egypt prior to the Roman period. Weaning was gradual and supplementary foods were introduced into the diet when the

child was several months old. After 30 BC, Egyptians were exposed to Roman ideas and practices regarding feeding. Roman physicians described weaning as a gradual process, with supplementary foods being introduced at six months; weaning was completed by three years of age.

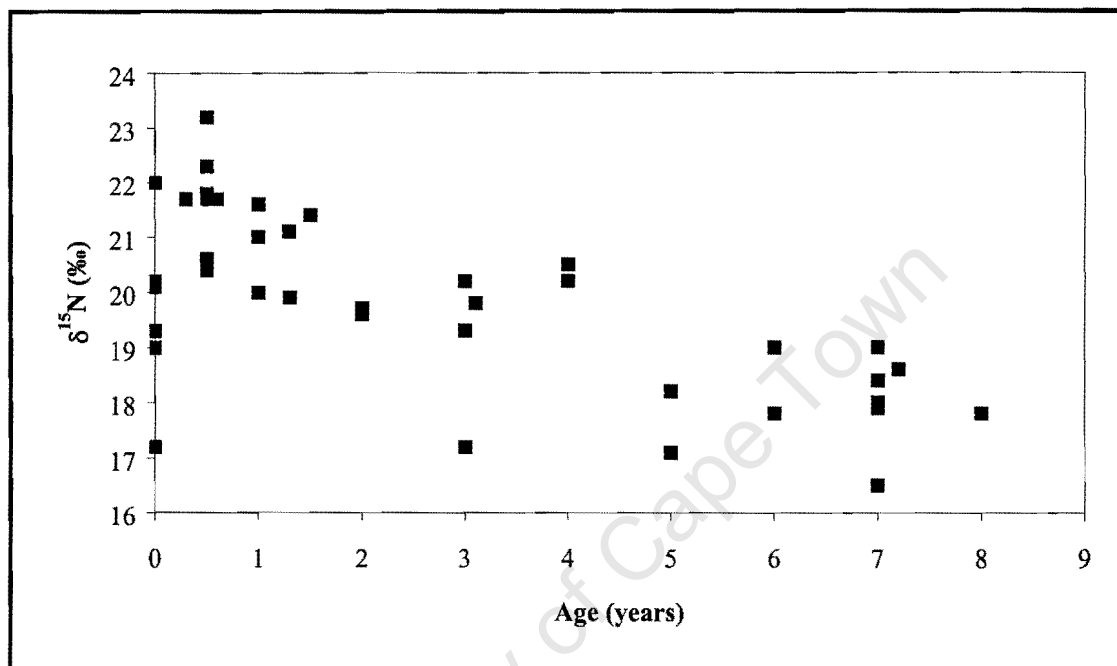


Figure 3.13: $\delta^{15}\text{N}$ values for humeral and rib collagen plotted against estimated age at death for infants and children from the Kellis 2 cemetery at Dakhleh Oasis (reproduced from Dupras *et al.* 2001).

Measuring the $\delta^{15}\text{N}$ values and plotting these against age for the entire population ($n = 110$) show that children below 2.5 years were enriched in ^{15}N compared to females. Infants reached a peak enrichment of approximately 3‰ at six months of age, after which their $\delta^{15}\text{N}$ values began to decline, approaching the adult female mean $\delta^{15}\text{N}$ value of 18‰ at three years of age.

Between zero and six months of age, infants seemed to become increasingly enriched in ^{13}C in comparison to the rest of the population, this parallels the trend seen in ^{15}N . $\delta^{13}\text{C}$ rises to a maximum of -17.8‰ by 1.5 years, and then decreased to within the

adult range. The authors attribute this increase during weaning to the consumption of dairy milk from cows, or goats, part of whose diets included C₄ millet. These results suggest a Roman influence on infant feeding in Egypt.

Another African example comes from Northern Sudan. White and Schwarcz (1994) studied the distribution of isotopic ratios across five cemeteries located along the west bank of the Nile River in the Wadi Halfa. The time sequence of the burials covers the three cultures of the Intensive Agricultural Period, spanning 350 BC to 1400 AD. The authors noted a negative correlation between $\delta^{15}\text{N}$ and age between one and six years. However, $\delta^{15}\text{N}$ values between 1.5 and 4.5 years old show no correlation, with lower values for six year olds (Fig. 3.14). Since establishing age at weaning was not the primary objective for this study, the effects of age on $\delta^{13}\text{C}$ values were not explored. The sample size ($n = 21$) is too small to draw any concrete conclusions with regard to infant feeding practices.

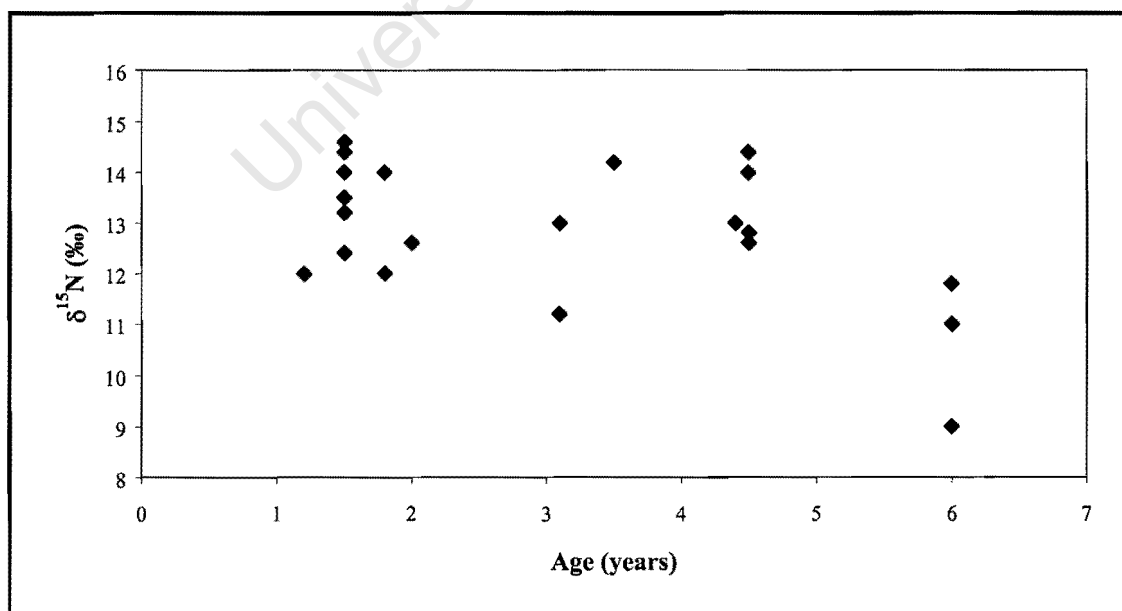


Figure 3.14: The relationship between $\delta^{15}\text{N}$ values and age for juveniles from Wadi Halfa, Northern Sudan (reproduced from White and Schwarcz 1994).

Determining weaning patterns is not restricted to the use of carbon, nitrogen and oxygen isotope ratios. Another approach to the problem is the use of strontium-calcium ratios (Sr/Ca). Unlike the use of nitrogen stable isotope ratios that are used to determine an age at which breastmilk is no longer ingested, Sr/Ca ratios in bone mineral attempts to get at an age at which foods other than breastmilk are introduced. Since human milk is exceptionally low in Sr/Ca, but solid foods are relatively high, it is possible to examine the pattern of dietary supplementation and age of weaning by reference to Sr/Ca ratios of juvenile skeletons. Sillen and Smith (1984) demonstrated this in their study of juvenile skeletons from the site of Dor (800-1300AD), located on the eastern Mediterranean coast, about 15km south of Haifa.

Strontium is discriminated against in favour of calcium in the mammary gland during the production of milk, thus the Sr/Ca ratio of milk is very low. Strontium is also discriminated against at the placenta, so newborn and nursing infants would be expected to have low Sr/Ca ratios in their bone mineral. Plants, on the other hand, have high Sr/Ca ratios. Since weaning diets are usually based on cereals, the Sr/Ca ratio in nursing and newborn infants will increase as solid foods are introduced into the diet as infants are weaned. The results of the Sillen and Smith (1984) study show exactly this, with a gradual increase in Sr/Ca peaking between 1.5 and 3.5 years of age. These data are consistent with the ethnographic information on weaning among traditional Palestinian Arab communities.

Summary

Weaning should be viewed as a process rather than an event. Earlier studies of prehistoric weaning behaviour discuss weaning from a point of view that suggests it is

an once-off event, and hence have tried to identify the age at which weaning occurs. The weaning process is in fact more complex with two ‘components’: the introduction of foods in addition to breastmilk can be seen as the *onset* of weaning and the *rate* of weaning is how rapidly breastmilk is replaced by new foods (Schurr 1997). Providing that weaning foods are high in protein, isotope measurements are most informative about weaning as a process rather than as an event. Should the weaning foods be low in protein, it is only once the child starts getting significant quantities of protein from weaning foods that the $\delta^{15}\text{N}$ values will start to drop.

Table 3.6: Summary of weaning studies through time.

<i>Site</i>	<i>Location</i>	<i>Time period</i>	<i>Estimated age at weaning</i>	<i>Source</i>
Tennessee Valley	Tennessee	5500 – 2000 BC	ca. 1.5 years	Fogel <i>et al.</i> (1989)
Dakhleh Oasis	Egypt	250 – 450 AD	ca. 6 months	Dupras <i>et al.</i> (2001)
Angel	Ohio Valley	1200 – 1450 AD	ca. 1.5 years	Schurr (1997)
Sully Site	South Dakota	1650 – 1700 AD	ca. 1.5 years	Fogel <i>et al.</i> (1989)
Kaminaljuyú	Guatemala	700 BC – 1500 AD	ca. 1 year	Wright and Schwarcz (1998, 1999)
Prospect Hill	Newmarket, Ontario	1824 – 1879 AD	ca. 1 year	Katzenberg and Pfeiffer (1995)
Wharram Percy	Yorkshire, England	Medieval	ca. 1 year	Mays <i>et al.</i> (2002), Richards <i>et al.</i> (2002)
MacPherson	Ontario	16 th century AD	Before 1 year	Katzenberg (1993)
St. Thomas	Belleville, Ontario	19 th century AD	ca. 5 months	Herring <i>et al.</i> (1998)
Dor	Haifa	800 – 1300 AD	Complete by 2 – 3 years	Sillen and Smith (1984)

Table 3.6 summarises estimated age at weaning for the case studies discussed above. Tennessee Valley is a prehistoric hunter-gatherer site, and weaning apparently took place at about 1.5 years. Very similar age at weaning is, surprisingly, also seen at the

Angel and Sully sites, where the inhabitants were fairly sedentary and practicing agriculture; theoretically, both factors should lower the weaning age. Earlier weaning (at approximately one year after birth) is observed at Kaminaljuyú, Prospect Hill, Wharram Percy and MacPherson. In the Egyptian example from Dakhleh Oasis, the influence of the Roman Empire can be seen even in changes in the breastfeeding patterns, leading to weaning by approximately six months of age. The early age of weaning at the oasis is comparable with that observed at the 19th century Canadian cemetery site of St. Thomas.

Individuals at Matjes River Rock Shelter were hunter-gatherers and their diets comprised both marine and terrestrial foods, introducing a degree of isotopic complexity. This thesis will try to establish age at weaning, for comparison with the examples above. The age profile of stable nitrogen isotope ratios should follow the generalised pattern shown below in Fig. 3.15:

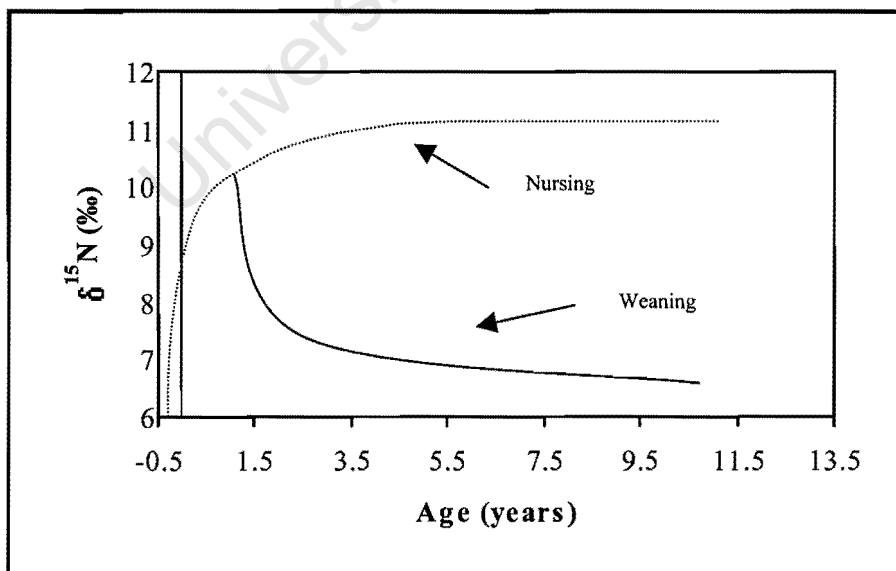


Figure 3.15: A generalised age profile of nitrogen stable isotope ratios (Schurr 1997).

Schurr (1997) pointed out that this curve is dependent on a number of factors. The rate of collagen synthesis is related to the growth rate. Should the growth rate be rapid, the nursing curve would have a higher slope. The onset of weaning, or the age at which foods other than breastmilk are introduced into the diet, as well as the isotopic composition of the weaning foods affects the curve. It is usually the case that the weaning foods have lower $\delta^{15}\text{N}$ values than breastmilk. A decrease in the rate at which the $\delta^{15}\text{N}$ values rise with respect to age indicates the onset of weaning. The rate of weaning or the rate at which weaning foods replace breastmilk also needs to be taken into consideration. Rapid weaning produces a more sudden change in the curve than slower weaning, and the isotopic composition of childhood diet determines the equilibrium level reached after the completion of the weaning process. Until more about the metabolic processes associated with breastfeeding and weaning is understood, the age at weaning remains an estimate.

Most studies rely on $\delta^{15}\text{N}$ values to give an indication of a weaning signal. In two studies where sufficient measurements of $\delta^{13}\text{C}$ were made (Wharram Percy and Prospect Hill), the results showed that children not yet weaned had more enriched $\delta^{13}\text{C}$ values than older children and adults in the population. The $\delta^{13}\text{C}$ measurements for the Kaminaljuyú population are not presented well enough to interpret fully. The remainder of the studies did not use $\delta^{13}\text{C}$ measurements as a method of determining weaning, or in some cases too few measurements were made to draw any concrete conclusions. It is evident that $\delta^{15}\text{N}$ values are a more reliable indicator for weaning in past populations. All studies reviewed show a change in $\delta^{15}\text{N}$ values with age.

With information about the diet of the adult population, and making some assumptions that diet is uniform, we should be able to establish the age at which the weaning process was set into motion at the Matjes River Rock Shelter.

University of Cape Town

CHAPTER FOUR

SAMPLING AND METHODS

Introduction

Previous isotopic studies of the archaeological human skeletons from the Matjes River Rock Shelter have included only the adults in the collection (Sealy and Pfeiffer 2000, Muller 2001). This study focuses on the analysis of juvenile individuals, although some adults were also sampled.

In total, bone samples were taken from 41 individuals, including one adult from Matjes River Rock Shelter and four juveniles from Robberg; the remaining individuals are juveniles from Matjes River. Isotopic analyses were successfully completed on all but three of these samples. The teeth from 18 adults were sampled, primarily for dentine (see Appendix for further details).

Sampling

Juvenile bone samples

With the guidance of *A Master Catalogue, Holocene Human Skeletons from South Africa* by A. Morris (1992), the Matjes River skeletal collection (housed at the National Museum, Bloemfontein) was separated into juveniles and adults. Small samples of bone (approximately 1 to 5g) were taken from ribs, damaged or broken bones, and at other points that would not hinder future osteological measurements. Ages of juveniles were estimated, wherever possible, from the stage of development of the dentition. This was done for 24 individuals by S. Pfeiffer (University of

Toronto), who is working on growth and development of Later Stone Age children in South Africa. The specimens sampled ranged in age from foetal to approximately eight years of age. Where no dental material was available, the long-bones were measured for comparison with the long-bone lengths of individuals with known dental ages. Individuals with no discernable features for age estimation were not sampled. All individuals sampled were morphologically normal.

Juvenile dentine samples

Dentine samples were taken from some individuals, from the root tips of canines and/or molars. These teeth were targeted because of the ages at which they are completely developed. For both maxillary and mandibular deciduous canines, the roots are complete between 2.5 and 3.5 years after birth, while the roots of the first deciduous molars are complete sometime between two and three years after birth. Roots of the second deciduous molars complete their growth slightly later, at about three years. The isotope ratios from the roots of these teeth should therefore provide more information regarding the diet of children between two and four years of age.

Adult dentine samples

Dentine samples were taken from the adults in the collection as a means of increasing the number of individuals sampled. The first permanent molar, for example, starts to calcify at birth or slightly before, the crown is completed between 2.5 and three years of age, and the roots are completely formed some time between nine and ten years. Thus sampling different parts of this tooth provides a record of diet at different stages between birth and approximately ten years of age. Different teeth erupt at different times, so the pattern can be obtained by sampling along a tooth row.

To minimise damage to the archaeological specimens, dentine was taken, where possible, from broken teeth. In a few cases, samples were taken from the occlusal surfaces of teeth from which the enamel had been worn away due to the nature of the hunter-gatherer diet. Teeth that were complete and in a good state of preservation, or that showed evidence of disease or wear due to activities other than eating, were not sampled.

Methods

Extraction of bone collagen

The nitrogen and carbon isotope ratios were measured for collagen extracted from the bone samples. The 'collagen' referred to in this thesis is actually the acid-insoluble protein fraction of the bone. The method of extraction depends on the sample form, i.e. whether the bone has been ground into powder form, or left as chunks. Bone chunks were used in this project, and the method of collagen extraction follows below.

Following Sealy (1997) the surfaces of whole bone chunks were cleaned with a *Dremel* hand-held drill fitted with an emery disc. The chunks were subsequently placed in 0.1M hydrochloric acid (HCl) at room temperature. This step decalcifies the bone, dissolving the mineral component. The period of decalcification ranged between five and nine days, or until the bone chunks were translucent. The bigger the chunk, the longer the reaction time with HCl. The acid was replaced every three to four days to ensure that there was enough acid to achieve complete decalcification. The resulting collagen pseudomorphs were rinsed in distilled water to remove the acid. Humic acids were removed from the acid insoluble protein by placing the

placing the decalcified bone in 0.1M sodium hydroxide (NaOH) overnight. After removing the “collagen” from the NaOH, the samples were soaked in distilled water and this was changed periodically over a period of one week to ensure neutrality. The final step consisted of freeze-drying the samples. Where bone chunks subjected to this extraction method preserve their original shape this indicates that the structure and cross-bonding of the collagen molecules is preserved.

Collagen quality evaluation in bone

Fresh bone contains about 20 weight percent collagen, with this percentage dropping during burial depending on climatic conditions. When collagen content drops to below 0.5% it becomes difficult to isolate collagen for analysis. Only bone with a collagen yield of greater than 1% is considered to give reliable isotopic results by the Oxford Radiocarbon Accelerator laboratory (van Klinken 1999). This cut-off is, however, very much lower than the level used by Ambrose (1990), who found that collagen was well preserved only down to 3.5% by weight.

The use of C:N ratios has been widely applied as an indicator of collagen quality. It has been proposed that if the modern C:N ratio is preserved in archaeological collagen samples, it affords some guarantee that collagen is well-preserved, and is likely to yield reliable analytical results. DeNiro (1985) showed that the atomic C:N ratio lies in the range of 2.9 – 3.6 in modern animals and humans. This ratio has since been the accepted range (see van Klinken 1999). The Oxford laboratory uses a range of 3.1 – 3.5 as a quality control measure.

Extraction of dentine collagen

The extraction method for dentine collagen is in essence the same as that for bone collagen. Dentine samples were removed from the archaeological specimens, in some cases in the form of chunks, in other cases as powder. Chunks were treated like bone chunks, as described above.

For the dentine powder, because the amount of starting material was greatly reduced, the process of collagen extraction was less time consuming but more labour intensive. Samples of between 2.5 and 10mg were transferred into pre-weighed Eppendorf tubes. To this 0.5ml of 0.05M HCl was added to the powder for time periods ranging from between five and 15 minutes, depending on the amount of powder. Tubes were tapped against the bench to ensure a uniform surface area for reaction with the HCl. During this time, the tubes were shaken at regular intervals as the powder settles to the bottom of the tubes. As the HCl decalcifies the dentine powder, it becomes gelatinous. The tubes were transferred to an Eppendorf centrifuge and centrifuged for approximately 20 seconds. The supernatant was discarded and the samples rinsed three times with distilled water. 1ml 0.1M NaOH was added to the remaining pellet of dentine collagen to remove humic contaminants, as in bone collagen extraction. The tube was shaken periodically over a period of 15 minutes. The tube containing both the pellet and the NaOH was centrifuged, and the supernatant was discarded. The samples were once again rinsed three times with distilled water to ensure neutrality. Samples were freeze-dried in the Eppendorf tubes covered with parafilm to ensure that none of the sample was lost in this process. If the final mass of the sample was significantly greater than 20% of the starting mass, the samples were again treated with acid, then rinsed until this yield was achieved. Dentine does have a slightly lower

percentage of collagen, 17.5 to 18.5% (Hillson 1986). Samples with high yields were put back into acid, allowing the excess inorganic component to dissolve. The samples were rinsed, as before, to ensure neutrality.

