Dietary Stable Carbon Isotope Signatures of the Early Iron Age inhabitants of Ngamiland

Morongwa Nancy Mosothwane

Introduction

The wide spread presence of Late Stone Age (LSA) and Early Iron Age (EIA) communities such as at the Tsodilo Hills, Matlapaneng, Serondela, Qogana, and other sites have been documented in Ngamiland, northwestern Botswana (Denbow 1980, 1986a, 1986b, 1999; Campbell 1982; Wilmsen & Denbow 2005). Radiocarbon dates from many of these sites are generally around the middle of the second millennium AD (Campbell 1982; Denbow 1986b; Wilmsen & Denbow 2005). The sequences of both LSA and EIA settlements show that the area was occupied continuously for several centuries. As early as the 6th century AD LSA hunter-gatherers and EIA farmers of the Tsodilo Hills co-existed within a few kilometres of each other (see Denbow, this volume and Wilmsen, this volume).

This study attempts to reconstruct the diets of the inhabitants of these sites using stable carbon isotope signatures of human and animal remains. Therefore, the sites included in this report are those where human graves have been excavated in the past mainly Divuyu, Nqoma, and Xaro. Reports indicate that other human remains may have been excavated in the past but their whereabouts are unknown. As such those sites have been excluded from this study. There three sites included in the site are all associated with the EIA period. Two of the sites, Divuyu and Nqoma, are both in the Tsodilo Hills while Xaro is along the banks of the Okavango River.

Previous attempts at reconstructing diets of the inhabitants of these sites as well as others have relied heavily on the composition and distributions of faunal and floral remains as well as ethnographic models. While faunal and floral assemblages are very important indicators of prehistoric diets, they are somewhat problematic in that they can only be used to answer more general questions and because they depend largely on preservation conditions. In order to answer more specific questions such as: (1) the role of foraging versus farming, (2) the role of animal versus plant protein in diets, (3) individuals lifetime dietary histories one has to use more advanced techniques such as the analysis of stable isotopes of human and animal skeletal remains.

The use of stable isotope analysis in reconstructing diet is based on the notion that 'you are what you eat'. In 1978, DeNiro and Epstein reported their finding of the relationship between the $\delta^{13}C$ values of various tissues from animals ranging from insects to mice and the $\delta^{13}C$ values of their diet. At the same time, there were experiments to investigate similar relationships on larger animals (Vogel 1978; Krueger and Sullivan 1984; Ambrose & Krigbaum 2003) and humans (van der Merwe 1982). Today, the use of stable isotope analysis in reconstructing diets and environmental conditions is a well known and scientifically renowned method of investigation in archaeology and other disciplines (e.g. Ambrose 1986; Ambrose & DeNiro 1986a, 1986b, 1989; Lee-Thorp *et al.* 1993).

Early Iron Age Sites Included in the Study

Divuyu and Nqoma (formerly known as Society) on two plateaux of the Female Tsodilo Hill are within 1 kilometre of each other and both have been attributed to the western stream of EIA farmers in the area (Rudner 1965; Denbow 1980, 1986b; Denbow & Campbell 1980; Wilmsen & Denbow 2005), but see Wilmsen, this volume. The ceramic decoration motifs from the sites were previously noted by Junod (1963) and subsequently described by Denbow (1986b). Similar pottery has been found at Kapako in northern Namibia, Sioma Mission in Zambia and other sites in Republic of Congo (Brazzaville), and Angola (Denbow & Campbell 1980; Campbell 1982; Denbow & Wilmsen 1986; Denbow 1986a, 1986b, 1990;

Wilmsen & Denbow 1990, 2005). The earliest formal archaeological excavations were done at Nqoma by Wilmsen and Campbell and since their work in 1979, many other archaeological missions have been completed in Ngamiland. In addition, several expeditions of various anthropologists have studied the cultural relationships between the present and prehistoric hunter-gatherer communities of this region (Lee 1968; Lee & DeVore 1970, 1976; Lee *et al.* 1998).

Divuyu currently represents the earliest arrival of a fully formed Iron Age community in Ngamiland (Denbow 1986a, 1990, 1999, Wilmsen & Denbow 2005). It is located about 160m above the surrounding plain (Denbow 1986b; 1999) and is unsuitable for both crop production and animal rearing. Dates from Divuyu range between about AD650 and AD800. The artefact assemblages suggest that interaction between farmers and foragers at Divuyu was relatively little (Denbow, this volume, 1986b, 1999; Wilmsen & Denbow 2005).

Nqoma is dated AD700-1090. Pottery similar to that found at Divuyu occurred on the lowest levels of Nqoma. Unlike Divuyu, increase in hunted animals at Nqoma parallels increase in LSA tools. The lithics clearly indicate a significant change in relations between hunter-gatherers and farmers during the occupation of Divuyu and the later occupation of Nqoma (Denbow 1999; Wilmsen & Denbow 2005). Individuals buried at this site were in flexed positions (Wilmsen & Denbow 2005) as is common in southern African Iron Age contexts. The graves were in varying degrees of preservation ranging from fragmented and incomplete (Fig. 1) to complete and intact skeletons (Fig. 2).

Figure 1. Nqoma burial 1 in situ (photo: Ed. Wilmsen).

The third site, named Xaro, is located just along the right bank of the Okavango River Panhandle. The site has been excavated by Wilmsen and Denbow and later by Wilmsen and Thebe. The ceramic assemblage is not fully understood in terms of links with other sites in the region. There are no lithics or other finds at Xaro to suggest that hunter-gatherers occupied the site (Denbow & Wilmsen, pers. comm. 2005). Thus, the site is believed to have been occupied by people associated with a farming mode of subsistence. The two individuals found at this site were also in horizontally flexed positions (Wilmsen pers. comm. 2006).