Instrumentation and standards

Carbon and nitrogen isotope ratios were measured on a Finnigan MAT 252 light isotope mass spectrometer with on-line Carlo-Erba preparation unit. A Sartorius microbalance was used to weigh prepared samples of between 0.5 and 0.6mg of the prepared collagen extractions. The samples were placed in tin capsules that were then pressed into a bead to exclude atmospheric nitrogen, and placed in a sample carousel. The carousel drops each capsule sequentially into a slide, which in turn, drops the capsule into a vertical furnace tube to be combusted. The capsule and sample are flash-combusted in a stream of oxygen at a temperature of approximately 1600°C. Evolved gases are carried in a stream of helium through an oxidizing furnace tube at 1020°C, a reducing furnace tube at 650°C, and a water trap at ambient temperature. The end products are carbon dioxide (CO₂) and nitrogen (N₂) gas. The emerging anhydrous CO₂ and N₂ pass through a packed chromatography column at 40°C which separates the gases from each other due to their different affinities for the column's exchange medium, with N₂ eluting from the column before CO₂. The gases are then carried in the helium stream to the mass spectrometer where they are analysed. The ratios of the analyte isotopes in the sample gases are measured against those of laboratory reference gases, the values of which are known, relative to the international Peedee Belemnite (PDB) standard (for carbon) and to atmospheric nitrogen.

Precision and accuracy are monitored using in-house standards: Merck gelatine (commonly referred to as “Merck gel”) has values for $\delta^{13}\text{C}$ of -20.1‰ and $\delta^{15}\text{N}$ of $+7.5\text{‰}$, and DL Valine gives values of -26.4‰ for $\delta^{13}\text{C}$ and $+11.8\text{‰}$ for $\delta^{15}\text{N}$. These values have been determined by repeated measurement, calibrated against international standards. The precision of the results is dependent on the equipment. Values for the standard deviations obtained for Merck gel and DL Valine standards run in the course of this thesis are tabulated below.

Table 4.1: Standard deviations for repeated analyses of standards.

<i>Merck gel</i>			<i>DL Valine</i>		
$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	N	$\delta^{13}\text{C}$	$\delta^{15}\text{N}$	N
$\pm 0.11\text{‰}$	$\pm 0.27 \text{‰}$	52	$\pm 0.06\text{‰}$	$\pm 0.20\text{‰}$	51

The results of the analysis are explored in the following chapter.

CHAPTER FIVE

RESULTS

Introduction

This chapter will outline the results obtained for isotopic analysis carried out on bone and dentine collagen. The effects of age on the carbon and nitrogen isotope ratios are recorded, presented in various diagrams and briefly discussed. By comparing the isotopic ratios for various skeletal elements, we gain a holistic view of infant feeding patterns in the society at the Matjes River Rock Shelter.

Isotope ratios in collagen

As reported in Chapter Four, bone samples were taken from 41 individuals for the extraction of bone collagen. Four of these were from the Robberg Peninsula and are included merely for interest, following the observation of a difference in the adult diets between the two sites (Sealy and Pfeiffer 2000, Muller 2001). Of the 37 individuals sampled from the Matjes River collection, three did not yield collagen (NMB 1301, NMB 1603, and Wilton Grave 1 “30M2/96”). One individual, NMB 1248, was sampled but not included in the list of results. Since only a mandible and cranium are present and the third molars had not erupted, it was initially thought that this individual was a juvenile. Subsequent x-rays of the mandible revealed that the tooth root of the second molar was complete and there was no sign of a third molar. Hence, this individual is an adult with a congenitally absent third molar.

The number of individuals analysed was increased by sampling dentine from adult and juvenile dentitions. Two samples proved to contain insufficient material for collagen extraction. An additional five samples were lost during mass spectrometry, and the results for the remaining 32 samples are reported below (Table 5.1). Collagen yields and C:N ratios for all samples were determined as indicators of collagen quality.

Following the practice at the Oxford Radiocarbon Accelerator laboratory, a collagen yield of greater than 1% by weight is considered to give reliable isotopic results. The yields for bone collagen ranged between 1.7 and 22.4% (Table 5.1). Only six samples yielded less than 10% collagen by weight. The majority yielded close to 20% collagen. C:N ratios ranged between 2.9 and 3.6, except for two bone samples (UCT 8185 and UCT 9146), which yielded C:N values of 3.8 and 3.7 respectively, which fall outside of the accepted range of 2.9 to 3.6 (see Chapter Four). One dentine sample (UCT 9825) has a C:N value of 3.7. The two bone samples, however, gave acceptable collagen yields of 21.8 and 17.3% by weight respectively. The dentine sample yielded 28% collagen by weight. The isotopic ratios will be included in the discussion below, but these three samples will be marked in the graphs in order to assess the possibility of their being anomalous.

Some dentine samples yielded more than 20% collagen by weight. These samples were treated again with dilute HCl, in the event they were not completely decalcified. For several samples (UCT 9801, 9804, 9807, 9808, 9818, 9821, 9822, 9834), collagen mass remained constant. It is not clear why these yields are so high, but the C:N ratios fall between 2.9 and 3.6, so the isotopic values may be reliable.

Nitrogen isotope ratios

33 bone collagen samples from Matjes River yielded $\delta^{15}\text{N}$ values ranging between 9.9 (UCT 8202) and 19.1‰ (UCT 8188), with a mean value at 14.3 ± 2.1 ‰. The four individuals from the Robberg Peninsula collection gave a higher mean at 17.1 ± 0.5 ‰, consistent with documented adult values (Sealy and Pfeiffer 2000, Muller 2001). These results will not be included in the graphs to follow because of the dietary differences between the two populations.

Fig. 5.1 shows $\delta^{15}\text{N}$ for bone collagen plotted against estimated age at death. The first striking feature about this plot is the values for those individuals who died around the time of birth, who also occupy both ends of the range for bone collagen $\delta^{15}\text{N}$ values. There is a difference of approximately 9‰ between the highest and lowest values. These three individuals died at or soon after birth, before the effect of diet can be detected in bone tissue laid down after birth. The two individuals at the lower end of the range, with $\delta^{15}\text{N}$ values of 10.0 and 9.9‰, respectively (UCT 8202 and UCT 8200) must have been the infants of mothers who ate diets with low average $\delta^{15}\text{N}$ during pregnancy, since tissue from neonates reflects the mothers' diets. The lowest value for adult bone collagen is 6.8‰.

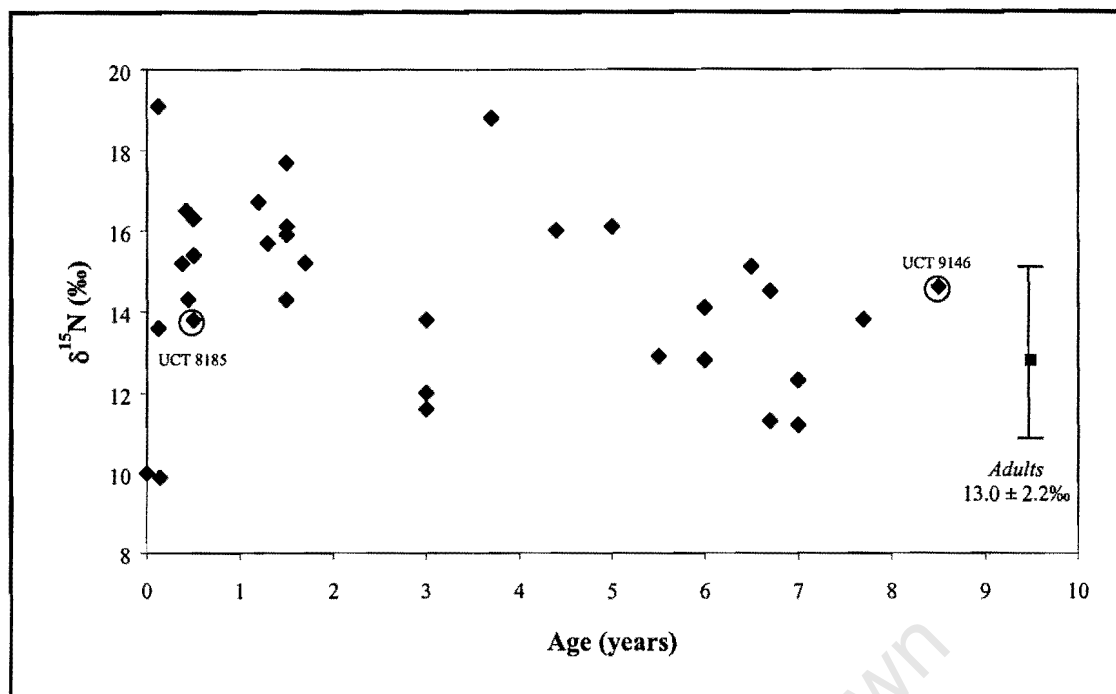


Figure 5.1: $\delta^{15}\text{N}$ values for bone collagen plotted against estimated age at death for infants and children from the Matjes River Rock Shelter collection. UCT 8185 and UCT 9146 are highlighted since their C:N values are higher than expected, and so may reflect possible contamination. The mean value for adults ± 1 standard deviation is shown.

At the other end of the dietary spectrum, the high value of 19.1‰ seen in UCT 8188 is somewhat higher than the upper end of the range for adults in the population, which is 17.7‰ (Muller 2001). Diets that led to such high values must have included high trophic level marine organisms such as seals or carnivorous fish.

Focussing on the remaining points on the plot, bone collagen from individuals of up to two years old have relatively high $\delta^{15}\text{N}$ values. This is a period of rapid growth, and bone collagen laid down at this time clearly registers the effect of breastfeeding, leading to elevated $\delta^{15}\text{N}$. $\delta^{15}\text{N}$ values for individuals in the two to four year age range show a great deal of variation (11.6 to 18.8‰). There are, however, only four data points in this range, making it difficult to assess any patterning. Children older than four years show a tendency towards decreasing $\delta^{15}\text{N}$ with age, as expected after

expected after weaning. The average $\delta^{15}\text{N}$ value for these children is 13.7 ± 1.6 (n = 12), comparable to the mean value for the adults in the population.

Since there are more crania and mandibles in the Matjes River collection than there are post-cranial skeletons, the number of individuals analysed was increased by including dentine collagen samples taken from both juveniles and adults in the collection. Collagen was extracted from the tips of the roots from three deciduous molars and one deciduous canine, taken from four different individuals. The roots of deciduous canines are complete between 2.5 and 3.5 years after birth, while the roots of the first deciduous molars are complete between two and three years after birth. Roots of the second deciduous molars complete their growth slightly later, at about three years. $\delta^{15}\text{N}$ results for collagen extracted from the root tips are plotted against age of root completion in Fig.5.2.

Inclusion of the results for dentine collagen from deciduous teeth confirms that there is indeed a high degree of variability in $\delta^{15}\text{N}$ in the two to four year age range. It is possible that the two to four year olds with lower $\delta^{15}\text{N}$ values were weaned early. However, it is also possible that we are looking at a multi-component weaning curve (see below). Also, since none of the juvenile skeletons have been radiocarbon dated, there exists the possibility that the variation observed could be due to temporal differences.

Table 5.1: Isotopic composition of bone collagen and dentine with measures of collagen quality.

<i>UCT Lab. No.</i>	<i>Museum Accession number/ description</i>	<i>Sample</i>	<i>Age (years)</i>	<i>% Collagen yield</i>	<i>C:N ratio</i>	$\delta^{15}N$	$\delta^{13}C$
8200	S4 26' Baba	Vault bone	0.0	9.5	3.6	10.0	-17.4
8188	NMB 1444	Rib fragment	0.1	11.5	3.2	19.1	-12.9
9150	212? Matjiesrivier (infant)	Rib fragment	0.1	10.2	3.3	13.6	-14.0
8202	S4/26'/36"	Vault bone	0.1	9.3	3.3	9.9	-16.9
8190	WSK1 (infant)	Rib fragment	0.4	21.2	3.4	15.2	-15.0
8205	MSK 6	Vault bone	0.4	15.0	3.0	16.5	-13.9
8203	Matjes River child's grave 5V 7-8/10	Vault bone	0.5	4.8	3.1	14.3	-14.9
8183	OKT 58	Rib fragment	0.5	14.3	3.0	15.4	-14.4
8185	S 592	Rib fragment	0.5	21.8	3.8	13.8	-17.8
8197	Unmarked Infant (box labelled "Skulls of infants (?))	Mandibular bone	0.5	10.9	3.0	16.3	-13.1
8208	WSK1 (juvenile)	Vault bone	0.9	1.7	3.2	15.2	-15.6
8187	NMB 1447 (juvenile) "New cave at Platbank"	Rib fragment	1.2	14.2	3.0	16.7	-14.5
8193	NMB 1255	Mandibular bone	1.3	17.6	3.0	15.7	-13.6
8194	NMB 1254 "MRA x ₂ "	Mandibular bone	1.5	22.4	3.0	17.7	-13.8
8196	NMB 1259	Mandibular bone	1.5	21.4	3.0	14.3	-14.1
8199	NMB 1276	Vault bone	1.5	8.3	3.1	16.1	-15.1
8204	NMB 1266 "MRA x ₁₁ "	Mandibular bone	1.5	15.9	3.0	15.9	-15.6
8209	NMB 1260	Vault bone	3.0	18.1	3.3	13.8	-13.8
9147	Unmarked Matjes River in box 'c1986 A-D'	Maxillary bone	3.0	13.3	3.1	11.6	-13.9
9148	NMB 1260 (with frontal)	Vault bone	3.0	20.7	3.0	12.0	-14.7
8207	NMB 1253	Mandibular bone	3.7	15.7	3.1	18.8	-12.4
8191	Skelette S5 proto	Rib fragment	4.4	16.2	3.1	16.0	-12.8
8201	NMB 1261	Vault bone	5.0	13.6	3.1	16.1	-13.4
8206	NMB 1258 "MRA x 1 7My.La"	Mandibular bone	5.5	20.1	3.0	12.9	-15.2
9151	NMB 1268 [MRSK and 1268]	Mandibular bone	6.0	4.8	3.1	14.1	-15.1
9152	M (juvenile)	Fragment of nasal bone	6.0	15.9	3.1	12.8	-14.7
8192	NMB 1287	Mandibular bone	6.5	14.2	3.2	15.1	-13.9
8186	Wilton uppermost stratum II - immature [A]	Cortical bone-medial side of ulna	6.7	22.0	2.9	11.3	-15.0
8189	Skeleton no. 4 top mytilus	Rib fragment	6.7	18.0	3.1	14.5	-13.3
8211	Wilton uppermost stratum II - immature [B]	Cortical bone-anterior surface of tibia	7.0	17.9	3.5	11.2	-14.7

<i>UCT Lab. No.</i>	<i>Museum Accession number/ description</i>	<i>Sample</i>	<i>Age (years)</i>	<i>% Collagen yield</i>	<i>C:N ratio</i>	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$
9149	With NMB 1260	Cortical bone-distal end of fibula	7.0	12.6	3.0	12.3	-13.0
8212	MRS K with 1268	Cortical bone-distal anterior surface of femur	7.7	16.0	3.3	13.8	-13.7
9146	Unmarked Matjes River [Clayton 2002]	Fragment of zygomatic arch	8.5	17.3	3.7	14.6	-17.7
*8182	NMB 1644	Rib fragment	0.083	20.5	3.2	17.9	-13.8
*8184	NMB 1643	Rib fragment	0.12	18.0	3.1	17.2	-14.8
*8198	NMB 1642	Cortical bone-proximal anterior surface of tibia	5.3	20.1	3.1	16.4	-12.3
*8210	NMB 1641	Cortical bone-proximal anterior surface of tibia	5.5	21.6	3.3	17.0	-12.3
<i>Deciduous teeth</i>							
9817	Skeleton no.4 top mytilus	Root tip - either deciduous M1 or M2	2.5	24.9	3.4	15.9	-15.2
9800	Unmarked Matjes River 'c1986 A - D'	Root tip - deciduous R M ₂	2.8	13.1	3.1	13.1	-14.6
9816	Skeleton no.4 top mytilus	Root tip - deciduous c	2.8	26.4	3.1	17.1	-13.0
9824	M (juvenile)	Root tip ~ deciduous M2	2.8	25.3	3.0	13.6	-14.6
<i>Permanent teeth **</i>							
9805	NMB 1602	R M ₁ wear stage 4+ ^a	1.5	20.9	3.4	13.9	-13.2
9813	NMB 1246	R M ₁ ¹ wear stage 3+ ^b	1.5	21.1	3.6	17.8	-14.2
9818	212? MR adult	R M ₁ wear stage 5+ ^b	1.5	26.1	3.4	14.8	-14.7
9820	Mr 5V.0.12	L M ₁ wear stage 4 ^b	1.5	23.5	3.2	9.9	-18.6
9821	SS1-4	L M ₁ wear stage unknown ^b	1.5	26.2	2.9	15.8	-15.3
9825	M (adult)	R M ₁ wear stage 5 ^b	1.5	28.0	3.7	12.6	-16.0
9828	NMB 1373	L M ₁ ¹ wear stage not noted ^a	1.5	21.1	3.1	8.9	-17.2
9835	NMB 1243	L M ₁ wear stage 5+ ^b	1.5	23.6	3.4	13.7	-15.7
9801	NMB 1451	L M ₁ ¹ wear stage not noted ^b	2.0	25.3	3.4	7.1	-16.3
9807	NMB 1308	R M ₁ ¹ wear stage 4 ^b	2.0	26.5	3.3	13.9	-16.7
9819	NMB 1251	R I ₂ wear stage 5++ ^b	2.0	24.1	3.0	9.7	-18.1
9836	NMB 1310	R I ₂ ² wear stage 5 ^a	2.0	21.1	3.4	13.0	-15.7
9815	NMB 1247	R M ₁ wear stage 5+ ^b	2.5	4.3	2.9	12.5	-17.3
9834	NMB 1264	L Man C wear stage 5 ^a	3.0	25.1	3.5	6.3	-22.0
9810	NMB 1246	L P ₁ ¹ wear stage 3+ ^a	3.5	34.1	3.3	13.5	-14.4
9809	NMB 1246	L Man C wear stage 3+ ^c	4.0	24.4	3.3	13.0	-15.5
9832	NMB 1373	R I ₂ wear stage not noted ^c	4.0	21.0	2.9	7.9	-17.0

<i>UCT Lab. No.</i>	<i>Museum Accession number/ description</i>	<i>Sample</i>	<i>Age (years)</i>	<i>% Collagen yield</i>	<i>C:N ratio</i>	$\delta^{15}\text{N}$	$\delta^{13}\text{C}$
9833	NMB 1373	R I ₂ wear stage not noted ^d	4.0	24.4	3.5	14.7	-14.7
9822	SS1-4	L M ₂ wear stage not noted ^b	4.5	35.0	3.2	14.5	-16.0
9803	NMB 1446	R M ² wear stage 5++ ^b	5.0	23.6	3.0	12.1	-16.6
9811	NMB 1246	L P ¹ wear stage 3+ ^c	5.0	20.6	3.4	9.4	-15.3
9812	NMB 1246	L M ² wear stage 3+ ^c	5.0	8.9	3.5	13.6	-16.4
9814	NMB 1247	L M ₂ wear stage 5+ ^b	5.0	16.1	3.6	14.1	-15.4
9804	NMB 1446	L P ₁ , wear stage 5++ ^d	6.0	26.1	3.2	12.4	-15.0
9831	NMB 1373	R Man C wear stage not noted ^c	6.0	15.3	3.4	13.0	-13.4
9806	NMB 1602	R M ₃ wear stage 4+ ^a	11.0	13.9	3.5	15.3	-12.5
9808	NMB 1308	R M ³ wear stage 4 ^a	11.0	25.2	3.6	8.6	-19.9
9823	SS1-4	L M ₃ wear stage unknown ^b	11.0	12.3	3.4	15.8	-14.2

* These samples are from the Robberg Peninsula. See Appendix for further details on all samples.

** Dentine samples from permanent teeth are coded as follows:

- a. Damaged tooth, sampled from immediately beneath occlusal enamel
- b. Sample taken from dentine on occlusal surface, exposed by tooth wear
- c. Damaged tooth, dentine from midway down the crown
- d. Damaged tooth, dentine chunk from neck of tooth
- e. Damaged tooth, dentine powder from neck of tooth

Wear stage was determined using Brothwell's (1981) classification of tooth wear.

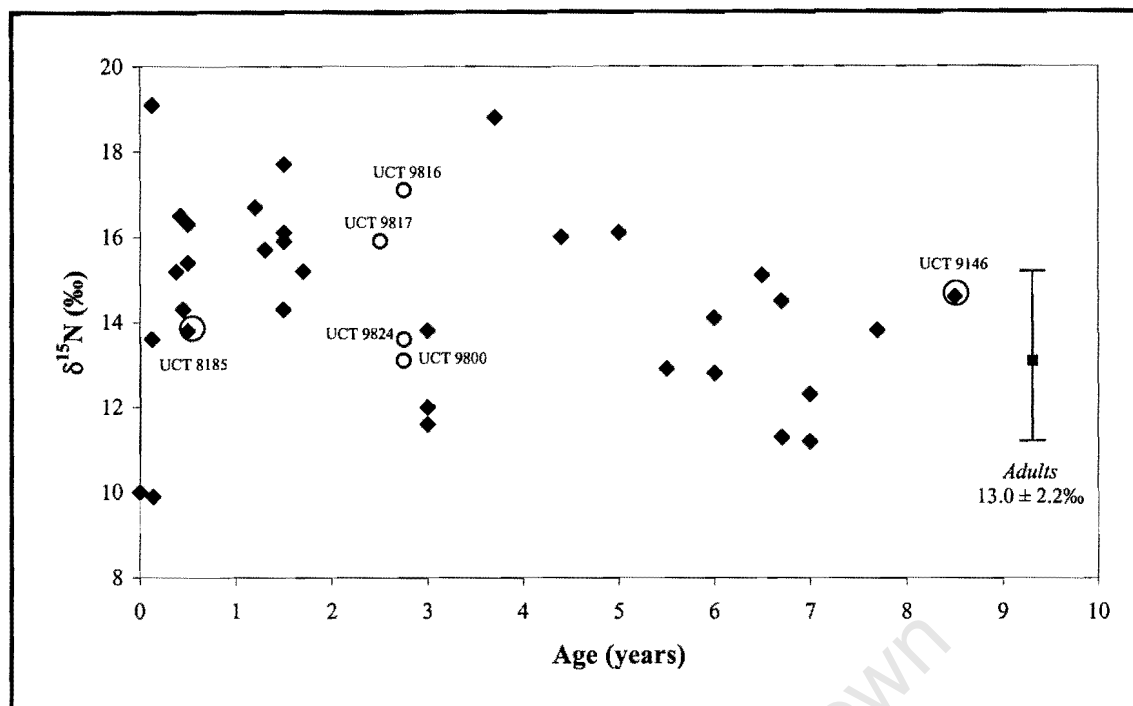


Figure 5.2: $\delta^{15}\text{N}$ values for bone (♦) and dentine from the root tips of deciduous teeth (○) plotted against estimated age for infants and children from Matjes River Rock Shelter. UCT 8185 and UCT 9146 are highlighted since their C:N values are higher than expected, and so may reflect possible contamination. The mean value for adults \pm 1 standard deviation is shown.

In Fig. 5.3 the data set has been divided into two, i.e. a set with higher $\delta^{15}\text{N}$ values (resulting from seafood-rich maternal diets) and one with lower $\delta^{15}\text{N}$ values (more terrestrial maternal diets). An interesting observation is that dividing the data set does not appear to have an effect on the age at which the $\delta^{15}\text{N}$ values reach a maximum; in both cases, this occurs at three to four years. Hence, the presence of more than one weaning curve is a likely explanation for the variation seen within an age group. Although the standard deviation for the mean $\delta^{15}\text{N}$ value in the adult population is low, the range in values is large enough to provide some support for the possibility of a multi-component weaning curve at Matjes River.

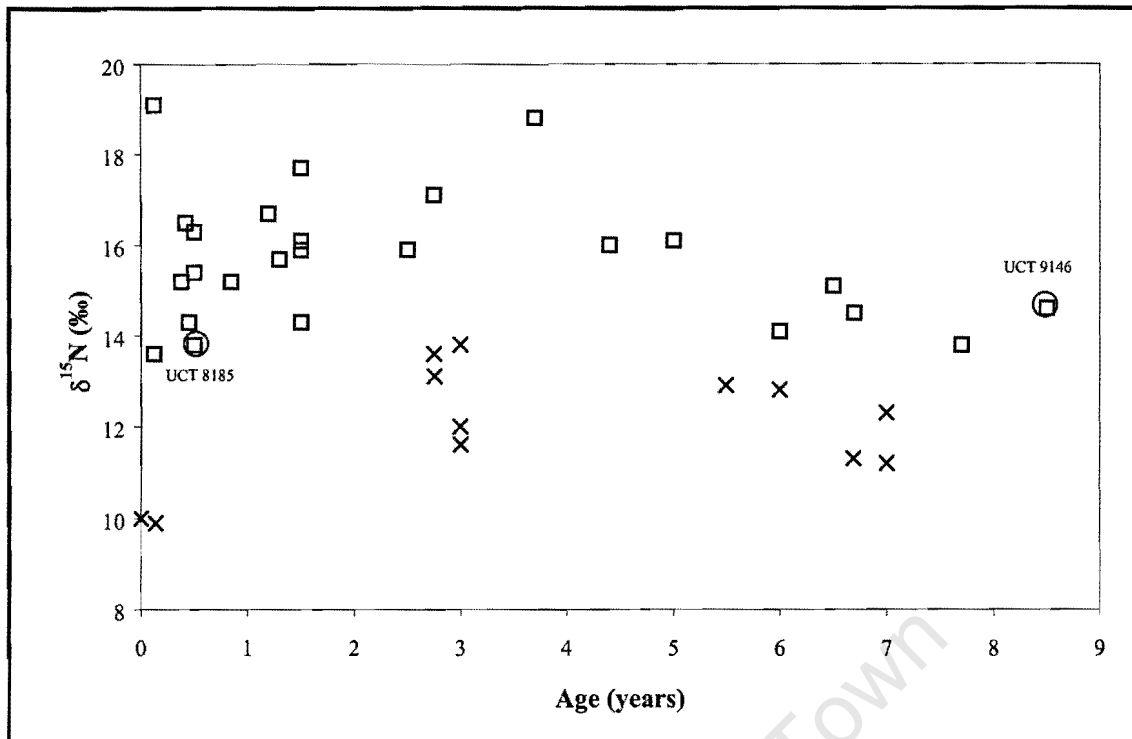


Figure 5.3: $\delta^{15}\text{N}$ values for bone and dentine from the root tips of deciduous teeth plotted against estimated age for infants and children from Matjes River Rock Shelter. Different symbols are used to show the possibility of a multi-component weaning curve. UCT 8185 and UCT 9146 are highlighted since their C:N values are higher than expected, and so may reflect possible contamination.

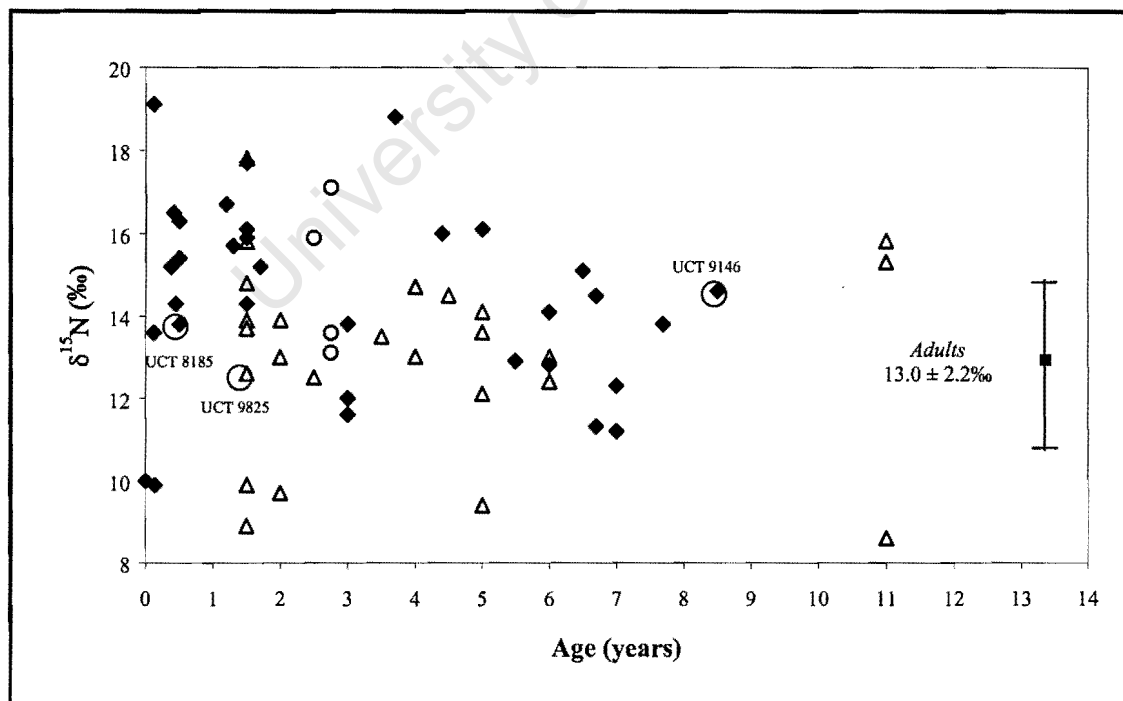


Figure 5.4: $\delta^{15}\text{N}$ values for bone (\blacklozenge), deciduous root tip (\circ) and permanent dentine collagen (\triangle) plotted against estimated age for individuals from Matjes River Rock Shelter. Circled points have high C:N values. The mean value for adults ± 1 standard deviation is shown.

In Fig. 5.4, $\delta^{15}\text{N}$ values for dentine samples from adult teeth are also plotted (refer to Chapter Four for discussion on determination of ages against which these results have been plotted). It should be noted that the plot does not change significantly if the dentine samples with high yields are eliminated. Clearly the inclusion of $\delta^{15}\text{N}$ values for dentine samples from permanent dentition introduces a great deal more variation than was evident in Fig. 5.2. The variation seen in this plot could be due to various factors. The large differences in $\delta^{15}\text{N}$ values within individuals of the same age could be the result of somewhat crude sampling techniques. Since dentine is laid down rather rapidly in the formation of teeth, the differences seen might reflect variation in diet over short periods. It is also possible that there are metabolic processes taking place in individuals from Matjes River that have not been fully explored. The variation observed will be discussed further in the next chapter.

Overall it is clear from the plots that juveniles tend to be enriched in $\delta^{15}\text{N}$ compared to the adults in the population ($13.0 \pm 2.2\%$, $n=33$). This is mainly due to the trophic level effect. The $\delta^{15}\text{N}$ values increase steadily from birth to at least two years of age, during which time children must be gaining all or most of the protein in their diets from breastmilk. Among the two to four year olds, $\delta^{15}\text{N}$ values are very varied. After the age of four years, values slowly decrease to approach the adult mean. The variation in the results for children older than two years suggests that some children were breastfed for shorter or longer periods than others, or that there were individual preferences for different protein sources.

The graphs above represent breastfeeding and weaning activities at a population level at Matjes River. There are, however, ten individuals from whom multiple collagen

samples were extracted, with different ages of formation. Hence, change in diet with age can be traced within these ten individuals (Table 5.2).

Table 5.2: $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values for collagen extracted from multiple skeletal elements of ten different individuals, tracking various stages of growth.

<i>UCT Lab. No.</i>	<i>Museum Accession Number</i>	<i>Sample</i>	<i>Age (years)</i>	<i>$\delta^{15}\text{N}$ (‰)</i>	<i>$\delta^{13}\text{C}$ (‰)</i>
9805	NMB 1602	RM ₁ wear stage 4+ ^a	1.5	13.9	-13.2
9806		RM ₃ wear stage 4+ ^a	11.0	15.3	-12.5
9813	NMB 1246	R M ¹ wear stage 3+ ^b	1.5	17.8	-14.2
9810		L P ¹ wear stage 3+ ^a	3.5	13.5	-14.4
9809		L Man C wear stage 3+ ^c	4.0	13.0	-15.5
9811		L P ¹ wear stage 3+ ^c	5.0	9.4	-15.3
9812		L M ² wear stage 3+ ^c	5.0	13.6	-16.4
9821	SS1-4	L M ₁ wear stage unknown ^b	1.5	15.8	-15.3
9822		L M ₂ wear stage not noted ^b	4.5	14.5	-16.0
9823		L M ₃ wear stage unknown ^b	11.0	15.8	-14.2
9828	NMB 1373	L M ¹ wear stage not noted ^a	1.5	8.9	-17.2
9832		R I ₂ wear stage not noted ^e	4.0	7.9	-17.0
9833		R I ₂ wear stage not noted ^d	4.0	14.7	-14.7
9831		R Man C wear stage not noted ^e	6.0	13.0	-13.4
9807		NMB 1308	R M ¹ wear stage 4 ^b	2.0	13.9
9808	R M ³ wear stage 4 ^a		11.0	8.6	-19.9
9815	NMB 1247	R M ₁ wear stage 5+ ^b	2.5	12.5	-17.3
9814		L M ₂ wear stage 5+ ^b	5.0	14.1	-15.4
9817	Skeleton no. 4 top mytilus	Root tip - either deciduous M1 or M2	2.5	15.9	-15.2
9816		Root tip - deciduous c	2.8	17.1	-13.0
8189		Rib fragment	6.7	14.5	-13.3
9800	Unmarked Matjes River 'c1986 A-D'	Root tip - deciduous R M ₂	2.8	13.1	-14.6
9147		Maxillary bone	3.0	11.6	-13.9
9824	M (juvenile)	Root tip - deciduous M2	2.8	13.6	-14.6
9152		Fragment of nasal bone	6.0	12.8	-14.7
9803	NMB 1446	R M ² wear stage 5++ ^b	5.0	12.1	-16.6
9804		L P ₁ wear stage 5++ ^d	6.0	12.4	-15.0

Changes in $\delta^{15}\text{N}$ values with age are observed within most of these individuals. No significant difference is seen in values for NMB 1446, M (juvenile) and SS1-4. NMB 1246, NMB 1308 and Unmarked Matjes River 'c1986 A – D' show higher $\delta^{15}\text{N}$ values in early childhood than in later childhood. The changes in $\delta^{15}\text{N}$ values with age

can be explained in terms of the transition from one protein source to another. NMB 1246 shows a fairly rapid decrease in $\delta^{15}\text{N}$ between the ages of 1.5 and 3.5 years. This is a little earlier than expected based on the general pattern seen in Figs. 5.1 to 5.3. NMB 1308 shows a decline of 5.3‰ between the ages of 2.0 and 11.0 years. The lower value, at 8.6‰, is comparable to the lowest values reported for adults at Matjes River. Unmarked Matjes River 'c 1986 A-D' shows a drop of 1.5‰ between the ages of 2.8 and 3.0 years, a period of just over two months. It is thus unclear whether the $\delta^{15}\text{N}$ values from this individual really reflect weaning or whether they are an example of the kind of intra-individual variation discussed below.

The values, however, do not always decrease with age (e.g. NMB 1602, NMB 1373 and NMB 1247). This effect may be due to the increased incorporation of marine food sources into the diet. Two individuals, NMB 1246 and NMB 1373, show marked differences in $\delta^{15}\text{N}$ values (4.2 and 6.8‰ respectively) for dentine collagen from different teeth, but supposedly formed at the same age. As mentioned earlier, this may reflect inaccuracies in the determination of age of dentine deposition, and/or a variable diet during a time of rapid deposition of dentine. The collagen extracted would then represent diet over a fairly short time period. With a bigger sample size, it would be possible to observe variations in diet in more detail throughout childhood.

Carbon isotope ratios

In Fig. 5.5, $\delta^{13}\text{C}$ values for the same samples are plotted against estimated age at death. Comparing Fig. 5.5 with Fig. 5.1, we notice that juvenile $\delta^{13}\text{C}$ values are more tightly clustered than $\delta^{15}\text{N}$ values. This is because carbon is less sensitive to trophic level effects. Breastfeeding infants are usually depleted in ^{13}C in comparison to adults

because of the consumption of lipids from breastmilk (Wright and Schwarcz 1998, 1999). In Fig. 5.5 $\delta^{13}\text{C}$ values become steadily more negative between birth and two years old, as predicted for primarily breastfed infants. This mirrors the steady progressive change in $\delta^{15}\text{N}$ for the same age category.

The inclusion of dentine collagen introduces slightly more variation within the two to four year age bracket. For individuals older than two years, the mean $\delta^{13}\text{C}$ value for bone collagen is $-14.2 \pm 1.2\%$. This value is not significantly different from the adult mean, indicating similar carbon isotopic composition of the diets of adults and older children.

In both Figs. 5.5 and 5.6, UCT 8185 and UCT 9146 are outliers, with the most negative $\delta^{13}\text{C}$ values in the entire sample set. The high C:N ratios for these two bone collagen extractions could perhaps be due to contamination with ^{13}C depleted carbon. One likely source is the presence of glue on the skeletal remains that was not recognised at the time of sampling. These $\delta^{13}\text{C}$ values will be disregarded although the $\delta^{15}\text{N}$ values are not outliers. UCT 9825, the dentine sample with a C:N ratio of 3.7, falls within the cluster of data points at 1.5 years. This individual gave a $\delta^{13}\text{C}$ value of -16.0% .

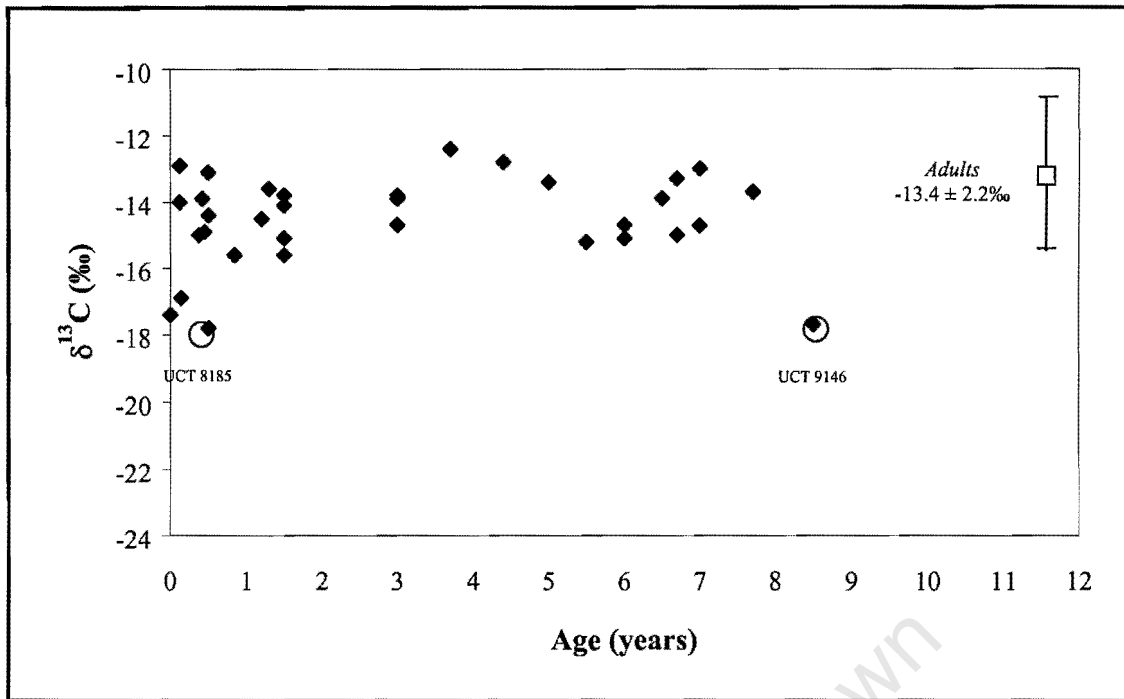


Figure 5.5: $\delta^{13}\text{C}$ values for bone collagen (♦) plotted against estimated age at death for infants and children from Matjes River Rock Shelter. UCT 8185 and UCT 9146 are highlighted since their C:N values are higher than expected, and so may reflect possible contamination. The mean value for adults ± 1 standard deviation is shown.

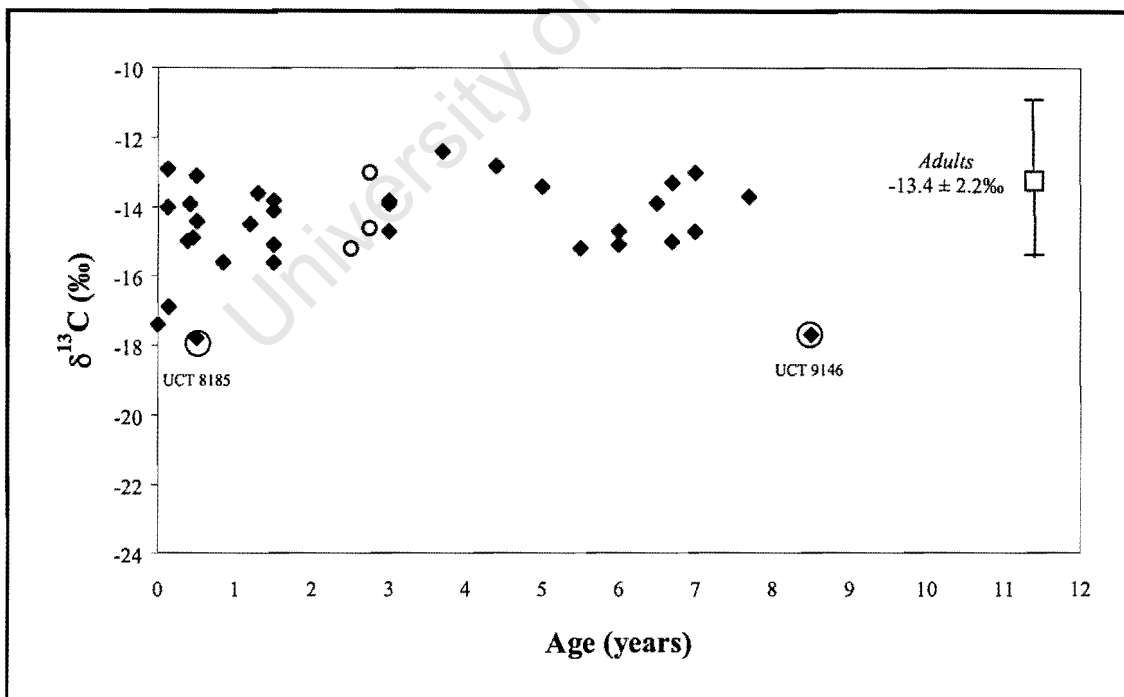


Figure 5.6: $\delta^{13}\text{C}$ values for bone (♦) and dentine from the root tips of deciduous teeth (o) plotted against estimated age for infants and children from Matjes River Rock Shelter. UCT 8185 and UCT 9146 are highlighted since their C:N values are higher than expected, and so may reflect possible contamination. The mean value for adults ± 1 standard deviation is shown.