Figure 2. Nqoma burial 2 in situ (photo: Ed. Wilmsen).

Environmental Conditions of the Ngamiland Area

Climatic and environment reconstructions of the last thousands of years have been made within the Ngamiland region. Results indicate that the Okavango Panhandle was dry during the period 7000-4000 years ago but with a wet phase around 6000 years ago. The period between 2300-1000 years ago was the wettest (Nash *et al.* 2006). This climatic reconstruction was made using sediments, stable carbon isotopes, and palynological samples from three sites along the Okavango Panhandle (Nash *et al.* 2006). Reconstruction of the Holocene vegetation of the Ngamiland area has been conducted using a speleothem core from Drosky's Cave (Burney *et al.* 1994). During the period about 10,000-7000 years ago the cave was surrounded by arid grassland with dry adapted tress like *Acacia* and *Commiphora*. A wet condition occurred between 7000-6000 years ago as shown by an increase in pollen samples of Combretaceae, Cyperaceae, and mesic savannah plants. A slightly drier period occurred between 5000-4000 years ago (Burney *et al.* 1994). It is possible that the results obtained by Nash *et al.* (2006) and Burney *et al.* (1994)

of the wet and dry periods of the Holocene might correspond with each other if the dates of the samples are calibrated.

Annual precipitation in the Kalahari increases towards the east. The Tsodilo Hills are situated between the driest southwest and wettest northern Kalahari and they are within 450-500mm annual mean rainfall. The Okavango River receives mean annual rainfall of between 500-550mm. Besides the annual rainfall, the Okavango River transports an estimated 11x109m^3 of water annually from its headstreams in the Angolan highlands (Cooke 1982).

Subsistence and Diet During the Early Iron Age

In this area, good arable soils are found along the immediate western part of the Okavango Delta. Due to limited arable land and unreliable rainfall in the area, farming around the Tsodilo Hills can be very productive in one season and completely bad the next season (Cooke 1982; Thomas & Shaw 1991). EIA farmers appear to have taken advantage of the little pockets of land next to the Tsodilo Hills where farming is possible. Prospects of farming are slim along the Okavango River. Carbonised sorghum (*Sorghum bicolor caffir*), pearl millet (*Pennisetum americanum thyphoide*), and melon seeds (Cucurbitaceae) recovered at Nqoma and other places are indicative of the importance of farming at many sites (Denbow 1986a, 1990, 1999; Robbins & Campbell 1990; Wilmsen & Denbow 1990, 2005). Domesticated cereals appear to have been supplemented with wild plants. For example, large quantities of mongongo nuts (*Schinziophyton rautanenii*), marula kernels (*Sclerocarya birrea)*, wild berries (*Grewia* spp.*)* have been found at many sites in Ngamiland including Divuyu, Nqoma, and Depression Cave (Denbow & Wilmsen 1986; Robbins 1990; Robbins & Campbell 1990). Even at present, mongongo nuts are one of the mainstays of the !Kung San in the Kalahari (Lee 1979; Marshall 1979; Robbins & Campbell 1990).

The faunal assemblage of Divuyu consists of ovicaprids, cattle, fish, river mollusc, and wild fauna (Turner 1987a). Sheep and goats contributed about 60% of the animal protein. Some wild fauna such as hippo, waterbuck, lechwe, and reedbuck, as well as fish, are naturally restricted to regular water sources and their presence at Divuyu can only be explained through exchange with people of the Okavango River and Delta (Turner 1987b; Denbow 1986b, 1990, 1999; Wilmsen & Denbow 1990, 2005). Contrary to Divuyu, cattle make up almost a third of the faunal assemblage at Nqoma (Denbow 1986a, 1986b, 1999; Turner 1987b). Sheep and goats are less represented and there is an increase in wild fauna compared to Divuyu (Turner 1987b; Denbow & Wilmsen 1983; Wilmsen & Denbow 1986b, 1990; Denbow 1983a, 1986b, 1990, 1999). However, the increase in domestic animals overrules the possibility of hunting as being more important than herding. Again, fish bones and river mollusc shells recovered at this site indicate exchange with the people along the river and/or Delta. Hunted animals at the Tsodilo Hills may have come from two or three habitats within the Ngamiland region. The lightly wooded acacia savannah plains were home to zebra, wildebeest, giraffe, and eland. Waterbuck, buffalo, and freshwater fish would have come from the marsh environment and/or the flood plains (Turner 1987a, 1987b; Wilmsen & Denbow 2005). At Xaro, fish appears to have played a more significant role (Wilmsen 1990; Denbow 1999) and this is expected given the proximity of the site to the Okavango River.

Dietary observations of historic San hunter-gatherers have also provided some clues regarding the dietary habits of the prehistoric communities in this region (Lee & DeVore 1976; Lee 1979; Denbow & Wilmsen 1983, 1986; Denbow 1984, 1986a, 1986b; Wilmsen 1989, 1990; Donahue & Robbins 1989; Robbins & Campbell 1990). Using a similar approach, it has been previously thought (though now proved to be wrong) that the dietary habits of historic Pedi communities served as an accurate model for the interpretation of all southern African Late Iron Age communities (Ambrose 1986; Lee-Thorp *et al.* 1993).