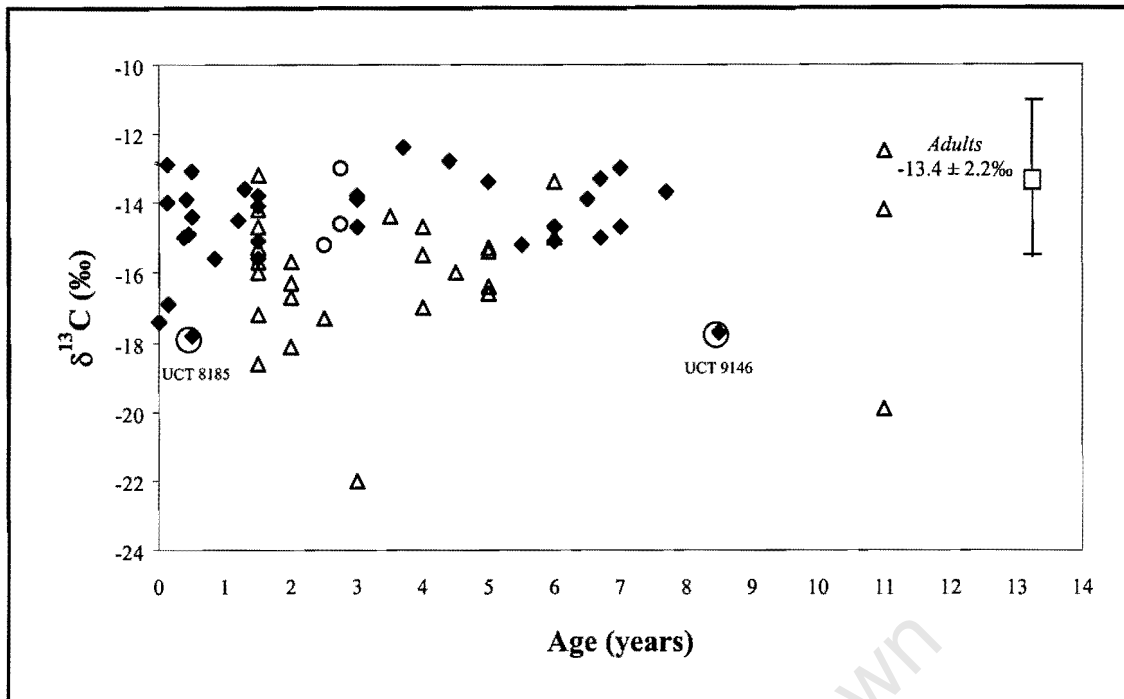


Figure 5.7: $\delta^{13}\text{C}$ values for bone (\blacklozenge), deciduous root tip (\circ), and permanent dentine (\triangle) collagen plotted against estimated age for individuals from Matjes River Rock Shelter. UCT 8185 and UCT 9146 are highlighted since their C:N values are higher than expected, and so may reflect possible contamination. The mean value for adults ± 1 standard deviation is shown.

In Fig. 5.7, results for dentine collagen extracted from permanent teeth have been included in the plot, showing the effect of age on $\delta^{13}\text{C}$ values. Although there is an increase in variation within the different age categories, this variation is not as big as it is for $\delta^{15}\text{N}$ values for dentine collagen from permanent teeth. As mentioned earlier, this is most likely due to the fact that carbon is less sensitive to the trophic level effect.

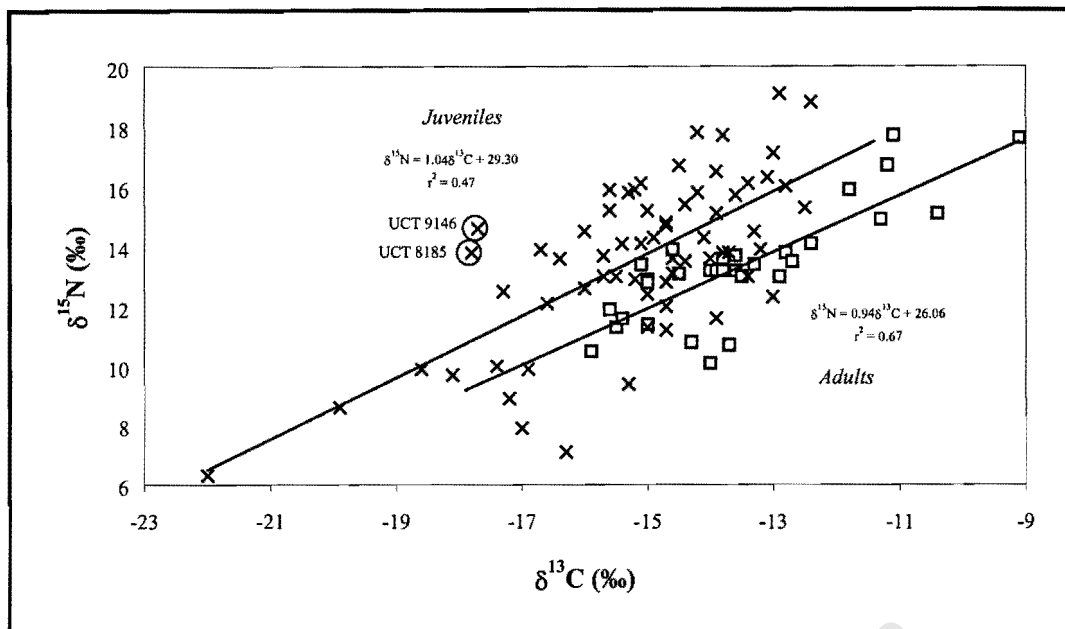


Figure 5.8: $\delta^{15}\text{N}$ plotted against $\delta^{13}\text{C}$ for collagen from adult (\square) and juvenile bone and dentine from all teeth (\times) at Matjes River Rock Shelter. This figure does not include two individuals, UCT 7411 ($\delta^{13}\text{C} = -17.6\text{‰}$ and $\delta^{15}\text{N} = 6.8\text{‰}$) and UCT 7407 ($\delta^{13}\text{C} = -5.6\text{‰}$ and $\delta^{15}\text{N} = 9.6$), from the adult data set. From the enriched $\delta^{13}\text{C}$ and low $\delta^{15}\text{N}$ values it is suspected that these individuals may have had access to domesticated C_4 plant foods (Muller 2001). Three other southern Cape skeletons with similar isotopic patterning dated to the second millennium AD, and two were particularly robust individuals (Sealy and Pfeiffer 2000). Based on the combination of date, stable isotopic ratios and physical form, it is likely that these individuals had contact with food producing communities in the Eastern Cape.

In Fig. 5.8 $\delta^{15}\text{N}$ is plotted against $\delta^{13}\text{C}$ for adult and juvenile skeletons from Matjes River. Juvenile $\delta^{15}\text{N}$ values are clearly elevated when compared with the results for adults. The equation for the regression line for juveniles is $\delta^{15}\text{N} = 1.04 \delta^{13}\text{C} + 29.30$. The equation of the regression line for adults is $\delta^{15}\text{N} = 0.94 \delta^{13}\text{C} + 26.06$. The data points at the end of the ranges have a significant influence on the regression lines. These points, along with UCT 8185 and UCT 9146, have been omitted in Fig. 5.9, and the regression equations recalculated accordingly. In the resulting plot, although the slope of the regression line for the juveniles changes, it remains distinct from the line for the adult population.

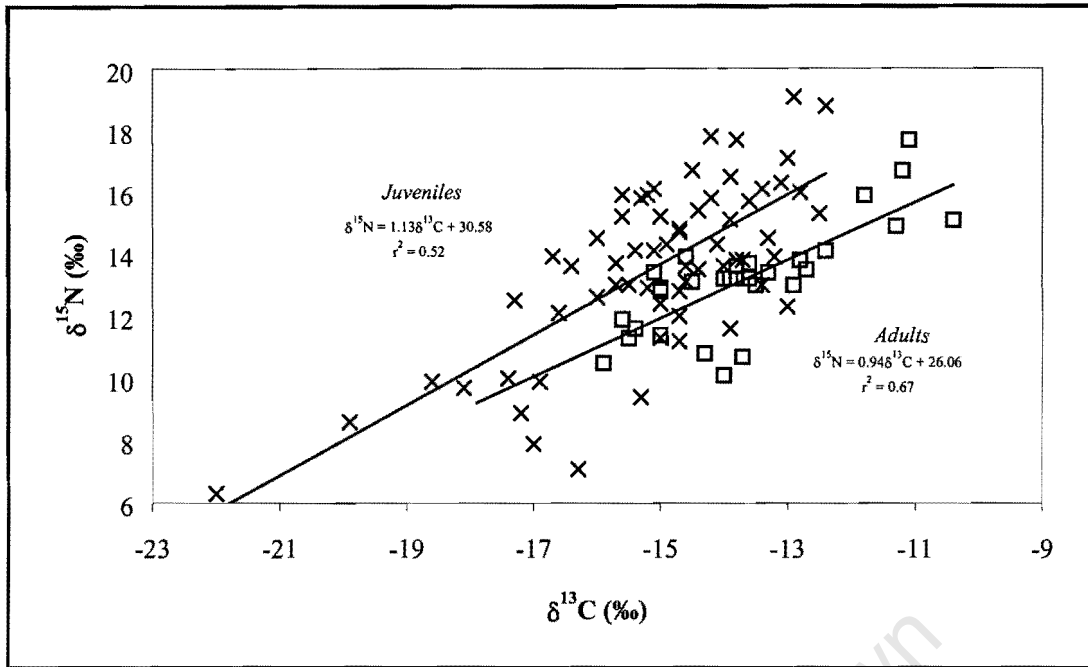


Figure 5.9: $\delta^{15}\text{N}$ plotted against $\delta^{13}\text{C}$ for collagen from adult (\square) and juvenile bone and dentine from all teeth (\times) at Matjes River Rock Shelter. This figure excludes extreme data points, which have a disproportionate influence on the regression lines. UCT 8185 and UCT 9146, have also been excluded from the plot, since their $\delta^{13}\text{C}$ values probably reflect contamination.

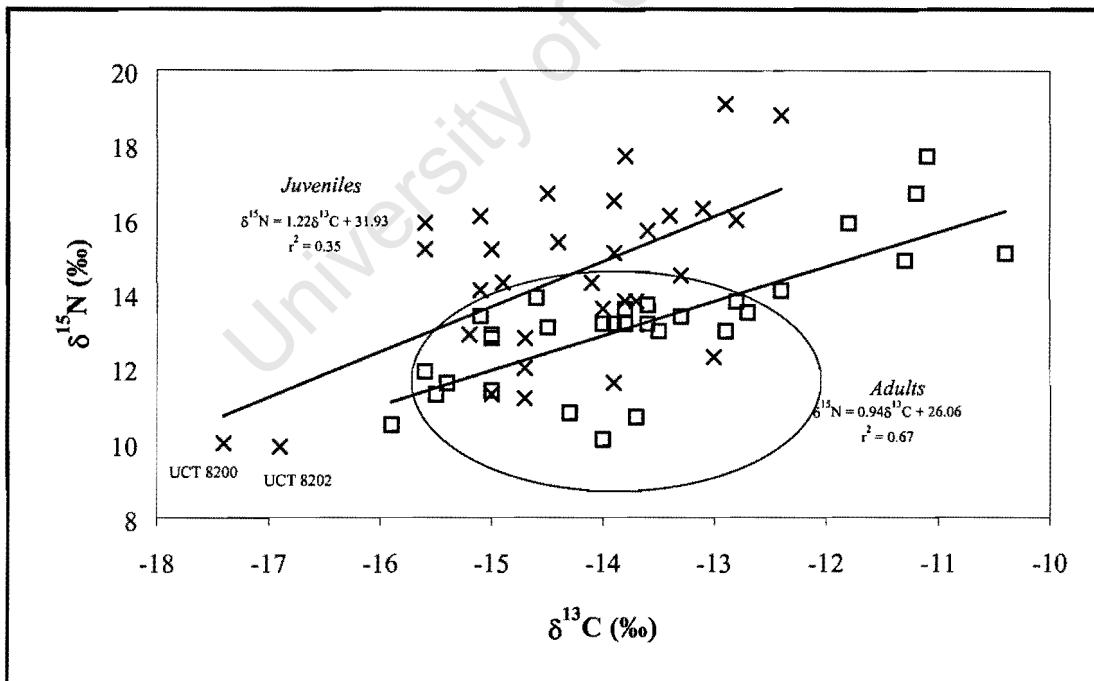


Figure 5.10: $\delta^{15}\text{N}$ plotted against $\delta^{13}\text{C}$ for collagen from adult (\square) and juvenile bone and dentine from the root tips of deciduous teeth (\times) at Matjes River Rock Shelter.

Both Figs. 5.8 and 5.9 are complicated by the inclusion of the dentine samples from adult teeth, which introduce more variation than was seen in the samples from juveniles. In Fig. 5.10, these are omitted. As before, $\delta^{15}\text{N}$ of juveniles are elevated compared with those of the adults. Differences in $\delta^{13}\text{C}$ between juveniles and adults are less clear, but it appears that the $\delta^{13}\text{C}$ values for juveniles are shifted slightly towards the more negative end of the range compared with adults. It is evident that the data for the adults are more tightly clustered around the regression line than the juveniles in the sample, especially in respect to $\delta^{15}\text{N}$. This is due to the fact that the adult diet is not affected by breastfeeding, as is the case in the infant sample. Older juveniles have less positive $\delta^{15}\text{N}$ values: juveniles enclosed within the oval are 2.75 years old and older, except UCT 9150 ($\delta^{15}\text{N} = 13.6$ and $\delta^{13}\text{C} = -14.0$) who is a neonate. Values for these children are approaching adult values, and the older children may in fact have already reached them.

Variation in $\delta^{15}\text{N}$ is due to trophic level effects, and/or to the inclusion of greater or smaller quantities of seafood in peoples' diets. Variation in $\delta^{13}\text{C}$ is partly due to these causes, but another factor also needs consideration. The environment around Matjes River includes some C_4 vegetation (Vogel *et al.* 1978). Did this contribute significantly to human diets, thus affecting $\delta^{13}\text{C}$ (but not $\delta^{15}\text{N}$) values? Figs. 5.8 and 5.9 shows relatively tight clustering around the regression line for the adults, ($r^2 = 0.67$), indicating that most of the variation in $\delta^{13}\text{C}$ correlates with variation in $\delta^{15}\text{N}$, due to differential consumption of seafood. Sealy (1997) reviewed the correlation for coastal humans who ate mixed marine/terrestrial diets in well-watered areas without terrestrial C_4 vegetation. She plotted $\delta^{15}\text{N}$ against $\delta^{13}\text{C}$ for skeletons from the literature; the regression equation was $\delta^{15}\text{N} = 0.84\delta^{13}\text{C} + 27.92$, with $r^2 = 0.72$ for 61

individuals from several areas and time periods. This r^2 value is very similar to that for adults at Matjes River. At Matjes River, approximately 30% of the variation in $\delta^{13}\text{C}$ is not linked to variation in $\delta^{15}\text{N}$, and is therefore probably due to factors other than the consumption of C_4 -based foods.

From the results presented above, it appears that children at Matjes River Rock Shelter were breastfed for at least the first two years of life. This relatively prolonged period of nursing would therefore have important consequences for demographic factors interbirth spacing and population size. The implications of weaning patterns for the society at Matjes River Rock Shelter, and more generally, for the archaeology of hunter-gatherers will be explored in the following chapter.

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CHAPTER SIX

DISCUSSION AND CONCLUSIONS

The isotopic results for juvenile individuals from Matjes River Rock Shelter show a relationship between $\delta^{15}\text{N}$ and age at death, as well as $\delta^{13}\text{C}$ and age at death. We can say with some confidence that infants were breastfed for at least the first two years after birth. This is shown by the elevation in $\delta^{15}\text{N}$ values during this period of growth, and correspondingly more negative $\delta^{13}\text{C}$ values. The weaning process for children from the Matjes River Rock Shelter took place between two and four years old. As nursing decreased, the incorporation of amino acids from breastmilk into collagen was replaced by the incorporation of amino acids from other sources of dietary protein. Thus, we see a gradual decrease in $\delta^{15}\text{N}$ in children between the ages of four and 8.5 years old.

Relationship between ethnography and isotopic analyses

The long period of breastfeeding observed for children from the Matjes River Rock Shelter corresponds with the ethnographic information available for contemporary Kalahari hunter-gatherer societies. !Kung women stop nursing their children when the mother falls pregnant again. The average documented interbirth interval is between three and four years (see Chapter Two). This means that children should have been completely weaned by about 2.5 to 3.5 years of age. Ethnographic records tell us about the end of the weaning process, while the isotopic results probably give us information about the point at which children were starting to obtain significant amounts of protein from sources other than breastmilk. Despite this, there is a general

agreement between what is documented for Kalahari hunter-gatherers, and the picture reconstructed for the inhabitants of Matjes River Rock Shelter.

The only other isotopic study of weaning patterns in prehistoric hunter-gatherers is based on the Archaic population of the Tennessee Valley, in North America (Fogel *et al.* 1989). This population was studied in order to compare weaning and interbirth intervals between pre-agricultural and agricultural populations. It was found that the diet of children at approximately two years of age was similar to that of the adults in the population (see Chapter Three). This implies that infants were weaned some time before the age of two years, earlier than the children at Matjes River Rock Shelter, and similar to results for agricultural populations. The results of the Tennessee Valley study are in contrast to what was believed about pre-agricultural societies. As no further investigation was carried out, it remains unclear why the age at weaning at this site was so early.

Access to resources and environmental effects

Some studies of modern foragers have shown that fertility rates tend to increase as populations become sedentary and/or have access to a greater abundance of food sources (see Chapter Two). With abundant terrestrial and marine food sources, the environment around Matjes River Rock Shelter is in contrast to the less predictable, thinly-scattered resources of the Kalahari Desert. This suggests that the population of hunter-gatherers at this site were not under the same pressure to find food. They would therefore not be forced to move as regularly as contemporary !Kung, almost certainly reducing the need for mobility within the Matjes River Rock Shelter community. The long interbirth interval in both the contemporary !Kung and

prehistoric hunter-gatherers at Matjes River Rock shelter shows that the environment was perhaps not an overwhelmingly important influence on fertility.

Hunter-gatherers, even those with access to a range of abundant food, may not always have suitable weaning foods for young children. In the Kalahari, protein-rich weaning foods have included larvae and caterpillars, but the availability of these food sources is, for the most part, seasonal. Schapera (1930) and Shostak (1990) report children being fed pre-masticated meat. At Matjes River Rock Shelter, fish, pre-masticated shellfish and meat could have been used as a weaning food. Children weaned between the ages of two and four years old have fully erupted deciduous dentitions and would probably cope better with solid foods, especially those that are hard to chew, than younger children. It would thus be easier to wean a child at a later age.

Health and fertility

Among populations whose fertility is not controlled by contraception, the !Kung have one of the lower rates of fertility (see Wood 1990). It has also been argued (Pennington 2001) that low fertility, and hence high birth intervals, among contemporary !Kung can be attributed to the effects of sexually transmitted diseases (STDs) such as gonorrhoea. STDs in the Kalahari are, however, largely derived from people coming back after working in the cities or mines. At present, from the skeletal remains, it is impossible to determine whether STDs were prevalent in prehistory. Other diseases and infections that are not visible in the archaeological record may have affected fertility in prehistory. The occurrence of STDs, and their effects on fertility, seems to be more prevalent in modern hunting and gathering communities

and from the literature it appears that duration of breastfeeding had a more profound effect on fertility rates.

Variation in weaning age

The significant difference in $\delta^{15}\text{N}$ values between individuals aged birth to two years old and those older than four years demonstrates that infants should not be included in the calculation of means and standard deviations when looking at diet at a population level. Besides the difference in $\delta^{15}\text{N}$ values between the adult and juvenile components of the population at Matjes River, variation is also observed between individuals of similar ages. As noted before, this could be the result of dietary preferences, producing different weaning curves for children of mothers favouring differing sources of dietary protein. Some individuals display a range of isotopic values that probably reflect life history.

However, the anomalous pattern created by the inclusion of results from analysis of dentine from permanent dentition may not be due to dietary preferences, but the result of the method of sampling employed. The variability may indicate that more secondary and tertiary dentine is deposited than previously thought, making the results difficult to interpret. In the case of $\delta^{15}\text{N}$, one would expect secondary and tertiary dentine, laid down later in life, to have lower $\delta^{15}\text{N}$ values than collagen of suckling infants. This prediction is consistent with the pattern seen in Fig. 5.4. In the case of $\delta^{13}\text{C}$, the situation is less clear. Future studies on dentine should take care to sample in such a way as to minimise the contribution of secondary and tertiary dentine. Sampling from dentine exposed by dietary wear is, therefore, probably best avoided. Although it appears that mothers at Matjes River breastfed their babies for at

least two years, factors such as the health of the infant, health of the mother, and conception of the next child may have influenced the duration of the nursing period.

Further discussion

The literature on breastfeeding, postpartum ovulation, and weaning reveal that there is a broad range of variability among societies and among individuals within societies. Cultural influence also plays an important role in infant feeding practices, and the length of the interbirth interval in prehistoric hunting and gathering groups is therefore dependent on many variables. These factors include variation in the health of the mothers, quality of food and water and also variation in the health of the infant. Breastfeeding, another major factor in interbirth intervals, is one of many factors that can affect fertility. It is therefore unrealistic to explain fertility patterns only from information on weaning and nursing in isolation from health, diet, age at menarche, and activity patterns. Various authors have studied the effects of these factors on birthspacing and fertility (see Chapter Two). It has also been shown that interbirth interval decreases, and subsequently population size increases, with the domestication of plants and animals. However, these demographic transitions are not always uniform among different societies.

Future research

None of the juvenile skeletons have been directly radiocarbon dated. It would be interesting to know if there were shifts in weaning patterns among different hunter-gatherer communities at different times in the past. This would give us the opportunity to explore whether periods of apparent population increase can be linked to changes in weaning patterns.

Another potential research question is the impact of farming on weaning, birthspacing and demography among Early Iron Age communities in Southern Africa. Does the hypothesis that agriculture and sedentism leads to a lower weaning age, decreased birth intervals and thus increased population sizes hold true for these communities?

The determination of weaning age also has implications for human evolution. It would be possible to construct a weaning age for early modern humans from Southern Africa. This study has demonstrated that there exists the potential to detect a weaning signal in collagen carbon, and opens up the possibility of using carbonate $\delta^{13}\text{C}$ measurements. Since hominid diet can be traced by means of analysing the inorganic component of teeth, i.e. enamel, precise sampling techniques can be used to trace change in diet through associated ages of tooth crown formation. This would enable us to observe variation, if any, in developmental biology of early modern humans, and to reconstruct behaviour further back in prehistory.

Chemical techniques such as stable nitrogen and carbon analyses of bone and dentine collagen have significantly contributed to the knowledge and understanding of prehistoric dietary behaviour and population adaptation. Studies have, in the past, focussed mainly on the adult segment of the population. The palaeonutrition of infants and children has been neglected, or at least has not been considered separately from that of the adults. With the application of chemical analysis to archaeological human remains, we can obtain direct data on this matter.

The importance of men or male activities has for many years been the central focus in both anthropological and archaeological studies. As a result there has been less

consideration of female-orientated concerns and activities, such as childbirth and lactation. In addition, not much attention was paid to the effects of female physiology on variables such as population growth. Chemical/isotopic methods are tools archaeologists can use to give us information that is otherwise inaccessible for past populations.

We can now reach conclusions about factors such as age at which non-breastmilk foods were introduced to the diet of infants and the duration of breastfeeding. It is also possible to track changes in childhood diet, not only within a population, but also within an individual. The majority of the studies reviewed here are from recent history. However, through documentation, something of infant feeding practices is known for these studies.

This thesis has provided a reconstruction of weaning practice for prehistoric hunters and gatherers from one site in Southern Africa. It is a significant contribution to Later Stone Age archaeology since its findings have implications for further understanding the effect breastfeeding and timing of weaning had on population dynamics in prehistory. It has demonstrated the potential of combining ethnographic and scientific evidence to understand aspects of prehistory not clearly visible within the archaeological record.

APPENDIX

Notes taken on specimens sampled

- NMB 1243

Mandible with molars, except M1, which was lost some time before death. Other teeth present include:

Right: C, P1, P2

Left: C, P1, M2

Teeth exhibit considerable tooth wear.

Sample: Dentine from the occlusal surface of the left mandibular M1 (UCT 9835).

- NMB 1244

Decided against sampling this individual because of the uncertainty regarding age. Tooth wear is minimal and third molar has not yet erupted, so individual could be anywhere between 12 and 18 years old.

- NMB 1246

Teeth only slightly worn. Mandibular M3s still in crypts. Maxilla is fragmentary. Left mandibular canine has been damaged. The left maxillary first premolar is damaged, exposing the dentine in the crown and close to the neck of the tooth. Enamel hypoplasias very obvious. Teeth are rather shiny and some are glued into the sockets.

Samples:

- 1) Dentine from approximately midway along the surface of the left mandibular canine (UCT 9809).
- 2) Dentine from inside the crown of the left maxillary P1 (UCT 9810).
- 3) Dentine taken from the middle of the crown the left maxillary P1 (UCT 9811).
- 4) Dentine from inside the crown of the left maxillary M2 (UCT 9812).
- 5) Dentine from the occlusal surface of the right maxillary M1 - lingual side of tooth (UCT 9813).

- NMB 1247

Teeth present in mandible include:

R M1

R & L M2

No indication that the M3s are closer to eruption. Advanced tooth wear. Dental lesion on mandibular M1, this was avoided during sampling. Mandible has been

reconstructed, so there is a possibility that the teeth are coated with preservative and/or adhesive.

Samples:

- 1) Dentine from occlusal surface of the left mandibular M2 (UCT 9814).
- 2) Dentine from the occlusal surface of the right mandibular M1, drilled in the direction of the root (UCT 9815).

▪ NMB 1248

Individual older than 12 years. Mandible is coated with preservative.

Sample: Cortical bone from the left side of the mandible (UCT 8195).

▪ NMB 1249

Mandible with the following teeth:

Right: I1, C, P1, P2 (I2 lost after death)

Left: I1, I2, C, P1, P2, M1

Other teeth have been lost before death. Considerable tooth wear on remaining teeth.

Decided against sampling this specimen because of unusual wear on the mandibular P2s.

▪ NMB 1251

Mandible with the following teeth:

Right: I1, I2, C, P1

Left: P1

All other teeth have been lost before death. Specimen exhibits considerable tooth wear.

Sample: Dentine from the occlusal surface of the right mandibular I2 (UCT 9819).

▪ NMB 1253

Only cranium and mandible. Most of the skeleton covered with preservative.

Sample: Cortical bone from the left side of the mandible (UCT 8207).

▪ NMB 1254 “MRA x₂”

Aged between 18 and 24 months. Mandible coated with preservative and/or adhesive.

Sample: Cortical bone taken from the left side of the incomplete mandible (UCT 8194).

- NMB 1255

Unfused mandible coated with preservative. Aged between 12 and 18 months, but closer to 12 months.

Sample: Cortical bone taken from the right half of the mandible (UCT 8193).

- NMB 1258 “MRA x 1 7My.La”

Aged at 5-5.5 years. Cranium reconstructed and coated with preservative/adhesive, as is mandible.

Sample: Cortical bone from left side mandible (UCT 8206).

- NMB 1259

Only cranium and mandible, both of which are covered with preservative. Individual is aged at approximately 18 months based on dentition. Note: NMB 1258 and NMB 1259 are dentally equivalent in age however, NMB 1259 has a smaller cranial vault, so possibly younger.

Sample: Cortical bone from the right side of the mandible (UCT 8196).

- NMB 1260 (with dentition)

No long bones. Two frontals in box, one with dentition and one with no ageable features. Specimen with dentition aged at approximately 3 years.

Sample: Fragment of vault bone (UCT 8209).

- NMB 1260 (with frontal)

This individual is in the same box as NMB 1260 (with dentition) for which S. Pfeiffer has recorded a dental age. The vaults are of similar size therefore they are probably of the same age \pm 3 years old. There are surface indentations on either side of the frontal bone, just above the orbits. These may be grooves left by veins and arteries, but probably needs to be reassessed.

Sample: Fragment of vault bone (UCT 9148).

- NMB 1261

Aged at roughly 5 years. Cranium and mandible reconstructed and covered with adhesive.

Samples:

- 1) Fragment of right side of mandible, questionable collagen preservation, no distinctive “collagen smell” during sampling .
- 2) Fragment of diploic vault bone, orientation and approximate position on cranium is unknown (UCT 8201).

- NMB 1264

Mandible with all teeth, except left M1 (lost some time before death). Left canine damaged. Considerable tooth wear. Some teeth have been glued into the sockets, including the tooth from which the sample was taken.

Sample: Dentine from the occlusal surface of the left mandibular canine (UCT 9834).

- NMB 1265

Teeth present include maxillary M1s and M2s, as well as a damaged, right maxillary canine. The left mandibular M1 and M2 are also present. Teeth exhibit slight tooth wear. Third molars are unerupted, so individual is probably a young adult.

Sample: Dentine from within the crown of the damaged canine (UCT 9827).

- NMB 1266 “MRA x₁₁”

Juvenile may show poorly formed enamel on both maxillary and mandibular teeth. This may be reflected in the results from isotopic analysis. Cranium and mandible reconstructed, with the mandible still unfused.

Sample: Cortical bone from the left side of the mandible (UCT 8204).

- NMB 1268 [MRSK & 1268]

Individual approximately 6 years old.

Sample: Fragment of mandible. Faint collagen smell during sampling (UCT 9151).

- NMB 1276

Intact mandible, reconstructed cranium, fragmented edges of cranial bone are covered with adhesive. Specimen approximately 18 months old.

Sample: Cranial bone fragment, length ~25mm, width ~15mm, thickness ~1.5mm, but varies across sample (UCT 8199).

- NMB 1284 (Wilton child)

No sample taken since there are no features from which an age can be estimated.

- NMB 1287

Co-mingled individuals. Box contains the left half a juvenile mandible with specimen labelled B2 (NMB 1287) possibly from the same individual sampled by C. Muller. Teeth present in mandible include M1 and 2 premolars. Based on dentition, the individual is aged between 6 and 7 years.

Sample: Cortical bone from the unmarked mandible (UCT 8192).

- NMB 1299

No sample taken, see NMB 1284.

- NMB 1300

Cannot be sampled.

- NMB 1301

Specimen very fragmentary also covered with preservative and/or adhesive. Individual aged between 3 and 5 years.

Sample: Fragment of vault bone (UCT 8216).

- NMB 1308

Fairly large islands of dentine. M3 may already have erupted since the left M2 has some wear on the posterior surface of the tooth crown. M3 has been damaged, exposing dentine from the crown through to the root as well as the entire root. Teeth are coated with preservative.

Samples:

- 1) Dentine from below the surface of the right mandibular M1 crown (UCT 9807).
- 2) Dentine from the occlusal surface of the right maxillary M3 (UCT 9808).

- NMB 1310 [MATJIESRIVIER (MRX) 115]

Maxilla with the following teeth:

Right: I1, I2, P1, P2, M1

Left: I1, I2, P1, P2, M1, M2

There is considerable tooth wear. Right I2 has been damaged, and the teeth are coated with preservative.

Sample: Dentine from the occlusal surface of the right maxillary I2 (UCT 9836).

- NMB 1373

Mandible labelled M130fE

Dentition in mandible:

Right: M2, M3 (I2, P1, P2, and M1 are all broken at the neck of the tooth).

Left: P1, P2, M1, M2, M3 (Canine broken at neck of tooth).

There is also a bag and container with the crowns of mandibular and maxillary teeth. Traces of glue on almost all of the damaged teeth.

Samples:

- 1) Dentine from the inside of the crown of the right maxillary M1 (UCT 9828).
- 2) Dentine from the inside of the crown of a unisided maxillary M3 (UCT 9829).
- 3) Dentine taken from the neck of the right mandibular P1 (UCT 9830).
- 4) Dentine taken from the neck of the right mandibular canine (UCT 9831).
- 5) Dentine taken from the neck of the right mandibular I2 (UCT 9832).
- 6) Dentine chunks from the neck of the right mandibular I2 (UCT 9833).

▪ NMB 1444

Newborn, as in NMB 1644. Anatomically normal.

Sample: 2 right rib fragments (sternal ends) from mid to lower thorax. One of which is approximately a third of length (~29mm), the other is approximately a half of length (~41mm) (UCT 8188).

▪ NMB 1446

Tooth wear is advanced in this specimen.

Sample:

- 1) Section of right maxillary first molar including enamel and dentine (UCT 9802).
- 2) Dentine from inside the crown of the right maxillary second molar, below the occlusal surface (UCT 9803).
- 3) Section of the left mandibular first premolar. This tooth is damaged with dentine exposed from crown to neck. Sample includes bit of enamel (UCT 9804).

▪ NMB 1447 (Adult)

Mandible with all teeth present except for the right canine and first premolar. Tooth wear considerable, but minimal on the second molars and absent on the third molars. The mandible has been reconstructed and there is glue in the sockets of all the incisors.

Sample: The enamel on the right mandibular first molar was damaged, so dentine from within the crown and close to the occlusal surface was sampled (insufficient material taken for isotopic analysis).

▪ NMB 1447 (juvenile) "New cave at Platbank"

Fragmented cranium with some fragments glued together. Mandible free from glue and not covered with preservative. Juvenile and adult co-mingled and

labelled with the same accession number. The juvenile is aged at approximately 1.2 years)

Sample: Mid-body fragment of right rib (UCT 8187).

- NMB 1451 (Box labelled Matjiesrivier?)

Samples:

- 1) Dentine sample from left maxillary first molar, close to occlusal surface (UCT 9801).
- 2) Dentine chunk from left maxillary first molar (insufficient material for isotopic analysis).
- 3) Enamel chunk spanning entire crown (not isotopically analysed).

- NMB 1602

Islands of dentine are rather big, but tooth wear is not fully advanced. The right mandibular M1 and M3 tooth crowns are broken and the dentine inside the crown is easily accessible.

Samples:

- 1) Dentine from the right mandibular M1 (UCT 9805).
- 2) Dentine from the right mandibular M3 (UCT 9806).

- NMB 1603

Based on dentition, individual probably younger than 12 years.

Sample: Cortical bone from the right side of the mandible with questionable collagen preservation (UCT 8214).

- NMB 1641 (From the Robberg collection)

Morphologically normal. Entire skeleton coated with preservative.

Sample: Cortical bone from proximal anterior surface of tibia (UCT 8210).

- NMB 1642 (From the Robberg collection)

As in the case of NMB 1641, the entire skeleton is covered with preservative. Morphologically normal.

Sample: Cortical bone from the anterior surface of the proximal end of the left tibia (UCT 8198).

- NMB 1643 (From the Robberg collection)

Newborn < 0.15 years, viable infant. 3 right mid sternal ribs, 9 left ribs.

Sample: 1 complete left rib, possibly number 8 (UCT 8184).

- NMB 1644

Newborn, probably postnatal, possibly foetal. Nine left and nine right ribs. Anatomically normal.

Sample: Right, lower rib, approximately ninth, with head and neck missing (UCT 8182).

- 212? MATJIESRIVIER (2/2)

The box, in which the specimen from which the samples were taken, is labelled as 12 M2/96.

Teeth present in mandible labelled 212 include:

Right: I1, I2, C, P2, M

Left: I2, C, P1, M2, M3

Considerable tooth wear on all teeth.

Sample: Piece of the right mandibular M1 (occlusal surface) with both dentine and enamel (UCT 9818).

In the same box, labelled 212? MATJIESRIVIER (2/2), there is a bag labelled 211 Matjies River infant/foetus. This individual is aged possibly between 1 and 2 months. This age was determined by using other aged specimen as a basis for comparison.

Sample: Fragment of rib (UCT 9150).

- JUVENILE LABELLED “WITH 1260”

No cranial or dental material.

Relatively complete set of long bones, including the following:

Humeri L & R

Femora L & R

Proximal tibia L & R

1 complete and 1 incomplete radius

2 partial ulnae

1 partial fibula

2 scapulae

1 ilium

2 ischae

2 pubic bones (unfused)

All these may well belong to the same individual but from the different vertebrae in the box, it seems that there may be two individuals since it's possible to construct two sets of 5 thoracic vertebrae that seem to come from the same part of the vertebral column. One set is reddish in colour, while the other is brownish. Both sets of vertebrae are of about the same size with the same degree of development. Also a couple of odd vertebrae, probably from a third individual since the spinous processes in these are fused, unlike the thoracic vertebrae mentioned earlier. Thoracic vertebrae have arches fused to body, but no long central processes. Vertebrae of sacrum unfused (i.e. separate). Pelvis in 3 separate pieces, with no sign of fusion. All long bone epiphyses are unfused: proximal and distal femora and humerus, proximal tibia, proximal and distal radius, margin of scapula. The long bones are longer than those from "WILTON UPPERMOST STRATUM II IMMATURE [A] and [B]" which are 6.7 and 7 years, respectively. These long bones are therefore probably from an individual \pm 9 years old. This individual has no associated cranial or dental material however, the lengths of the long bones have been recorded:

Lengths:

Left humerus: 198mm

Right humerus: 220mm

Left (?) radius: 163mm

Right femur: 287mm

According to S. Pfeiffer (pers. comm.) the age of this individual can be estimated from individuals in the collection with age estimates based on both skeletal and dental material.

Sample: End of broken fibula. (UCT 9149).

▪ M (adult)

Fragment of mandible marked 'M' in box with another, unmarked adult mandible. Teeth present: Right: I1, I2, P1, P2, M1, M2, and M3.

Tooth wear advanced in all other teeth except M3, where wear is moderate.

Sample: Dentine from the occlusal surface of the M1 (UCT 9825).

▪ M (juvenile) from box containing MRC, SS1 – 4, and WILTON GRAVE 1.

Full juvenile dentition, looks as though the first permanent molar is close to eruption. Individual probably 5.5 to 6.5 years old.

Samples:

1) Bone from the nasal arch (5.5 to 6.5 years) (UCT 9152).

2) Root tip from deciduous M2 (this gives an age of 2.5 – 3 years because of the stage of formation) (UCT 9824).

- MATJES RIVER CHILDS GRAVE 5V 7-8

10

Fragmentary remains with right femur glued. 1 right clavicle, 1 right tibia, 1 radius, 1 ulna, fragments of cranium. Morphologically normal. Aged between 3 and 4 months.

Sample: Fragment of diploic bone, probably parietal with following dimensions: length ~25mm, width ~15mm, thickness ~2mm (UCT 8203).

- MR 5V.0.12 5V 0 – 12

12

Tooth wear advanced with large islands of dentine exposed on occlusal surface of teeth. Traces of glue/preservative on the mandible, also looks as if glue was applied to the teeth. Dental lesions on left mandibular M1 and M3. These were avoided when samples were taken.

Sample: Dentine from the occlusal surface of the left mandibular M1. There are particles of sand in the sample (UCT 9820).

- MRSK with 1268

Only femur available for sampling. Box from which specimen was taken has the remains of more than one individual, both adult and juvenile. Femur is morphologically normal.

Sample: 2 cortical bone samples taken from anterior distal end of right femur (UCT 8212 and UCT 8213).

- MSK 6 5V-2

10

Morphologically normal vault bone.

Sample: Fragment with suture lines along two sides, length ~20mm, width ~10mm, thickness across fragment ~1mm (UCT 8205).

- OKT 58 (see notes on S4 26' BABA)

Skeleton nearly complete. Unglued and not covered with preservative. Individual aged at less than 6 months.

Sample: 12th right rib (UCT 8183).

- S4 26' BABA

(This is one of the individuals brought to the Quaternary Research Unit from the archaeology storeroom at the National Museum Bloemfontein. According to Zoë Henderson, these individuals were excavated from Matjes River).

Individual is possibly foetal. Signs of ochre on cranial fragments.

Sample: Fragment of vault bone (UCT 8200).

▪ S4 26' 36''

Sample brought back from JCS and SP's trip to the Albany Museum (UCT 8202).

▪ S 592 (see notes on S4 26' BABA)

Nearly complete skeleton with adhesive on cranial vault. Individual between 4 and 6 months.

Sample: Rib fragment with head from the 10-12 group (UCT 8185).

▪ SKELETON # 4 TOP MYTILUS

The unerupted permanent dentition includes: incisors, canines, premolars and molars. Morphologically normal individual.

Samples:

- 1) Root tip from deciduous canine. Completion of root tip is between 2.5 and 3 years (UCT 9816).
- 2) Root tip from deciduous molar (unsure whether M1 or M2). For M1, root tips are complete at 2 – 2.5 years, and for M2 at 3 years old (UCT 9817).
- 3) Unsided midbody fragment (~50mm) of lower rib (UCT 8189).

▪ SS1 – 4

Mandible with fragments of the following teeth:

Right: P1, M2, M3

Left: P1

All tooth fragments are broken at the neck of the tooth. The only nearly complete teeth are the left M1, M2, and M3. There is no sign of preservative on the teeth, but the two halves of the mandible have been glued together.

Samples:

Three dentine samples from the occlusal surfaces of the left mandibular M1, M2 and M3 (UCT 9821-9823).

▪ SKELETTE S5 PROTO 5V-2

10

Morphologically normal.

Sample: Left rib fragment ~30mm long include head and neck from mid sternal region (UCT 8191).

- UNMARKED INFANT FROM BOXED LABELLED “SKULLS OF INFANTS (?3)”

Approximately 6 months old. Edges of bone fragments covered with adhesive.

Sample: Portion of the left side of the mandible (UCT 8197).

- UNMARKED MATJES RIVER [CLAYTON 2002]

Permanent incisor close to eruption. Roots on first maxillary molar complete. Individual between 8 and 9 years old.

Sample: Piece of zygomatic arch (UCT 9146).

- UNMARKED MATJES RIVER

In box ‘c1986 A-D’. Individual aged at approximately 3 years old based on the dentition and the completion of the molar roots. Lack of tooth wear on molars is evidence to support placing the individual at 3 years.

Samples:

- 1) Root ends from right mandibular second molar (UCT 9800).
- 2) Maxillary bone taken away from tooth row and unerupted teeth (UCT 9147).

- WILTON UPPERMOST STRATUM II – Immature [A]

Sample: Cortical bone from the medial surface of the right ulna (UCT 8186).

- WILTON UPPERMOST STRATUM II – Immature [B]

Sample: Cortical bone from the anterior surface of the right tibia (UCT 8211).

- WILTON GRAVE 1 “30 M2/96”

Individual aged between 6 and 8 years. Fragmentary mandible and cranium belonging to same individual. Both fragments are blackened, but don’t seem to have been burnt.

Sample: Cortical bone from the left side of the mandible. No characteristic collagen smell from this process during sampling (UCT 8215).

- WSK 1 (Wilton infant 36M2/96)

Infant approximately 3-6 months old.

Sample: 2 mid-body rib fragments approximately 30-40mm in length (UCT 8190).

- WSK1

Juvenile/child. Morphologically normal. Skeleton covered in ochre, glue/preservative on broken edges of bones. Dentition consistent with 0.75 to 1 year.

Sample: Vault bone with smooth coronal (?) suture (UCT 8208)

- WSK 3

Fragments of mandible and maxilla, both with associated teeth. Few loose teeth also. There was a note in the box which labelled all teeth present, this note was however incorrect. The maxillary fragment was labelled as mandibular and vice versa.

Sample: Dentine from the occlusal surface of the left maxillary M1 (UCT 9826).

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REFERENCES

- Ambrose, S. H. 1991. Effects of diet, climate and physiology on nitrogen isotopes in terrestrial foodwebs. *Journal of Archaeological Science* **18**: 293-317.
- Ambrose, S. H. 1993. Isotopic analysis of paleodiets: Methodological and interpretive considerations. In Sandford, M. K. (ed.) *Investigations of ancient human tissues: chemical analysis in anthropology*: 59-130. New York: Gordon and Breach.
- Ambrose, S. H. and Norr, L. 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In Lambert, J. B. and Grupe, G. (eds). *Prehistoric human bone- archaeology at the molecular level*: 1-37. Berlin: Springer-Verlag.
- Bahuchet, S. 1999. Aka Pygmies. In Lee, R. B. and Daly, R. H. (eds) *The Cambridge encyclopedia of hunters and gatherers*: 190-194. New York: Cambridge University Press.
- Barness, L. A. 1987. History of infant feeding practices. *American Journal of Clinical Nutrition* **46**: 168-170.
- Bender, M. M. 1971. Variations in the $^{13}\text{C}/^{12}\text{C}$ ratios of plants in relation to the pathway of photosynthetic carbon dioxide fixation. *Phytochemistry* **10**: 1239- 1245.
- Blurton Jones, N. 1986. Bushman birth spacing: a test for optimal interbirth intervals. *Ethology and Sociobiology* **7**: 91-105.
- Blurton Jones, N. G., Smith, L. C., O'Connell, J. F., Hawkes, K. and Kamuzora, C. 1992. Demography of the Hadza, an increasing and high density population of savanna foragers. *American Journal of Physical Anthropology* **89**: 159-181.
- Boskey, A. L. and Posner, A. S. 1984. Structure and formation of bone mineral. In Hastings, G. W. and Ducheyne, P. (eds) *Natural and living biomaterials*: 27-41. Boca Raton, Florida: CRC Press Incorporated. Brothwell, D. R. 1981.