Carbon Isotopes in Terrestrial Ecosystems

Stable isotope values of carbon are expected to differentiate between foragers and farmers within the study area because of the differences in carbon isotope ratios of the primary sources of plant and animal protein exploited under these two subsistence strategies. The use of carbon isotopes in dietary reconstruction is based on the different photosynthetic pathways used by different groups of plants at the base of food webs in terrestrial ecosystems (Vogel *et al.* 1978; van der Merwe 1982; Berry 1988; Farquhar *et al.* 1989). In its pure form, atmospheric air has carbon isotope ratios of -7‰. As will be seen in the next paragraphs, during photosynthesis plants fractionate atmospheric carbon to result in different carbon isotope ratios based on the type of photosynthesis involved. There are three photosynthetic pathways: the C_3 (Calvin-Benson), C_4 (Hatch-Slack) and the CAM cycles. These photosynthetic pathways differ in terms of leaf anatomy as well as in enzymes involved in the metabolism of carbon dioxide (CO_2).

Under the C_3 photosynthetic pathway, cells involved responsible for absorbing of CO_2 are not in contact with each other. The rubilose biophosphate carboxylase/oxylase (Rubisco) enzyme converts CO_2 into a 6-carbon molecule which then splits into two phosphoglycerate (PGA) molecules. These PGA molecules have three carbon atoms each and hence the term C_3 (van der Merwe 1982; Berry 1988; Farquhar 1989). Fractionation process in C_3 photosynthesis results in plants being about 19‰ more negative than the atmosphere. Thus, these plants have average $\delta^{13}C$ values of -26‰. All trees, bushes, shrubs, and legumes as well as grasses in temperate and Mediterranean environments use the C_3 photosynthesis. Grasses in the Ngamiland area, which is neither temperate nor Mediterranean use a different photosynthetic pathway, the C_4 photosynthesis.

In C_4 photosynthetic plants, cells are arranged in a wreath-like structure and layered directly on top on each other (Vogel 1978; van der Merwe 1982; Elheringer *et al.* 1997; Hibberd & Quick 2002). In these plants, the phosphoenolpyruvate carboxylase (PEPc) enzyme is the main catalyst in converting CO_2 into a four carbon molecule and hence the term C_4. The molecule is known as oxaloacetate (OAA) (Kohn & Cerling 2002). Fractionation processes under C_4 photosynthesis deplete atmospheric $^{13}C/^{12}C$ ratios by about -5.5‰ resulting in plants with $\delta^{13}C$ values of about -12.5‰ (Vogel *et al.* 1978; van der Merwe 1982). Grasses in tropical, sub-tropical, arid, and savannah salt marsh environments use the C_4 photosynthesis (Vogel *et al.* 1978). These also include domesticated cereals such as sorghum, maize, millet, and sugar cane. The third photosynthetic pathway, CAM is only common among succulent plants. These plants alternate between the C_4 and the C_3 photosynthetic mode depending on environmental conditions.

Fractionation of carbon in freshwater aquatic ecosystems are not fully known. However, results show that plants at the base of freshwater ecosystems have carbon isotope values similar to those of terrestrial C_3 plants (Ambrose 1993).

Vegetation in Ngamiland includes both C_3 (-26‰) and C_4 (-12.5‰) plants as well as vegetation in the freshwaters of the Okavango River and its delta. Grazers there (e.g. cattle and zebra) are expected to consume exclusively C_4 grasses while browsers (e.g. tortoise, kudu, and steenbok) consume C_3 vegetation. Mixed feeders (e.g. sheep and goats) consume both C_3 and C_4 vegetation.

Carbon Isotopes in Bone Protein Collagen

Carbon from plants is assimilated into different types of mammalian tissues and each result in specific carbon isotope ratios. For purposes of this study the tissue of choice was the protein collagen component of bone. About 70% of the carbon in protein collagen comes from the nonessential amino acids and the remaining 30% comes from essential amino acids (Klepinger 1984; Klepinger & Mintel 1986; Ambrose & Norr 1993). The 30% nonessential amino acids in protein collagen originate from dietary protein (Klepinger & Mintel 1986).

Fractionation of carbon during the formation of bone protein collagen results in the consumer having $\delta^{13}C$ values that are about 5‰ more positive than that of the diet (Vogel 1978; van der Merwe 1982; Cerling & Harris 1999). In other words, animal browsers and humans that feed predominantly on plants that use the C_3 photosynthetic pathway ($\delta^{13}C$ value of about -26‰) or freshwater vegetation will have bone collagen $\delta^{13}C$ value of about -21‰ (Vogel 1978; van der Merwe 1982; Ambrose & DeNiro 1986a, 1986b; Ambrose 1986, 1989; Cerling & Harris 1999; Ambrose & Krigbaum 2003). Using ethnographic models as analogues for the prehistoric inhabitants of Ngamiland, one would expect hunter-gatherers to have relied heavily on plants using the C_3 photosynthetic pathway. These would have been different species of wild fruits, nuts, roots, melons, and others. Likewise, reliance on plants that use the C_4 photosynthesis results in animal grazer and human bone collagen $\delta^{13}C$ values of around -7.5‰ (Vogel 1978; van der Merwe 1982; Ambrose & DeNiro 1986a, 1986b; Ambrose 1986; Cerling & Harris 1999; Ambrose & Krigbaum 2003). Farmers are known to have relied heavily on domestic cereals which are C_4 photosynthetic. Mixed feeders such as sheep and goats would have bone collagen $\delta^{13}C$ values reflecting combinations of C_3 and C_4 plants (Vogel 1978; DeNiro & Epstein 1978; van der Merwe 1982; Ambrose & DeNiro 1986a, 1986b; Ambrose 1986; Cerling & Harris 1999; Cerling *et al.* 1999; Ambrose & Krigbaum 2003).