Digging up bones: the excavation, treatment, and study of human skeletal remains. New York: Cornell University Press.

- Bryant, J. D. and Froelich, P. N. 1995. A model of oxygen isotope fractionation in body water of large mammals. *Geochimica et Cosmochimica Acta* **59**: 4523-4537.
- Buikstra, J. E., Konigsberg, L. W. and Bullington, J. 1986. Fertility and the development of agriculture in the prehistoric midwest. *American Antiquity* **51**: 528-546.
- Bustamente, R. H. and Branch, M. G. 1996. The dependence of intertidal consumers on kelp-derived organic matter on the west coast of South Africa. *Journal of Experimental Biology and Ecology* **196**: 1-28.
- Cavalli-Sforza, L. L. 1986. Demographic data. In Cavalli-Sforza, L. L. (ed.) *African Pygmies*: 23-44. Orlando, Florida: Academic Press.
- Cerling, T. E. and Harris, J. M. 1999. Carbon isotope fractionation between diet and bioapatite in ungulate mammals and implications for ecological and paleoecological studies. *Oecologia* **120**: 347-363.
- Chisholm, B. S., Nelson, D. E. and Schwarcz, H. P. 1982. Stable-carbon isotope ratios as a measure of marine versus terrestrial protein in ancient diets. *Science* **216**: 1131-1132.
- Cronk, L. 1989. From hunters to herders: subsistence change as a reproductive strategy among the Mukogodo. *Current Anthropology* **30**(2): 224-234.
- Deacon, H. J. and Deacon, J. 1999. *Human beginnings in South Africa: uncovering the secrets of the Stone Age*. Cape Town: David Philip Publishers.
- DeNiro, M. J. 1985. Postmortem preservation and alteration of *in vivo* bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* **317**: 806-809.
- DeNiro, M. J. and Epstein, S. 1981. Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta* **45**: 341-351.
- Döckel, W. 1998. Re-investigation of the Matjes River rock shelter. Unpublished Masters thesis. University of Stellenbosch.

- Dupras, T. L., Schwarcz, H. P. and Fairgrieve, S. I. 2001. Infant feeding and weaning practices in Roman Egypt. *American Journal of Physical Anthropology* **115**: 204-212.
- Ehleringer, J. R. and Rundel, P. W. 1989. Stable isotopes: history, units and instrumentation. In Rundel, P. W., Ehleringer, J. R. and Nagy, K. A. (eds) *Stable isotopes in ecological research*: 1-16. New York: Springer-Verlag.
- Erlandson, J. M. 1994. *Early hunter-gatherers of the California coast*. New York: Plenum Press.
- Falkowski, P. G. 1997. Evolution of the nitrogen cycle and its influence on the biological sequestration of CO₂ in the ocean. *Nature* **387**: 272-275.
- Ferin, M., Jewelewicz, R. and Warren, M. 1993. *The menstrual cycle: physiology, reproductive disorders, and infertility*. New York: Oxford University Press.
- Fogel, M., Tuross, N. and Owsley, D. W. 1989. Nitrogen isotope tracers of human lactation in modern and archaeological populations. *Annual Report of the Director, Geophysical Laboratory, Carnegie Institution of Washington, 1988-1989*: 111-116. Washington, D.C.: Carnegie Institution of Washington.
- Frisch, R. E. 1978. Population, food intake, and fertility. *Science* **199**: 22- 29.
- Fuller, B. T., Richards, M. P. and Mays, S. 2001. Stable isotopes from bone and tooth collagen reveal dietary patterns and the age of weaning at the Medieval village site of Wharram Percy, Yorkshire, UK. Poster paper presented at the 6th Advanced Seminar on Palaeodietary Research, Santa Cruz, California, 5 – 9 September.
- Griffin, P. B. 1984. Forager resource and land use in the humid tropics: the Agta of northeastern Luzon, the Philippines. In Schrire, C. (ed.) *Past and present in hunter gatherer studies*: 95-121. California: Academic Press.
- Griffin, P. B. and Griffin, M. B. 1999. The Agta of eastern Luzon, Philippines. In Lee, R. B. and Daly, R. H. (eds) *The Cambridge encyclopedia of hunters and gatherers*: 289-293. New York: Cambridge University Press.
- Handley, L. L., Scrimgeour, C. M. and Raven, J. A. 1998. ¹⁵N at natural abundance levels in terrestrial vascular plants: a précis. In Griffiths, H. (ed.) *Stable*

isotopes: integration of biological, ecological and geochemical processes:
89-98. Oxford: Bios Scientific Publishers.

- Harpending, H. 1994. Infertility and forager demography. *American Journal of Physical Anthropology* **93**: 385-390.
- Hassan, F. A. 1979. Demography and archaeology. *Annual Review of Anthropology* **8**: 137-160.
- Hassan, F. A. 1980. The growth and regulation of human population in prehistoric times. In Cohen, M. N., Malpass, R. S. and Klein, H. G. (eds) *Biosocial mechanisms of population regulation*: 305-319. London: Yale University Press.
- Hawkes, K. O'Connell, J. F. and Blurton Jones, N. G. 1997. Hadza womens' time allocation, offspring provisioning, and the evolution of long postmenopausal life spans. *Current Anthropology* **38**(4): 551-577.
- Hayden, B. 1972. Population control among hunter/gatherers. *World Archaeology* **4**: 205-221.
- Heaton, T. H. E. 1999. Spatial, species, and temporal variations in the $^{13}\text{C}/^{12}\text{C}$ ratios of C_3 plants: implications for palaeodiet studies. *Journal of Archaeological Science* **26**: 637-649.
- Heaton, T. H. E., Vogel, J. C., von la Chevallerie, G., and Collett, G. 1986. Climatic influence on the isotopic composition of bone nitrogen. *Nature* **322**: 822-823.
- Herring, D. A, Saunders, S. R. and Katzenberg, M. A. 1998. Investigating the weaning process in past populations. *American Journal of Physical Anthropology* **105** (4): 425-440.
- Hewlett, B. S., van de Koppel, J. M. H. and van de Koppel, M. 1986. Causes of death among Aka Pygmies of the Central African Republic. In Cavalli-Sforza, L. L. (ed.) *African Pygmies*: 45-62. Orlando, Florida: Academic Press.
- Hill, K., Hawkes, K., Kaplan, H. and Hurtado, M. 1987. Foraging decisions among Ache hunter-gatherers: New data and implications for optimal foraging models. *Ethology and Sociobiology* **8**: 1-36.

- Hill, K. and Hurtando, A. M. 1999. The Ache of Paraguay. In Lee, R. B. and Daly, R. H. (eds) *The Cambridge encyclopedia of hunters and gatherers*: 92-95. New York: Cambridge University Press.
- Hillson, S. 1986. *Teeth*. Cambridge: Cambridge University Press.
- Hoefs, J. 1997. *Stable isotope geochemistry*. Berlin: Springer-Verlag.
- Holmes, M. E. 1996. Introduction. In Holmes, M. E. (ed.) *Reconstruction of surface ocean nitrate utilisation in the Southern Atlantic based on stable nitrogen isotopes*: 1-4. Berichte aus dem Fachbereich Geowissenschaften der Universität Bremen.
- Hopkins, D. W., Wheatley, R. E. and Robinson, D. 1998. Stable isotope studies of soil nitrogen. In Griffiths, H. (ed.) *Stable isotopes: integration of biological, ecological and geochemical processes*: 75-88. Oxford: Bios Scientific Publishers.
- Howell, N. 1978. The population of the Dobe area !Kung. In Lee, R. B. and DeVore, I. (eds) *Kalahari hunter-gatherers: studies of the !Kung San and their neighbors*: 137-151. Cambridge, Massachusetts: Harvard University Press.
- Howell, N. 1979. *Demography of the Dobe !Kung*. New York: Academic Press.
- Howland, M., Jones, V., Young, S. M. M., van der Merwe, N. J., Mitchell, A., Jim, S. and Evershed, R. P. 2002. Tracing the routing and synthesis of amino acids using gas chromatography-combustion isotope ratio mass spectrometry. Poster paper presented at the 6th Advanced Seminar on Palaeodietary Research, Santa Cruz, California, 5 – 9 September.
- Ichikawa, M. 1999. The Mbuti of northern Congo. In Lee, R. B. and Daly, R. H. (eds) *The Cambridge encyclopedia of hunters and gatherers*: 210-214. New York: Cambridge University Press.
- Jenkins, S. G., Partridge, S. T., Stephenson, T. R., Farley, S. D. and Robbins, C. T. 2001. Nitrogen and carbon isotope fractionation between mothers, neonates, and nursing offspring. *Oecologia* **129**: 336-341.
- Johnston, A. M. and Kennedy, H. 1998. Carbon isotope fractionation in marine systems. In Griffiths, H. (ed.) *Stable isotopes: integration of biological,*

ecological and geochemical processes: 239-256. Oxford: Bios Scientific Publishers.

Kaare, B. and Woodburn, J. 1999. The Hadza of Tanzania. In Lee, R. B. and Daly, R. H. (eds) *The Cambridge encyclopedia of hunters and gatherers: 200-204.* New York: Cambridge University Press.

Kaplan, J. 1993. *The state of archaeological information in the coastal zone from the Orange River to Ponta do Oura.* Pretoria: Department of Environment Affaris.

Katzenberg, M. A. 1993. Age differences and population variation in stable isotope values from Ontario, Canada. In Lambert, J. B. and Grupe, G. (eds) *Prehistoric human bone- archaeology at the molecular level: 40-62.* Berlin: Springer-Verlag.

Katzenberg, M. A., Schwarcz, H. P., Knyf, M. and Melbye, F. J. 1995. Stable isotope evidence for maize horticulture and paleodiet in southern Ontario, Canada. *American Antiquity* **60** (2): 335-350.

Katzenberg, M. A. and Pfeiffer, S. 1995. Nitrogen isotope evidence for weaning in a nineteenth century Canadian skeletal sample. In Grauer, A. L. (ed.) *Bodies of evidence: reconstructing history through skeletal analysis: 221-235.* New York: Wiley-Liss.

Konner, M, and Worthman, C. 1980. Nursing frequency, gonadal function, and birth spacing among !Kung hunter-gatherers. *Science* **207**: 788-791.

Krueger, H. W. and Sullivan, C. H. 1984. Models for carbon isotope fractionation between diet and bone. In Turnlund, J. R. and Johnson, P. E. (eds) *Stable isotopes in nutrition: 205-220.* American Chemical Society Symposium Series, Washington, D. C.

Lee, P. C., Majluf P., and Gordon, I. J. 1991. Growth, weaning and maternal investment from a comparative perspective. *Journal of the Zoological Society of London* **225**: 99-114.

Lee, R. B. 1968. What hunters do for a living. Or, how to make out on scarce resources. In Lee, R. B and DeVore, I. (eds) *Man the hunter: 30-48.* Chicago: Aldine.

- Lee, R. B. 1972. Population growth and the beginnings of sedentary life among the !Kung Bushmen. In Spooner, B. (ed.) *Population growth*: 329-342. Cambridge, Massachusetts: Massachusetts Institute of Technology.
- Lee, R. B. 1979. *The !Kung San*. Cambridge: Cambridge University Press.
- Lee, R. B. 1980. Lactation, ovulation, infanticide, and women's work: a study of hunter-gatherer population regulation. In Cohen, M. N. Malpass, R. S. and Klein, H. G. (eds) *Biosocial mechanisms of population regulation*: 321-348. London: Yale University Press.
- Lee, R. B. and DeVore, I. (1976) *Kalahari hunter-gatherers: studies of the !Kung San and their neighbors*. Cambridge, Massachusetts: Harvard University Press.
- Lee-Thorp, J. A. and van der Merwe, N. J. 1987. Carbon isotope analysis of fossil bone apatite. *South African Journal of Science* **83**: 71-74.
- Lee-Thorp, J. A., Sealy, J. C., and van der Merwe, N. J. 1989. Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. *Journal of Archaeological Science* **16**: 585-599.
- Louw, J. T. 1960. *Prehistory of the Matjes River Rock Shelter*. National Museum of Bloemfontein Memoir no. 1.
- Lubell, D., Jakes, M., Schwarcz, H., Knyf, M. and Meiklejohn, C. 1994. The Mesolithic-Neolithic transition in Portugal: isotopic and dental evidence of diet. *Journal of Archaeological Science* **21**: 201-216.
- Marion, B. D. and McElroy, M. B. 1991. Isotopic composition of atmospheric CO₂ inferred from carbon in C₄ plant cellulose. *Nature* **349**: 127-131.
- Marion, G. M. 1987. Use of nitrogen-15 to assess terrestrial nitrogen cycling process. In Tenhunen, J. D. (ed.) *Plant response to stress: functional analysis in Mediterranean ecosystems*: 129-155. New York: Springer-Verlag in cooperation with NATO Scientific Affairs Division.
- Marshall, L. 1976. *The !Kung of Nyae Nyae*. Cambridge, Massachusetts: Harvard University Press.
- Mays, S. 1998. *The archaeology of human bones*. London: Routledge.

- Mays, S. S., Richards, M. P. and Fuller, B. T. 2002. Bone stable isotope evidence for infant feeding in Medieval England. *Antiquity* **76**: 654-656.
- McGovern-Wilson, R. and Quinn, C. 1996. Stable isotope analysis of ten individuals from Afetna, Saipan, Northern Mariana Islands. *Journal of Archaeological Science* **23**: 59-65.
- Millard, A. R. 2000. A model for the effect of weaning on nitrogen isotope ratios in humans. In Goodfriend, G. A. (ed.) *Perspectives in amino acid and protein geochemistry*: 51-59. Oxford University Press.
- Minagawa, M. and Wada, E. 1984. Stepwise enrichment of ^{15}N along food chains: further evidence and the relation between $\delta^{15}\text{N}$ and animal age. *Geochimica et Cosmochimica Acta* **48**: 1135-1140.
- Morris, A. G. 1992a. *A Master Catalogue. Holocene human skeletons from South Africa*. Johannesburg: Witwatersrand University Press.
- Morris, A. G. 1992b. *The skeletons of contact: a study of protohistoric burials from the lower Orange River valley, South Africa*. Johannesburg: Witwatersrand University Press.
- Muller, C. 2001. Investigation of possible dietary differences between the inhabitants of the Robberg/Plettenberg Bay and Matjes River Rock Shelter in the Later Stone Age: an isotopic approach. Unpublished MA thesis. University of Cape Town.
- Newman, J. 1995. How breastmilk protects newborns. *Scientific American*, December: 58-61.
- Nóbrega, F. J. 1996. Total protein, protein nitrogen, and non protein nitrogen in colostrum, transition and mature milk of mothers of term and preterm infants from different socioeconomic levels. In Nóbrega, F. J. (ed.) *Human milk composition*: 225-236. São Paulo: Revinter.
- Oxford English Dictionary. 2002. Oxford University Press. <http://www.dictionary.oed.com> (11 June 2002).
- Pate, F. D., Anson, T. J., Noble, A. H. and Schoeninger, M. J. 1998. Bone collagen stable carbon and nitrogen isotope variability in modern South Australian mammals: a baseline for palaeoecological inferences. *Quaternary Australia*

- 16(1): page numbers unavailable. Journal paper available from http://www.rses.anu.edu.au/envgeo/AQUADATA/AQUA/QA/1998_16_1/16_1_p1.html. (5 June 2002).
- Pennington, R. 2001. Hunter-gatherer demography. In Panter-Brick, C., Layton, R. H. and Rowley-Conwy, P. (eds) *Hunter-gatherers: an interdisciplinary perspective*. Cambridge: Cambridge University Press.
- Pennington, R. L. 1996. Causes of early human population growth. *American Journal of Physical Anthropology* **99**: 259-274.
- Pennington, R. and Harpending, H. 1988. Fitness and fertility among the Kalahari !Kung. *American Journal of Physical Anthropology* **77**: 303-319.
- Polischuk, S. C., Hobson, K. A. and Ramsay, M. A. 2001. Use of stable-carbon and nitrogen isotopes to assess weaning and fasting in female polar bears and their cubs. *Canadian Journal of Zoology* **79**: 499-511.
- Pollard, A. M. and Wilson, L. 2001. Global biogeochemical cycles and isotope systematics – how the world works. In Brothwell, D. R. and Pollard, A. M. (eds) *Handbook of archaeological sciences*: 191-201. Chichester: John Wiley and sons.
- Probyn, T. A. 1992. The inorganic nitrogen nutrition of phytoplankton in the southern Benguela: new production, phytoplankton size and implications for the pelagic foodwebs. *South African Journal of Marine Science* **12**: 411-420.
- Protch, R. and Oberholzer, J. J. 1975. Paleoanthropology, chronology and archaeology of the Matjes River rock shelter. *Zoological Morphology and Anthropology* **67**(1): 32-43.
- Richards, M. P. and Hedges, R. E. M. 1999. Stable isotope evidence for similarities in the types of marine foods used by Late Mesolithic humans at sites along the Atlantic coast of Europe. *Journal of Archaeological Science* **26**: 712-722.
- Richards, M. P., Mays, S. and Fuller, B. T. 2002. Stable carbon and nitrogen isotope values of bone and teeth reflect weaning age at the Medieval Wharram Percy site, Yorkshire, UK. *American Journal of Physical Anthropology* **119**: 205-210.

- Richards, M. P. and Mellars, P. A. 1998. Stable isotopes and the seasonality of the Oronsay middens. *Antiquity* **72**: 178-184.
- Richards, M. P., Hedges, R. E. M., Molleson, T. I. and Vogel, J. C. 1998. Stable isotope analysis reveals variations in human diet at the Poundbury Camp Cemetery site. *Journal of Archaeological Science* **25**: 1247-1252.
- Rosner, A. E. and Schulman, S. K. 1990. Birth interval among breast-feeding women not using contraceptives. *Pediatrics* **86**: 747-752.
- Schapera, I. 1930. *The Khoisan peoples of South Africa*. London: Routledge and Kegan Paul.
- Scheuer, L. and Black, S. 2000. *Developmental juvenile osteology*. London: Academic Press Limited.
- Schoeller, D. A. 1999. Isotope fractionation: why aren't we what we eat? *Journal of Archaeological Science* **26**: 667-673.
- Schoeninger, M. J. and DeNiro, M. J. 1984. Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science* **220**: 1381-1383.
- Schoeninger, M. J. and Moore, K. 1992. Bone stable isotope studies in archaeology. *Journal of World Prehistory* **6**(2): 247-296.
- Schoeninger, M. J., DeNiro, M. J. and Tauber, H. 1983. Stable nitrogen isotope ratios of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* **46**: 625-639.
- Schurr, M. R. 1997. Stable nitrogen isotopes as evidence for the age of weaning at Angel Site: a comparison of isotopic and demographic measures of weaning age. *Journal of Archaeological Science* **24**: 919-927.
- Schurr, M. R. 1998. Using stable nitrogen isotopes to study weaning behaviour in past populations. *World Archaeology* **30**(2): 327-342.
- Schwarcz, H. P. 1991. Some theoretical aspects of isotope palaeodiet studies. *Journal of Archaeological Science* **18**: 261-275.
- Schwarcz, H. P. and Schoeninger, M. 1991. Stable isotope analyses in human nutritional ecology. *Yearbook of Physical Anthropology* **34**: 283-321.