Unfortunately, many animal species do not always stick to their expected feeding habits during stressful periods of food shortages (Vogel 1978; DeNiro & Epstein 1978; van der Merwe 1982; Ambrose & DeNiro 1986a, 1986b; Ambrose 1986; Cerling & Harris 1999; Cerling *et al.* 1999). For instance, grazers such as hartebeest and zebra supplement their diets with locally available vegetation, which may be of a different photosynthetic pathway, during dry seasons (Vogel 1978). At the Tsodilo Hills grasses are seasonally very sparse and both grazers and mixed feeders are compelled to rely substantially on C_3 vegetation for extensive parts of the year.

Bone collagen carbon isotope ratios have been used to investigate the relative contributions of C_3 versus C_4 plants in terrestrial human diets in Botswana (Murphy 1996, 2010; Mosothwane 2010) and other parts of Africa (van der Merwe 1982; Ambrose 1986; Ambrose & DeNiro 1986a; Lee-Thorp *et al.* 1993). Studies in Botswana are mostly on the Toutswe EIA communities of east central Botswana. The results indicate heavy reliance on C_4 based plant protein for the humans (Murphy 1996, 2010; Mosothwane 2010) and domestic animals (Mosothwane 2010).

Ambrose (1986) found that some (e.g. sheep and goats) South African Later Iron Age communities of the northern Transvaal had mean carbon isotope values of -8.2±0.5‰. Their diet is believed to have been similar to that of the historic Pedi communities (Maggs & Whitelaw 1991) which was dominated by C_4 crops, legumes and pumpkin plus small amounts of cattle and small stock (Monnig 1967). In contrast, the historic Griqua in the Orange Free State, South Africa, were pastoralists who depended largely on cattle, small stock, and wheat for protein. Wheat is a C_3 photosynthetic crop. The Griqua $\delta^{13}C$ value average was -13.0±1.0‰ (Ambrose 1986; Ambrose & DeNiro 1986a). For diets made of C_3 and C_4 agriculture combined with small numbers of cattle and caprines, Kikuyu communities in Kenya had $\delta^{13}C$ values averaging -10.6±1.4 (n=12) and -12.7‰ (n=5) for males and females respectively (Ambrose 1986; Ambrose & DeNiro 1986a). In another study, the mean $\delta^{13}C$ values of four human skeletons from Skutwater, a small Iron Age site near K2 was reported to be -11.3±0.8‰ (Lee-Thorp *et al.* 1993). Subsistence at this site was comprised of mixed farming, gathering, and substantial hunting (25% of the total faunal assemblage).

Materials and Methods

In order to investigate the most dominant sources of dietary protein of the EIA period in Ngamiland, bone collagen samples were extracted from animal and human skeletal remains. Bone collagen isotope values trace dietary habits of the last few years prior to an individual's death. The standard procedure with isotope studies is to include animal collagen samples which are then used as a platform for the interpretation of human results. Unfortunately, faunal remains from Divuyu and Xaro did not fall within the criteria to be included in the analysis. It is only from Nqoma that a very small number of animal fragments were included in the study. One bone collagen sample per animal was analysed. In case of humans, more than one bone sample from different skeletal parts was analysed where possible. Where the differences between samples were sufficiently small that they probably result merely from random variation, the isotope results were averaged.

A single infant (Morris 1996) skeleton was recovered at Divuyu. The infant had been interred in a sitting position facing east with the lower parts extending into an acid soil layer (Denbow & Wilmsen pers. comm. 2006). As a result, preservation was compromised where the skeleton had been in contact with the acid soil. One fragment of bone collagen was extracted from the skeleton for isotopic analysis. From Nqoma three individuals including an infant, a juvenile, and an adult (Morris 1996) were available for study. Cranial characteristics of the 14–15 year old juvenile, Nqoma 2, have been described as being very similar to those of the Khoisan (Morris 1996). A total of five bone collagen samples were extracted from the three individuals. In addition, there were samples of three cattle and three ovicaprids from the same site. Other samples were obtained from the two adult males whose remains were excavated at Xaro site just along the Okavango River.

Small pieces of bone, approximately 1x1cm each, were placed in dilute hydrochloric acid (125ml H2O: 1.0ml concentrated HCl) for a few days to remove the mineral component (Ambrose 1990). Following rigorous rinsing in distilled water, the extracted collagen pseudomorphs were put in 0.1M sodium hydroxide (NaOH) for several hours to remove humic acids (Ambrose 1990; van Klinken 1999; Garvie-Lok *et al.* 2004; Jorkov *et al.* 2007). It is acknowledged that some amounts of lipids in bone may be preserved long after death and these can actually alter the isotope composition of collagen by 5-10‰ (Ambrose 1990, 1993, Liden *et al.* 1995; Garvie-Lok *et al.* 2004; Jorkov *et al.* 2007) if not removed. It was deemed unnecessary to treat archaeological samples with de-fatting solution since most of the lipids would have been lost through leaching.

Samples of bone collagen of between 0.4-0.8 milligrams were combusted in a Flash EA 1112 series elemental analyser (Thermo Finnigan, Italy) and gases produced were fed into a Delta Plus XP IRMS (isotope ratio mass spectrometer) (Thermo electron, Germany) via a Conflo 111 gas control unit (Thermo Finnigan, Germany). The UCT Archaeometry lab in-house standards used were valine and chocolate, which have been calibrated against International Atomic Energy Agency (IAEA) standards. Repeated analysis of the standards demonstrated that a precision of better than ±0.2‰ was obtained for carbon isotope results.

The purity of collagen was tested through well-documented collagen quality indicators. They included collagen yield, atomic carbon to nitrogen ratios, and carbon and nitrogen weight (DeNiro 1985; Schoeninger *et al.* 1989; Ambrose 1990; Grupe 1995; Pate 1998; van Klinken 1999; Jorkov *et al.* 2007). For example, well-preserved bone collagen is reported to have atomic C:N ratios ranging between 2.9-3.6 (DeNiro 1985) and weight %C of approximately 40-47% (Ambrose 1990, Grupe 1995; Jorkov *et al.* 2007). Samples whose collagen quality indicators fell outside these prescribed limits were excluded.

Results

Cattle from Nqoma have $\delta^{13}C$ values of between -9.7‰ and -9.2‰ with an average of -9.6±0.3‰ (Table 1). Using the model proposed by van der Merwe (1982), cattle from the Tsodilo Hills are estimated to have been raised on diets constituting 85% C_4 (tropical + sub-tropical grasses and domestic cereals) and 15% C_3 (browse) based plants (Mosothwane 2010).

The $\delta^{13}C$ values of ovicaprids vary from -15.7‰ to -8.9‰ (Mosothwane 2010) with a mean of -12.2±3.4‰ (Table 1). The standard deviation for this group suggests a wide variation in the $\delta^{13}C$ values of the ovicaprids despite the fact that only three individuals were analysed. The ovicaprids appear to have regularly browsed on C_3 based photosynthetic plants (60%) as well as grazing on C_4 photosynthetic grasses (40%). A single steenbok sample has a $\delta^{13}C$ value of -21.7‰ (Table 1) which is consistent with 100% browsing on C_3 photosynthetic plants. Steenbok browse on low-level tree leaves and fruits as well as feeding on roots and tubers.

Table 2 shows the carbon isotope values for the humans. The single infant from Divuyu has a $\delta^{13}C$ value of -8.8‰ (Mosothwane 2010). For Nqoma, the three individuals have $\delta^{13}C$ values ranging between -10.5 and -9.3‰ (Mosothwane 2010). These are similar to values for cattle from the same site but

Table 1: Carbon isotope results for Nqoma animals

species	UCT no.	$\delta^{13}C$ value (‰)
cow	12613	-9.7
	12614	-9.2
	12615	-9.8
	mean	-9.6±0.39
sheep/goat	12610	-8.9
	12611	-12.0
	12612	-15.7
	mean	-12.2±3.4
steenbok	12669	-21.7

Table 2. Carbon isotope values for humans

site	individual	$\delta^{13}C$ value (‰)
Nqoma	1	-9.3
	2	-10.5
	3	-9.3
	mean	-9.7±0.7
Divuyu	1	-8.8
Xaro	1	-16.6
	2	-16.9

are more positive compared to the values of ovicaprids. Thus, the dietary sources of protein for both humans and cattle at Nqoma was dominated (about 80%) by plants using the C_4 photosynthetic pathway (Mosothwane 2010). For humans, these would most probably be domesticated cereals while for cattle it would be grasses. In contrast, the $\delta^{13}C$ values of the two individuals from Xaro show heavy reliance on C_3 based dietary protein. Their values are much more depleted compared to sites in the Tsodilo Hills.

Discussion and Conclusion

The $\delta^{13}C$ values of cattle at the Tsodilo Hills are more depleted than those from Toutswe sites in the eastern Hardveld. Reported estimates indicate that the Toutswe cattle depended on 100% C_4 based graze (Denbow *et al.* 2008; Mosothwane 2010) as opposed to the 85% estimated for Tsodilo Hills. These differences signal substantial differences in environmental conditions between the two regions. The Tsodilo Hills are located within a semi-desert in an area where C_4 grasses do not survive long. Rains are scarce and soil fertility in the area is poor (Thomas & Shaw 1991). Therefore, it is expectable that cattle in this type of environment will incorporate significant trees, bushes, and shrubs in their diets.

The estimated C_4 portions for small stock at the Tsodilo Hills and Toutswe area are only marginally different. Toutswe small stock consumed 70% C_4 graze while at the Tsodilo Hills they consumed 60% C_4 graze (Mosothwane 2010). The marginal differences in dietary compositions of small stock between the regions can be attributed to the dietary habits of these animals. As mixed feeders, sheep and goats tend to be less restricted by environmental conditions and follow their preferences more. Therefore, while pastures might have been different, the animals appear to have preferred plants using similar photosynthetic pathways.

The $\delta^{13}C$ values for humans from Divuyu and Nqoma are reflective of diets dominated by C_4 photosynthetic plants. It was expected that humans from these sites would demonstrate slightly more depleted $\delta^{13}C$ values resulting from increased consumption of both domestic and wild C_3 photosynthetic plant protein (wild plants were expected to be significant since farming is limited). The carbonised remains of *marula* and mongongo nuts at Nqoma signalled that wild plants formed significant portions of the overall diet at the Tsodilo Hills (Denbow 1999) compared to the dietary composition of the EIA communities in the Toutswe area (Murphy 1996, 2010; Mosothwane 2010). The new isotope evidence now shows that the ratio of sorghum and millet to legumes and wild foods were equal at both localities (Mosothwane 2010). It is interesting to note that despite low number of C_4 grazers in the faunal assemblage of Divuyu (Turner 1987a) and low crop yield estimated for Divuyu, the infant from this site had a $\delta^{13}C$ value indicative of C_4 dominant diet. Until more individuals are recovered, it is difficult to interpret the origins of the Divuyu infant who seems to have been raised on a C_4 based diet but buried in an environment where C_3 plants dominate.