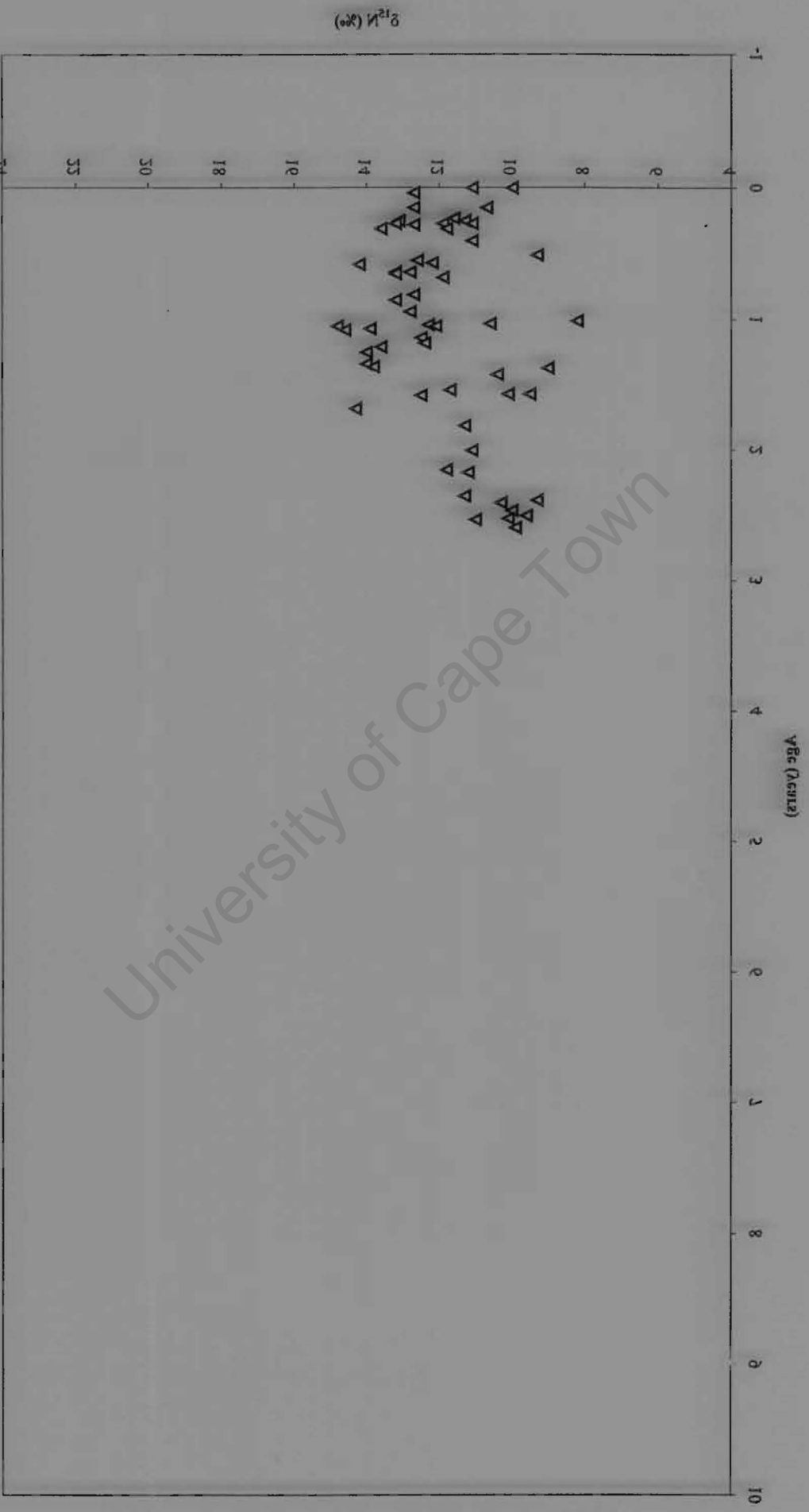
- Schwarcz, H. P., Dupras, T. L. and Fairgrieve, S. I. 1999. ^{15}N enrichment in the Sahara: in search of a global relationship. *Journal of Archaeological Science* **26**: 629-636.
- Sealy, J. C. 1989. The use of chemical techniques for reconstructing prehistoric diets: a case study in the southwestern Cape. *South African Archaeological Society Goodwin Series* **6**: 69-76.
- Sealy, J. 1996. Seasonality of rainfall around the Last Glacial Maximum as reconstructed from carbon isotope analyses of animal bones from Nelson Bay Cave. *South African Journal of Science* **92**: 441-444.
- Sealy, J. C. 1997. Stable carbon and nitrogen isotope ratios and coastal diets in the Later Stone Age of South Africa: a comparison and critical analysis of two data sets. *Ancient Biomolecules* **1**(2): 131-147.
- Sealy, J. 2001. Body tissue chemistry and palaeodiet. In Brothwell, D. R. and Pollard, A. M. (eds) *Handbook of archaeological sciences*: 269-279. Chichester: John Wiley and sons.
- Sealy, J. C. and Pfeiffer, S. 2000. Diet, body size, and landscape use among Holocene people in the Southern Cape, South Africa. *Current Anthropology* **41**(4): 642-655.
- Sealy, J. C. and van der Merwe, N. J. 1985. Isotope assessment of Holocene human diets in the southwestern Cape, South Africa. *Nature* **315**: 138-140.
- Sealy, J. C., van der Merwe, N. J., Lee-Thorp, J. A. and Lanham, J. L. 1987. Nitrogen isotope ecology in southern Africa: implications for environmental and dietary tracing. *Geochimica et Cosmochimica Acta* **51**: 2707-2717.
- Sealy, J., Armstrong, R. and Schrire, C. 1996. Beyond lifetime averages: tracing life histories through isotopic analysis of different calcified tissues from archaeological human skeletons. *Antiquity* **69**: 290-300.
- Shostak, M. 1990. *Nisa: The life and words of a !Kung woman*. London: Earthscan Publications Limited.
- Sillen, A. and Smith, P. 1984. Weaning patterns are reflected in strontium-calcium ratios of juvenile skeletons. *Journal of Archaeological Science* **11**: 237-245.

- Smith, A, Malherbe, C, Guenther, M. and Berens, P. *The Bushmen of Southern Africa: A foraging society in transition*. Cape Town: David Philip Publishers, Athens: Ohio University Press.
- Smith, B. N. and Epstein, S. 1971. Two categories of $^{13}\text{C}/^{12}\text{C}$ ratios for higher plants. *Plant Physiology* **47**: 380- 384.
- Smith, J. 1998. Infant nutrition.
<http://www.mc.vanderbilt.edu/peds/pidl/nutrit/infantnutr.htm#Composition>.
 (28 August 2002).
- Solomon, E. P. 1992. *Introduction to human anatomy and physiology*: 47-75. Philadelphia: W. B. Saunders Company.
- Sprent, J. I. 1987. *The ecology of the nitrogen cycle*. Chapter 6. Cambridge: Cambridge University Press.
- Stuart-Macadam, P. 1995. Breastfeeding in prehistory. In Stuart-Macadam, P. and Dettwyler, K. A. (eds) *Breastfeeding: biocultural perspectives*: 75-99. New York: Aldine De Gruyter.
- Tauber, H. 1981. ^{13}C evidence for dietary habits of prehistoric man in Denmark. *Nature* **292**: 332-333.
- Tieszen, L. L. and Fagre, T. 1993. Effect of diet quality and composition on the isotopic composition of respiratory CO_2 , bone collagen, bioapatite, and soft tissues. In Lambert, J. B. and Grupe, G. (eds) *Prehistoric human bone-archaeology at the molecular level*: 122-155. Berlin: Springer-Verlag.
- Turnbull, C. M. 1986. Survival factors among Mbuti and other hunters of the Equatorial African rain forest. In Cavalli-Sforza, L. L. (ed.) *African Pygmies*: 103-121. Orlando, Florida: Academic Press.
- Tuross, N. and Fogel, M. L. 1994. Stable isotope analysis and subsistence patterns at the Sully site. In Owsley, D. W. and Jantz, R. L. (eds) *Skeletal biology in the Great Plains: Migration, warfare, health and subsistence*: 283-289 Washington D. C.: Smithsonian Institution Press.
- van Beek, G. C. 1983. *Dental morphology: an illustrated guide*. Oxford: Wright.

- van der Merwe, N. J. and Vogel, J. C. 1978. ^{13}C content of human collagen as a measure of prehistoric diet in Woodland North America. *Nature* **276**: 815-816.
- van der Merwe, N. J., Tykot, R. H., Hammond, N. and Oakberg, K. 2000. Diet and animal husbandry of the Preclassic Maya at Cuello, Belize: Isotopic evidence and zooarchaeological evidence. In Ambrose, S. H. and Katzenberg, M. A (eds) *Biogeochemical approach to paleodietary analysis*: 23-38. New York: Kluwer Academic/ Plenum Publishers.
- van Klinken, G. J. 1999. Bone collagen quality indicators for paleodietary and radiocarbon measurements. *Journal of Archaeological Science* **26**: 687-695.
- Virginia, R. A. and Delwiche, C. C. 1982. Natural abundance of presumed N_2 -fixing and non- N_2 -fixing plants from selected ecosystems. *Oecologia* **54**: 317-325.
- Vitzthum, V. J. 1994. Comparative study of breastfeeding structure and its relation to human reproductive ecology. *Yearbook of Physical Anthropology* **37**: 307-349.
- Vogel, J. C., Fuls, A. and Ellis, R. P. 1978. The geographical distribution of Kranz grasses in South Africa. *South African Journal of Science* **74**: 209-215.
- White, C. D. and Schwarcz, H. P. 1989. Ancient Maya diet: As inferred from isotopic and elemental analysis of human bone. *Journal of Archaeological Science* **16**: 451-474.
- White, C. D. and Schwarcz, H. P. 1994. Temporal trends in stable isotopes for Nubian mummy tissues. *American Journal of Physical Anthropology* **93**: 165-187.
- White, C. D., Healy, P. F., and Schwarcz, H. P. 1993. Intensive agriculture, social status, and Maya diet at Pacbitum, Belize. *Journal of Anthropological Research* **49**: 347-375.
- Wood, J. W. 1990. Fertility in anthropological populations. *Annual Review of Anthropology* **19**: 211-242.
- Wright, L. E. and Schwarcz, H. P. 1998. Stable carbon and oxygen isotopes in human tooth enamel: identifying breastfeeding and weaning in prehistory. *American Journal of Physical Anthropology* **106**: 1-18.

Wright, L. E. and Schwarcz, H. P. 1999. Correspondence between stable carbon, oxygen and nitrogen isotopes in human tooth enamel and dentine: infant diets at Kaminaljuyú. *Journal of Archaeological Science* **26**: 1159-1170.

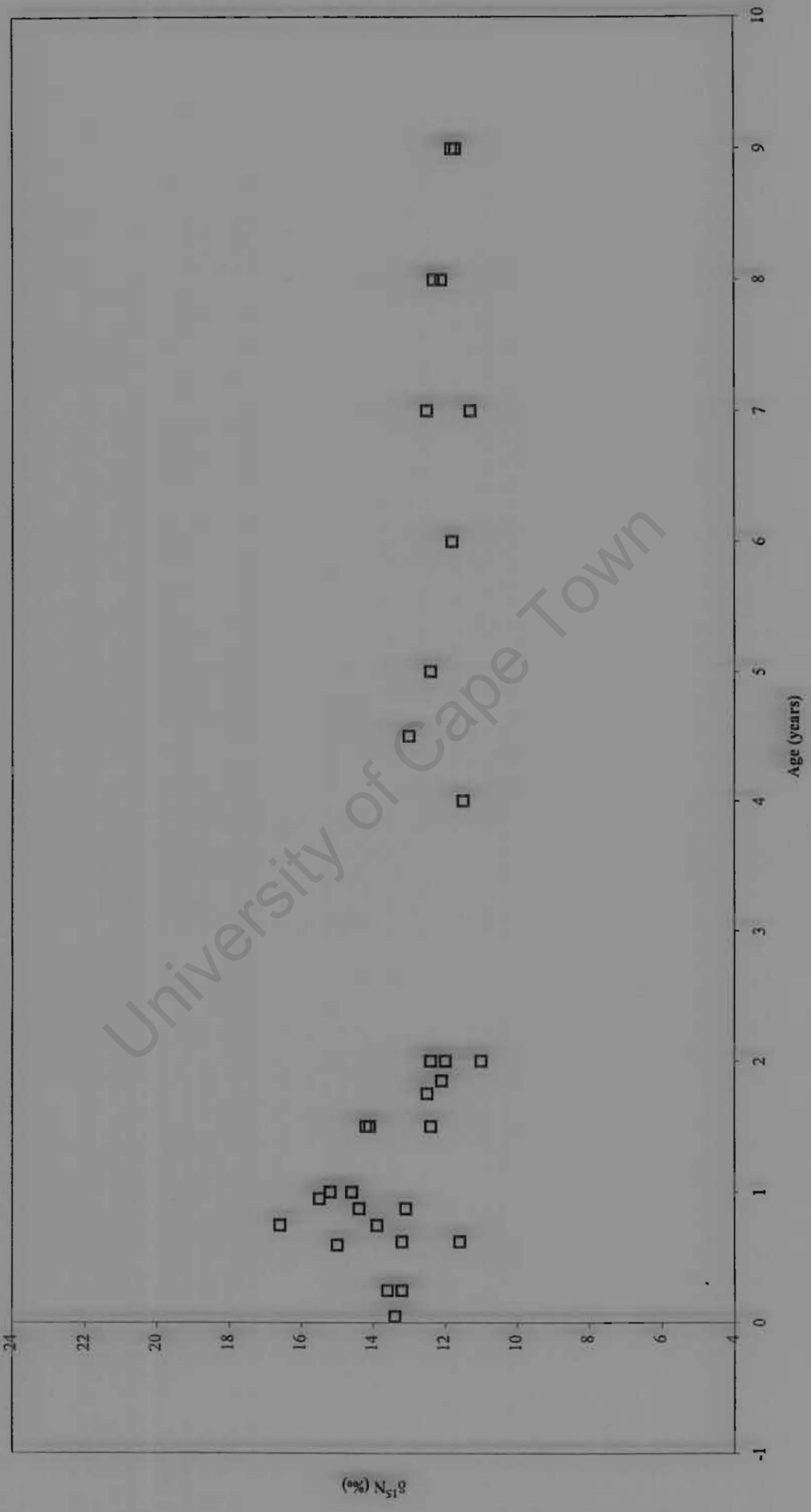
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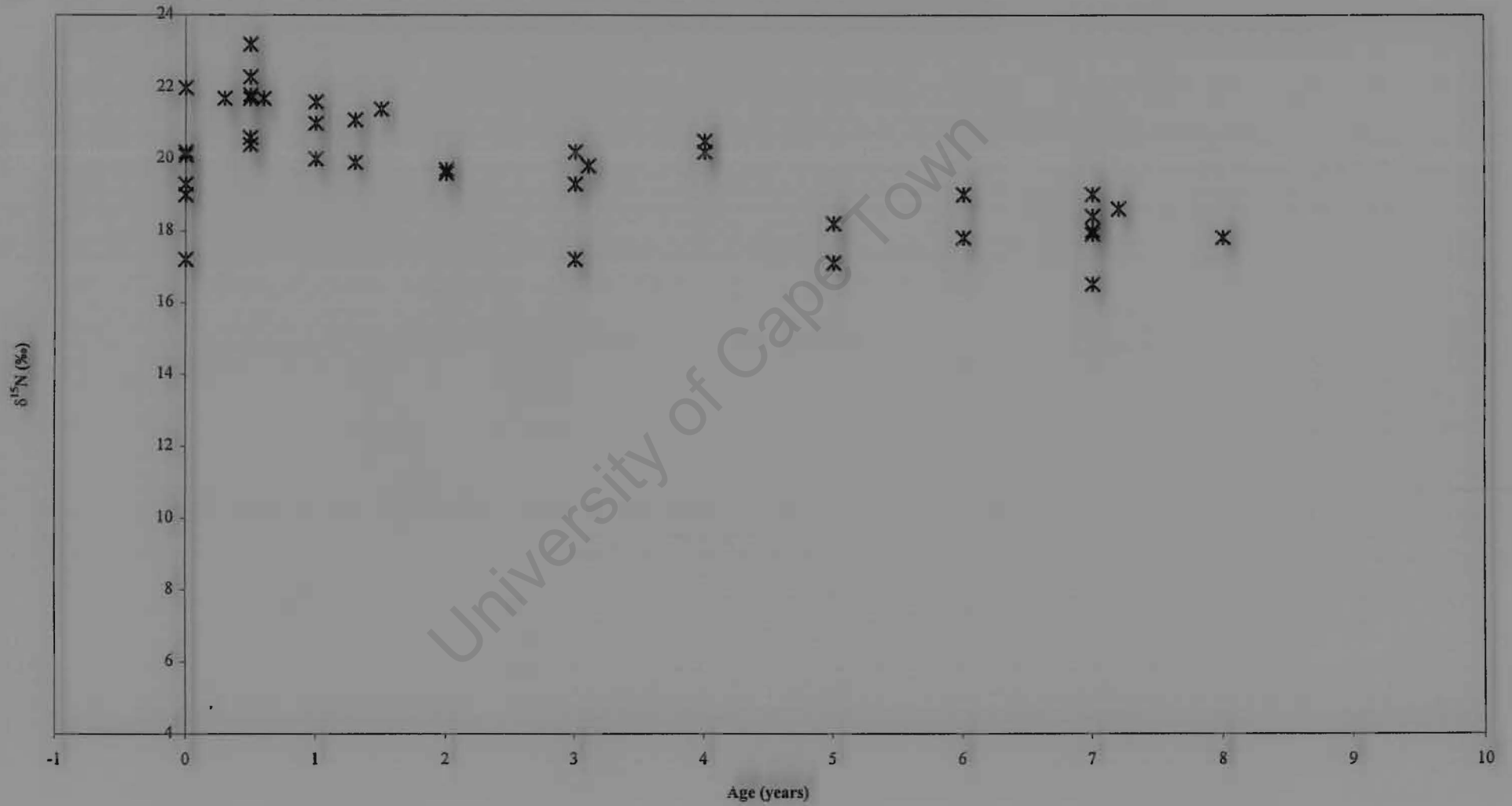
^{210}Pb Plotted against Age for St. Thomas Anglican Cemetery Juveniles

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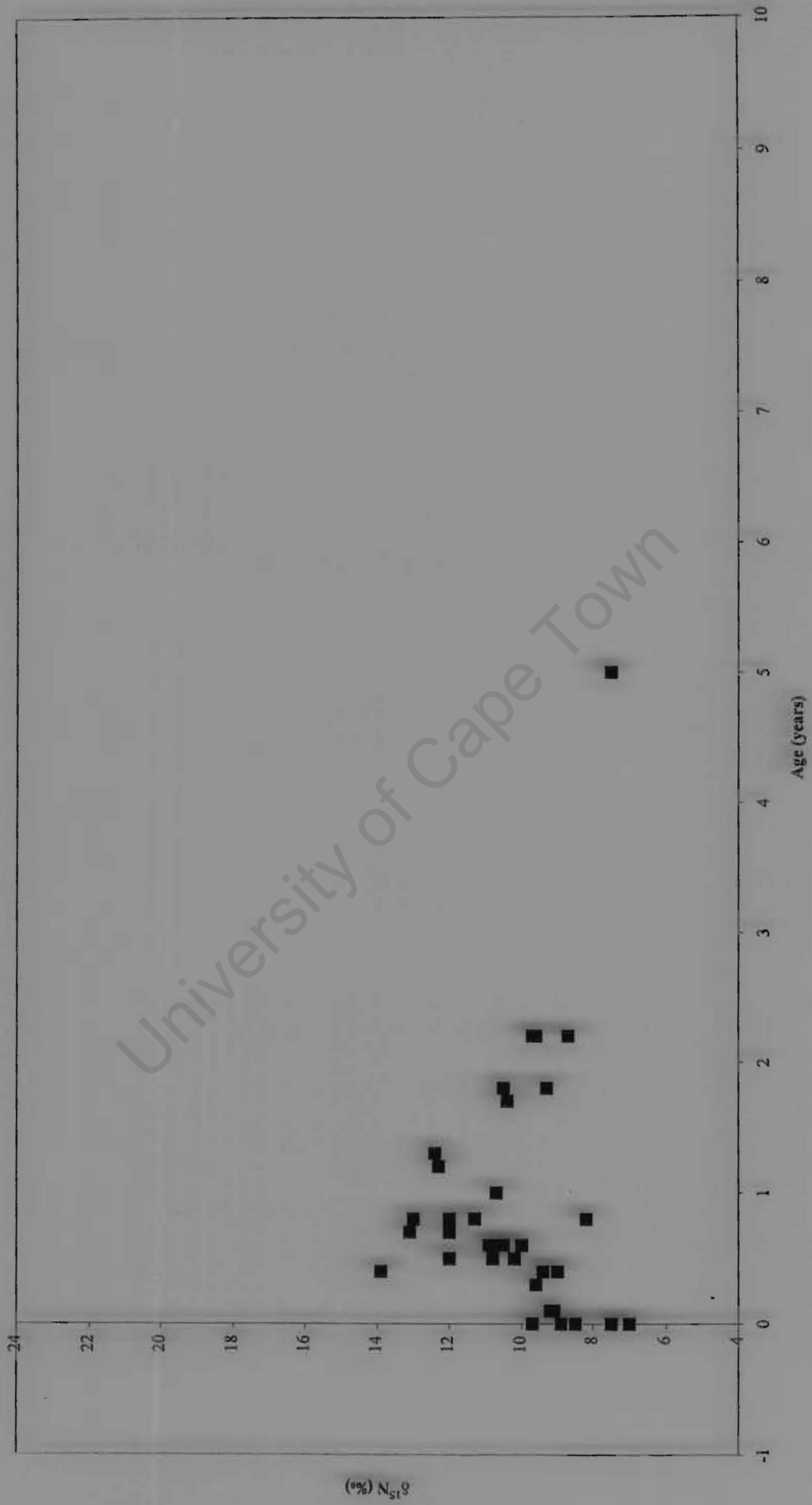
$\delta^{15}\text{N}$ Plotted against Age for Prospect Hill Juveniles