The $\delta^{13}C$ values of the Xaro individuals are strongly associated with diets in which C_3 photosynthetic plants and/or freshwater fish dominate (mean - 16.7‰). As previously mentioned, freshwater fish have $^{13}C/^{12}C$ ratios similar to those of C_3 plants (Schoeninger & DeNiro 1984; Hedges & Reynard 2007). Given that the site is along the riverbank and has been found to have fish bones, it is tempting to assume that its inhabitants relied on fishing for food. It is highly likely that Xaro inhabitants were fishermen whose plant portion of the diet came from wild fruits, nuts, and berries; C_4 photosynthetic plants played a minor role in the overall diet. Thus, they most probably practiced foraging combined with fishing. Such a subsistence practice has been documented among Bayeyi (Sommer 1995) and the so-called 'River San' or 'Banoka', whose ancestry is of Bantu people but who speak Khoisan languages (Cashden 1986; Hitchcock 1999). These communities are hunter-gatherers as well as fishers.

Freshwater fish are known to elevate the $^{15}N/^{14}N$ ratios of the consumer more than the consumption of terrestrial animals (Schoeninger *et al.* 1983; Schoeninger & DeNiro 1984; Hedges & Reynard 2007). It was, therefore, expected that Xaro occupants would have $\delta^{15}N$ values higher than values recorded for people consuming terrestrial meat. The $\delta^{15}N$ values (mean = 10.6‰) of the two Xaro humans are similar to values recorded for Nqoma and Toutswe humans (Mosothwane 2010). It is difficult to interpret the $\delta^{15}N$ values of the Xaro individuals because of small sample sizes and lack of animal isotope values, which would be a platform from which results for humans can be interpreted. As it is the results suggest that the occupants of Xaro supplemented a C_3 dominant diet with freshwater fish.

In conclusion, results of the stable carbon analysis of five individuals from EIA contexts indicate substantial variation in diet and subsistence in Ngamiland. At the Tsodilo Hills, domestic cereals appear to have dominated the overall dietary protein. The production of domestic cereals seems to have been of a magnitude that allowed long-term sustainability of the communities. Cattle and small stock also appear to have had good C_4 graze pastures though C_3 browsing was a necessary supplement. The results for the Tsodilo Hills are within expected ranges given that previous studies based on material culture and recovered fauna and flora classified the sites as being those of farming communities. In contrast, the site Xaro which has been classified as being of a farming community indicate heavy reliance on wild and fished resources. Given that the area has no record of EIA domestic C_3 crops (e.g. wheat), it can be concluded that the depleted $\delta^{13}C$ values for the individuals are from wild plants and fish. The samples used in this study are very small and therefore more still needs to be done in order to strengthen the conclusions.

Acknowledgements

My sincere gratitude goes to the Wenner-Gren Foundation which funded the field and laboratory phases of my study. The South African National Research Fund (NRF), Paleo-Anthropology Scientific Trust (PAST), and Wits University sponsored other aspects of the programme for which I am very grateful. I am also grateful for the guidance and support I got from my supervisors Karim Sadr (Wits) and Judith Sealy (UCT). The two have done the best they could to see me through the programme and I therefore take full responsibility for any errors that might be noted in this report.

References

Ambrose, Stanley H.

1993 Isotopic analysis of paleodites: methodological and interpretive considerations. In M.K. Sanford (ed.), *Investigations of ancient human tissue chemical analysis in anthropology*. Langhorne: Gordon and Breach, pp. 59-130.

1990 Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science* 17:431-451.

1986 Stable carbon and nitrogen isotope analysis of human and animal diet in Africa. *Journal of Human Evolution* 15:707-731.

Ambrose, Stanley H. and Michael J. DeNiro

1989 Climate and habitat reconstruction using stable carbon and nitrogen isotope ratios of collagen in prehistoric herbivore teeth from Kenya. *Quarterly Research* 31:407-422.

1986a Reconstruction of African human diet using bone collagen carbon and nitrogen isotope ratios. *Nature* 319:321-324.

1986b The isotope ecology of east African mammals. *Oecologia* 63:395–406.

Ambrose, Stanley H. and John Krigbaum

2003 Bone chemistry and bioarchaeology. *Journal of Anthropological Archaeology* 22:193-199.

Ambrose, Stanley H. and Lynette Norr

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 J.B. Lambert and G. Grupe (eds.), *Prehistoric Human Bone Archaeology at the Molecular Level*. Berlin: Springer, pp.1-37.

Berry, Joseph A.

1988 Studies of mechanisms affecting the fractionation of carbon isotopes in photosynthesis. In P.W. Rundel, J.R. Ehleringer, and K.A. Nagy (eds.), *Stable Isotopes in Ecological Research, Ecological Studies 68*. New York: Springer, pp.82-94

Burney, David A., George A. Brook, and James B. Cowart

1994 A Holocene pollen record for the Kalahari Desert of Botswana from a U-series dated speleotherm. *The Holocene* 4:225-232.

Campbell, Alec

1982 Notes on the prehistoric background to 1840. In: R.R. Hitchcock and M.R. Smith (eds.), *Settlement in Botswana*. Gaborone: Botswana Society, pp. 13-22.

Campbell, Alec and David Coulson

1988 Cultural confrontation at Tsodilo. *Optima* 36:12-19.

Cashdan, Elizabeth

1986 Competition between foragers and food producers on the Boteti River, Botswana, Africa. *Journal of the International African Institute* 56:299-318.

Cerling, Thure E. and John M. Harris

1999 Carbon isotope fractionation between diets and bioapatite in ungulate mammals and implications for ecological and paleoecological studies. *Oecologia* 120:347-363.

Cerling, Thure E., John M. Harris, and Meave G. Leakey
1999 Browsing and grazing in elephants: the isotope record of modern and fossil proboscideans. *Oecologia* 120:364-374.

Cooke, J.H.
1982 The physical environment of Botswana. In Hitchcock, R.R. and Smith, M.R. (eds). *Settlement in Botswana*. Gaborone: Botswana Society, pp. 1-12.

Denbow, James
1999 Material culture and the dialectics of identity in the Kalahari: AD 700-1700. In S.K. McIntosh (ed.), *Beyond Chiefdoms: Pathways to Complexity in Africa.* Cambridge: Cambridge University Press, pp. 110-123.
1990 Congo to Kalahari: data and hypotheses about the political economy of the western stream of the Early Iron Age. *The African Archaeological Review* 8:139-176.
1986a A new look at the later prehistory of the Kalahari. *Journal of African History* 27:3-28.
1986b After the flood: A preliminary account of recent geological, archaeological and linguistic investigations in the Okavango region of northern Botswana. In R. Vossen and K. Keuthmann (eds.), *Contemporary Studies on Khoisan in Honour of Oswin Köhler on the Occasion of his 75th Birthday,* Part 1. Hamburg: Helmut Buske Verlag, pp.181-214.
1984 Prehistoric herders and foragers of the Kalahari: the evidence of 1500 years of interaction. In C. Schrire (ed.), *Past and Present in Hunter Gatherer Studies*. Chicago: Academic Press, pp. 175-193.
1980 Early Iron Age from the Tsodilo Hills, North-Western Botswana. *South African Journal of Science* 76:474-475.

Denbow, James and Alec Campbell
1980 National Museum of Botswana-Archaeological research program. *Nyame Akuma* 17:3-9.

Denbow, James and Edwin N. Wilmsen
1983 Iron Age pastoralist settlements in Botswana. *South African Journal of Science* 79:405-407.
1986 Advent and course of pastoralism in the Kalahari. *Science* 234:1509-1515.

Denbow James, Jeanette Smith, Nonofo M. Ndobochani, Kerstin Atwood, and Duncan Miller
2008 Archaeological excavations at Bosutswe, Botswana: cultural chronology, paleo-ecology and economy. *Journal of Archaeological Science* 35:59-90.

DeNiro, Michael J.
1985 Post-mortem preservation and alteration of in vivo bone collagen isotope ratios in relation to paleodietary reconstruction. *Nature* 317:182-191.

DeNiro, Michael J and Samuel Epstein
1978 Influence of diet on distribution of carbon isotopes in animals. *Geochimica et Cosmochimica Acta* 42:495-506.

Donahue, Randolph and Lawrence H. Robbins
1989 Evidence of microwear on tools from the Tsodilo Hills Depression site, Botswana. *Nyame Akuma* 31:8-11.

Ehleringer, James R., Thure Cerling, and Brent R. Helliker
1997 C4 photosynthesis, atmospheric C02 and climate. *Oecologia* 112:285-299.

Farquhar, G.D., James R. Ehleringer, and K.T. Hubick
1989 Carbon isotope discrimination and photosynthesis. *Annual Review Plant Physiology* 40:503-537.

Garvie-Lok, Sandra J., Tamara L. Varney, and Anne M. Katzenberg
2004 Preparation of bone carbonate for stable isotope analysis: the effects of treatment time and acid concentration. *Journal of Archaeological Science* 31:763-776.

Grupe, Gisela
1995 Preservation of collagen in bone from dry sandy soil. *Journal of Archaeological Science* 22:193-199.

Hedges, Robert and Linda M. Reynard
2007 Nitrogen isotopes and the trophic level of humans in archaeology. *Journal of Archaeological Science* 34:1240-1251.

Hibberd, Julian M. and Paul W. Quick
2002 Characteristics of C4 photosynthesis in stems and peticoles of C3 flowering plants. *Nature* 415:451-454.

Hitchcock, Robert K.
1999 Introduction: Africa. In Lee, R.B. and Daly, R. (eds.), *The Cambridge Encyclopedia of Hunters and Gatherers*. Cambridge, Cambridge University Press, pp. 175-184.

Jorkov, Marie L., Jan Heinemeir, and Niels P. Lynnerup
2007 Evaluating bone collagen extraction methods for stable isotope analysis in dietary studies. *Journal of Archaeological Science* 34:1824-1829.

Junod, S.M.
1963 A note on pottery from Tsodilo, Bechuanaland. *South African Archaeological Bulletin* 18:20.

Klepinger, Linda L.
1984 Nutritional assessment from bone. *Annual Review of Anthropology* 13:75-96.

Klepinger, Linda L. and Richard W. Mintel
1986 Metabolic considerations in reconstructing past diet from stable carbon isotope ratios of bone collagen. In Olin, J.S. and Blackman, M.J. (eds.), *Proceedings of the 24th International Archaeometry Symposium*. Washington DC: Smithsonian Institution Press, pp. 43-48.

Kohn, Matthew J. and Thure E. Cerling
2002 Stable isotope compositions of biological apatite. *Reviews in Mineralogy and Geochemistry* 48:455-488.

Krueger, Haroid W. and Charles H. Sullivan
1984 Models for carbon isotope fractionation between diet and bone. In Turnlund, J. and Johnson, P.E. (eds.), *Stable Isotopes in Nutrition*. Washington DC: American Chemical Society Symposium Series 258, pp. 205-222.

Lee, Richard B.

1979 *The !Kung San: Men, Women and Work in a Foraging Society*. New York: Cambridge University Press.

Lee, Richard B., Megan Biesele, and Robert K. Hitchcock

1998 Three decades of ethnographic research among the Ju/'hoansi of northwestern Botswana. *Botswana Notes and Records* 28:107-120.