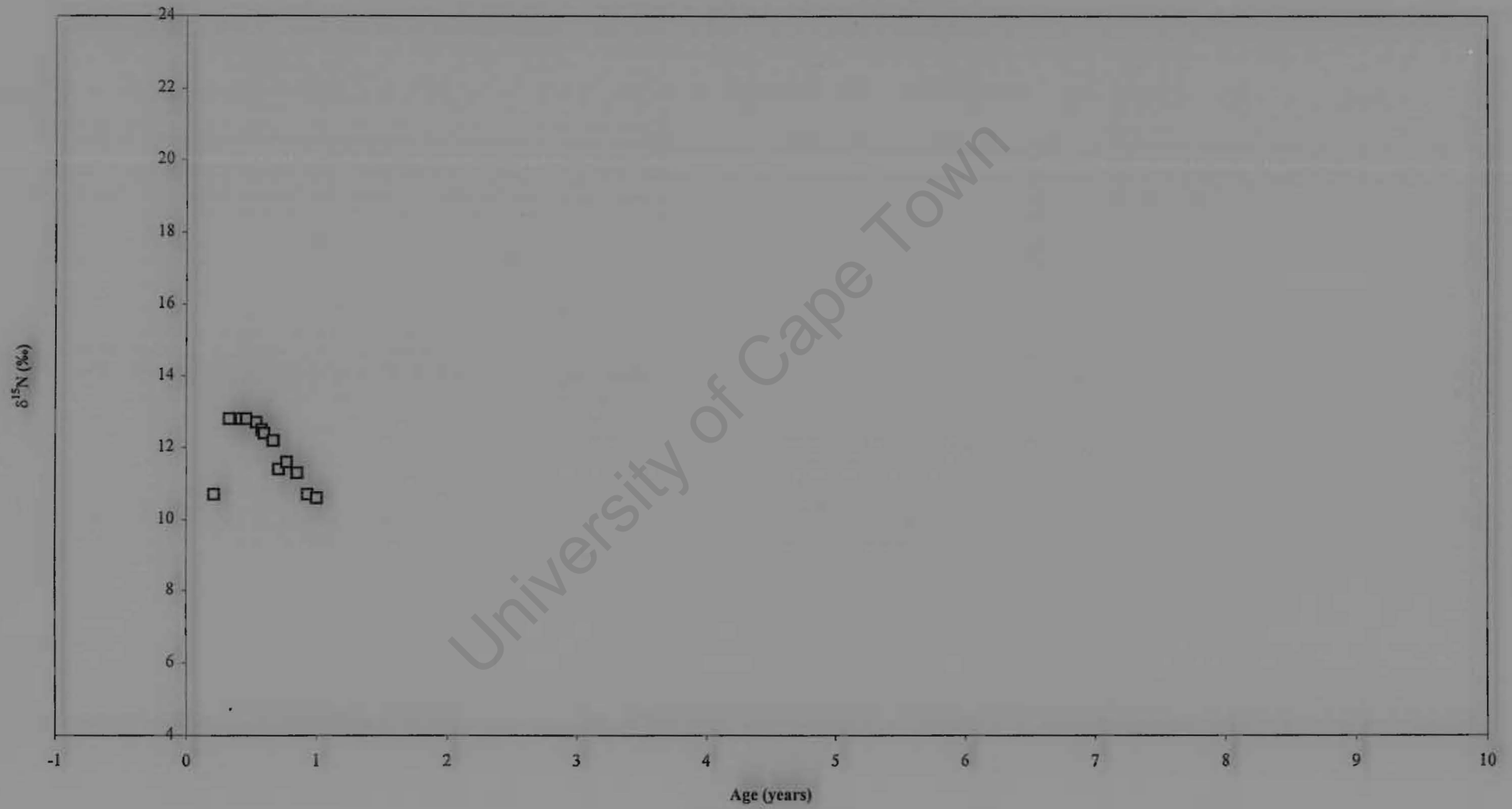
$\delta^{15}\text{N}$ Plotted against Age for Dakhleh Oasis Juveniles



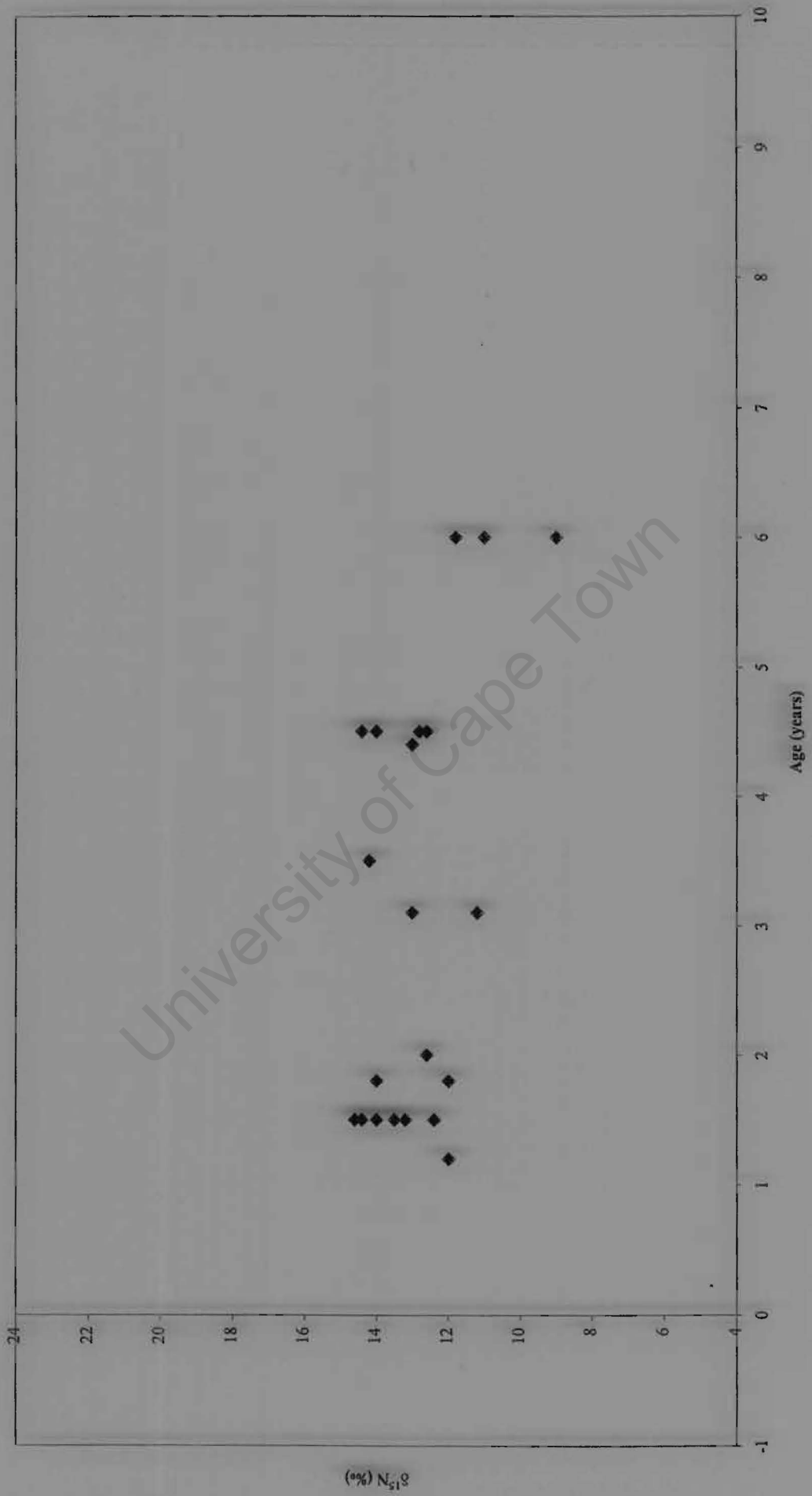
$\delta^{15}\text{N}$ Plotted against Age for Tennessee Valley Juveniles



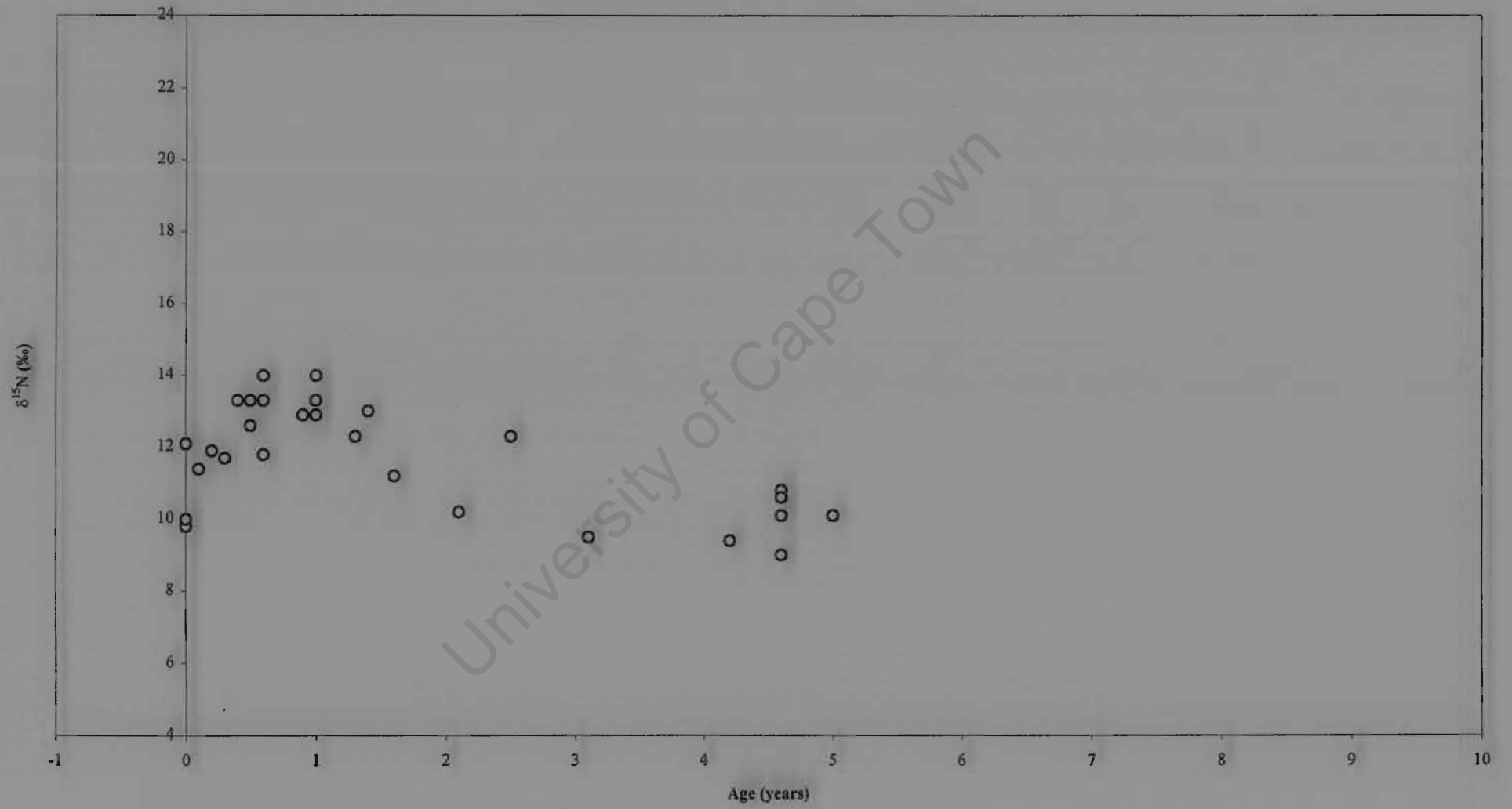
$\delta^{15}\text{N}$ Plotted against Age for Fogel *et al.*'s (1989) longitudinal study



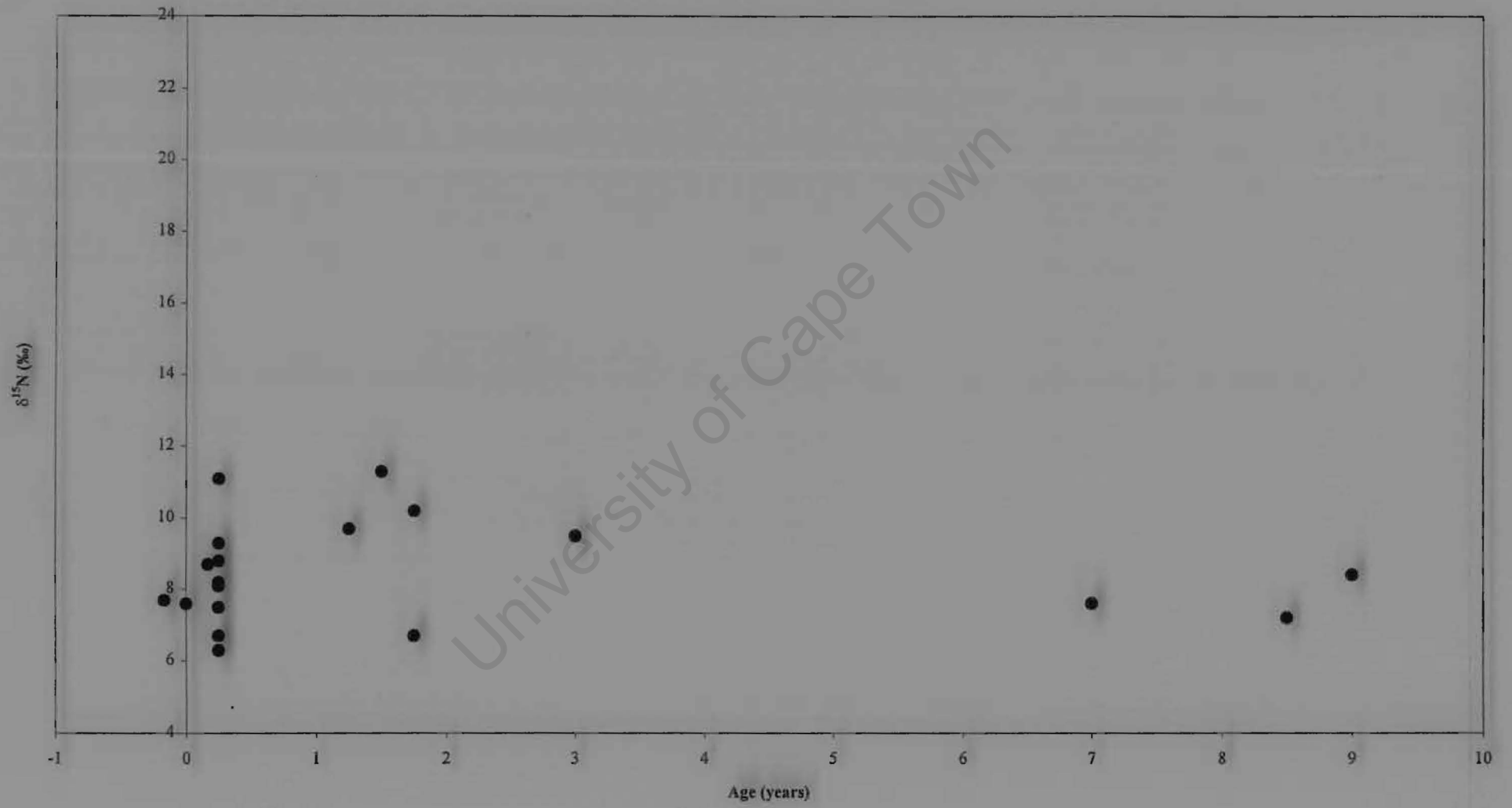
$\delta^{15}\text{N}$ Plotted against Age for Nubian Mummies



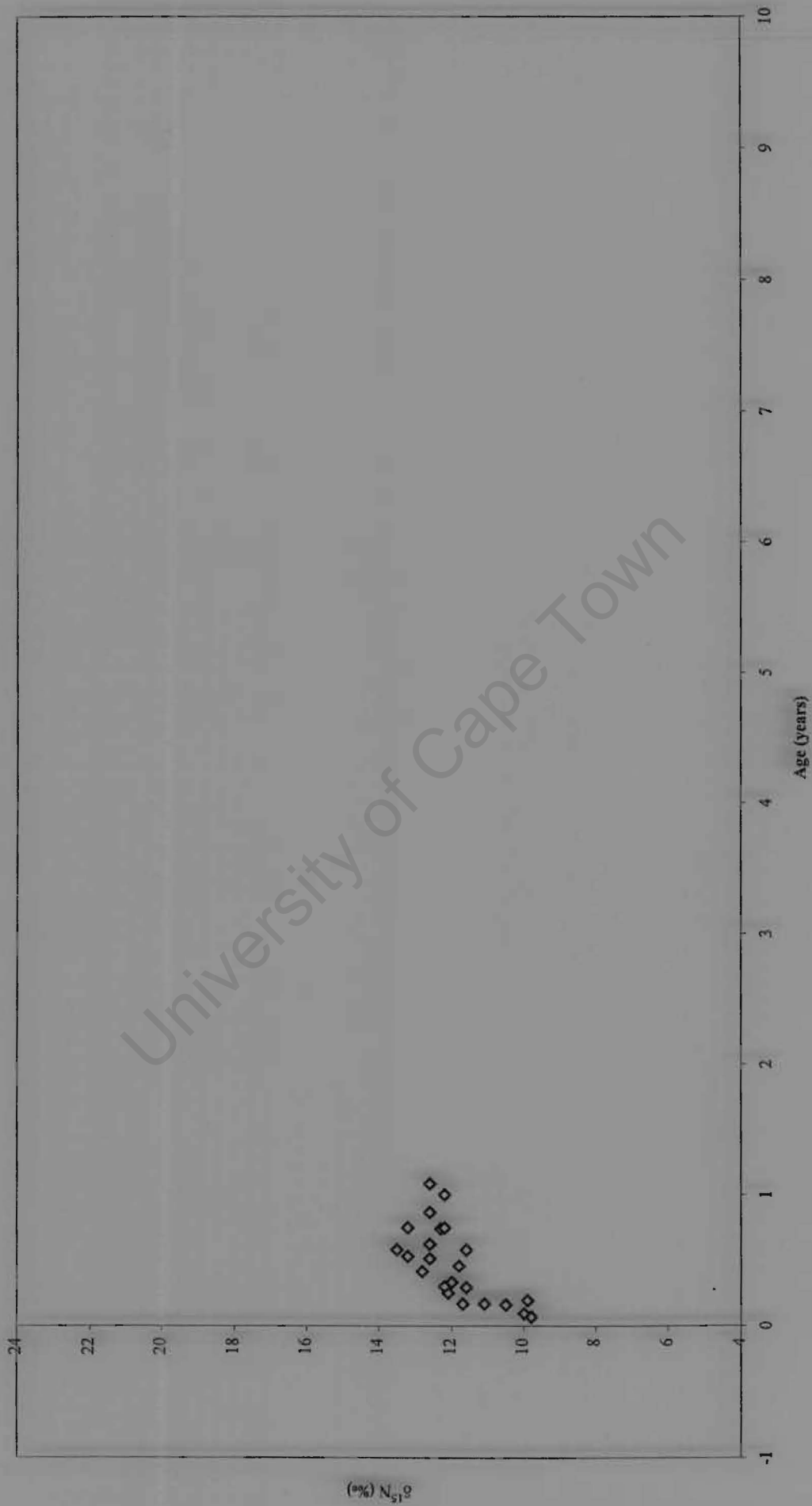
$\delta^{15}\text{N}$ Plotted against Age for Sully Site Juveniles



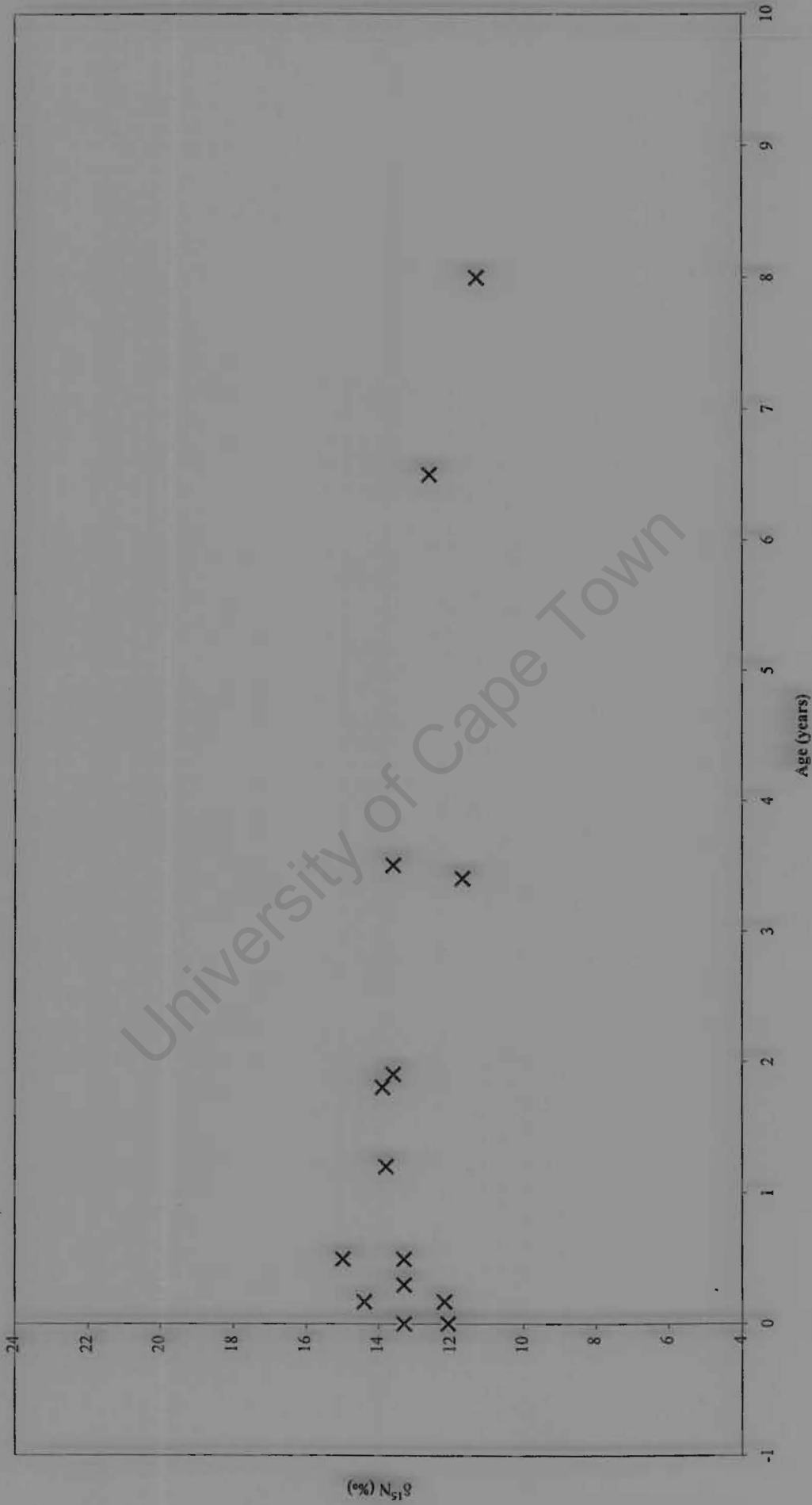
$\delta^{15}\text{N}$ Plotted against Age for Angel Juveniles



$\delta^{15}\text{N}$ Plotted against Age for Fogel *et al.*'s (1989) cross-sectional study



$\delta^{15}\text{N}$ Plotted against Age for MacPherson Juveniles



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$\delta^{15}\text{N}$ Plotted against Age for Wharram Percy Juveniles