Lee, Richard B. and Irvin DeVore

1970 Ngamiland !Kung Bushmen: research in progress. *Botswana Notes and Records* 2:122-125.

Lee, Richard B and Irvin DeVore (eds.)

1976 *Kalahari hunter-gatherers: Studies of the !Kung San and their neighbours*. Cambridge: Harvard University Press.

1968 *Man the Hunter*. Chicago: Aldine.

Lee-Thorp, Julia A. , Judith C. Sealy, and Alan G. Morris

1993 Isotopic evidence for diets of prehistoric farmers in South Africa. In Lambert, J.B. and Grupe, G. (eds.), *Prehistoric Human Bone: Archaeology at the Molecular Level*. Berlin: Springer, pp. 99-120.

Liden, Kerstin, Cheryl Takahashi, and Nelson Erel

1995 The effects of lipids in stable carbon isotope analysis and the effects of NaOH treatment on the composition of extracted bone collagen. *Journal of Archaeological Science* 22:321-326.

Maggs, Tim and Gavin Whitelaw

1991 A review of recent archaeological research on food producing communities in southern Africa. *Journal of African History* 32:3-24.

Marshall, Lorna

1976 *The !Kung of Nyae Nyae*. Cambridge: Harvard University Press.

Monnig, Harris O.

1967 *The Pedi*. Pretoria: Van Schaik.

Morris, Alan

1996 Human skeletal remains from Ngamiland sites. Unpublished report.

Mosothwane, Morongwa N

2010 Foragers among farmers in the Early Iron Age of Botswana? Dietary evidence from stable isotopes, Unpublished PhD Thesis, University of the Witwatersrand.

Murphy, Kimmarie A.

2010 A meal on the hoof or wealth in the kraal? Stable isotopes at Kgaswe and Taukome in eastern Botswana. *International Journal of Osteoarchaeology*, n/a. doi: 10.1002/oa.1166.

1996. The skeletal elements of the Iron Age in central and southern Africa: a bioarchaeological approach to the reconstruction of prehistoric subsistence. Unpublished PhD Thesis, Indiana University.

Nash, David J, Michael E. Meadows, and Vana Gulliver

2006 Holocene environmental change in the Okavango Panhandle, northwest Botswana. *Quaternary Science Reviews* 25:1302-1322.

O'Leary, Marion H
1993 Biochemical basis of carbon isotope fractionation. In Ehleringer, J.R., Hall, A.E., Farquhar, G.D. (eds.), *Stable isotopes and Plant Carbon-Water Relations*. Chicago: Academic Press, pp. 19-28.

Pate, Donald F
1998 Bone collagen preservation at the Roonka Flat Aboriginal burial ground: a natural laboratory. *Journal of Field Archaeology* 25:203-217.

Robbins, Lawrence H.
1990 The Depression site: a Stone Age sequence in the northwest Kalahari Desert, Botswana. *National Geographic Research* 6:329-338.

Robbins, Lawrence H. and Alec Campbell
1990 Prehistory of mongongo nut exploitation in the western Kalahari Desert, Botswana. *Botswana Notes and Records* 22:37-39.

Rudner, Iona
1965 Archaeological report on the Tsodilo Hills, Bechuanaland. *South African Archaeological Bulletin* 20:51-70.

Schoeninger, Margaret J., Michael J. De Niro, and H. Tauber
1983 Stable nitrogen ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science* 220:1381-1383.

Schoeninger, Margaret J. and Michael J. DeNiro
1984 Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial mammals. *Nature* 297:577-578.

Schoeninger, Margaret J., Katherine M. Moore, Matthew L. Murray and John D. Kingston
1989 Detection of bone preservation in archaeological and fossil samples. *Applied Geochemistry* 4:281-292.

Sommer, Gabriele
1995 *Ethnographie des Spachwechsels: Soziale Wandel und Sprachverhalten bei den Yeyi in Ngamiland (Botswana)*. Cologne: Rüdiger Köppe.

Thomas, David S. and Paul Shaw
1991 *The Kalahari Environment*. Cambridge: Cambridge University Press.

Turner, Gill
1987a Herders and hunters of the Okavango Delta, northern Botswana. *Botswana Notes and Records* 19:25-40.
1987b Early Iron Age in north western Botswana: the faunal evidence. *Botswana Notes and Records* 19:7-21.

van der Merwe, Nicholas J.
1982 Carbon isotopes, photosynthesis and archaeology. *American Scientist* 70:596-606.

van Klinken, G.J.
1999 Bone collagen quality indicators for paleodietary and radiocarbon measures. *Journal of Archaeological Science* 26:687-695.

Vogel, John C
1978 Isotopic assessment of dietary habits of ungulates. *South African Journal of Science* 74:298-301.

Vogel, John C, A. Fuls, R.P. and Ellis
1978 The geographical distribution of Kranz grasses in South Africa. *South African Journal of Science* 78:209-215.

Wilmsen, Edwin
1990 The antecedents of contemporary pastoralism in western Ngamiland. *Botswana Notes and Records* 20:29-39.
1989 *Land Filled with Flies: A Political Economy of the Kalahari*. London: University of Chicago Press.

Wilmsen, Edwin and James Denbow
2005 Early villages at Tsodilo: the introduction of livestock, crops and metal working. In Campbell, A., Robbins, L., and Taylor, M. (eds.), *Tsodilo Hills: Copper Bracelet of the Kalahari*. East Lansing: Michigan State University Press and Gaborone: Botswana Society, pp. 85-93.
1990 Paradigmatic history of San-speaking people and current attempts at revision. *Current Anthropology* 31:489-524.