THE EARLY INHABITANTS OF THE UPEMBA DEPRESSION, THE DEMOCRATIC REPUBLIC OF CONGO

A biological review of the cultural continuity theory

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ABSTRACT

The early inhabitants of the Upemba Depression, the Democratic Republic of Congo: a biological review of the cultural continuity theory.

By Nonhlanhla DLAMINI, 29 August 2014.

This research set out to shed light on the contradiction between the archaeological evidence pointing towards cultural continuity and the Luba's rejection of ancestral relationships with the human skeletal remains found in the Upemba Depression of Central Katanga, the Democratic Republic of Congo. This was done by assessing the biological variation of the human skeletal remains of the early inhabitants from the Upemba Depression in the southeast of the Katanga Province (DRC) by using metric and non-metric dental morphological traits.

Dental analyses of these Iron Age people have revealed homogeneity between the sexes, time periods and sites in Central Katanga. This is in contrast with the oral history from the Luba, who believe that the Iron Age remains are of their enemies who came from the northeast. In support of the archaeology, the dental morphological results from the current research have confirmed that present-day Luba people can trace their origins in Central Katanga as far back as AD 700.

The analysis of patterns of dental disease, carbon, nitrogen and oxygen stable isotopes as well as phytoliths demonstrate that the diets and behaviours varied amongst these Iron Age communities. This may have been related to differences in food preparation and hygiene. In the northern end of the Depression, the diets were rich in C_4 plants or C_4-based animal protein, with a much smaller contribution from C_3 foods. C_3 foods were more important in the diets of the individuals from the southern site of Katoto highlighting a robust pattern resulting from a significant dietary difference between this site and others. The findings have contributed to our understanding of the emergence and history of farming societies and kingdoms of south-central Africa pre-AD1800.

Plagiarism Declaration

I know the meaning of plagiarism and declare that all of the work in the dissertation (or thesis), save for that which is properly acknowledged, is my own.

Signature:

Dedication

This thesis is dedicated first, to my late beloved mother, Duduzile Sylvia Dlamini, for instilling in me a strong sense of self and pride in what I do; for the life lessons you taught me so indirectly. I am grateful to have had you as my mother.

Second, I dedicate this thesis to my beloved husband, Andreas Stoll, and my beautiful daughter, Nala Uju Stoll, for their love and patience. Thank you for everything you generously bring in my life.

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Chapter 1: INTRODUCTION

Over the last few decades, questions about the emergence of social complexity and origins of pre-colonial civilizations have been central to the study of later prehistoric populations of sub-Saharan Africa (McIntosh 1999; de Maret 2012; Mayor *et al*. 2014). The research reported in this dissertation focuses its attention on central Africa, in relation to these issues and especially in connection with the history of the Luba of Katanga, in the Democratic Republic of the Congo. The geographical location of the archaeological sites excavated in the Katanga Province, particularly Sanga, has led scholars to link the origins of the Luba Kingdom to this region of the central Africa.

Central Africa, an area so rich in cultural, linguistic and biological diversity, is fraught with unanswered questions that pertain to the history of its inhabitants, such as migration routes of the Bantu-speakers' expansion, indigenous people who lived there before the arrival of Bantu speakers, and so on, are examples of these yet-to-be fully understood subjects. For example, central Africa's role in the spread of early Bantu agriculturists across the sub-continent is pivotal in the understanding of this prehistoric phenomenon. It is an area where one can be certain of finding important new information on African civilizations of the pre-colonial era. Yet archaeological exploration has been limited, perhaps due to lack of interest in the African past before independence, and the ongoing challenging political and economic situation of this region of Africa (de Maret 1999). Much remains to be learned about the early history of central African kingdoms.

We know that a great number of states or kingdoms flourished in central Africa during the recent past. Most of this knowledge has come from oral traditions (Verhulpen 1936 in Nenquin 1963; Reefe 1981), linguistic studies (Ehret 1982; Vansina 1995; Williamson & Blench 2000), early historical records (for example, see Hochschild 2012) and to some extent, from archaeology (Phillipson 2005). Although the pre-colonial history of some Bantu-speaking populations of central Africa has been studied, little is known of their biological relationships. We still do not know enough about their origins, as well as the nature and extent of their interactions with one another and with other groups with whom they came into contact.

Archaeology has made significant contributions to our knowledge of the origins and prehistory of the Bantu-speaking peoples of central Africa (de Maret 1985a, 1985b, 1986, 1992, 1999; Nenquin 1963; Hiernaux *et al*. 1967; Clist 1991; Denbow 1990; Eggert 1993; Vansina 1990); but the evidence is incomplete. There is also the issue of reliability of both oral traditions and archaeology. Oral traditions tend to be limited in time depth and concentrate on political histories, while archaeology relies on vestiges left behind by past peoples. Human remains, on the other hand, offer an alternative tool to look into the past; perhaps a more reliable one as these harbour genetic and phenotypic information that is less affected/distorted by human error or by the environment. By investigating the biological variation of the ancient Upembans, this research hopes to better understand the long-term history of these societies.

This project, therefore, employs a multiple-disciplinary approach to investigate the biological origins of the Luba people. It does this by using dental morphology as a means to unravel the biological affinities and continuity of the early and late farming societies from the Upemba Depression to modern Luba people. Non-metric dental morphological traits provide useful and powerful means for evaluating the biological affinities between different populations. In addition, this thesis looks at the role played by different economic strategies adopted by Iron Age Bantu speakers.

Similar to the rise of complex societies in other regions of the world, the communities of the African Iron Age showed progressive development of more intensive exploitation and local specialization of food resources, in addition to cultural and technological changes associated with plant and animal domestication. This period witnesses communities co-existing side-by-side in very diverse environments. Therefore, subsistence strategies adopted by these peoples can tell us a great deal about the interactions of neighbouring communities, such as complementary existence and/or understanding the impetus for socio-political organisation that may be related to the management of resources, and so on. Hence, this study uses analyses of oral diseases, stable isotopes, and phytoliths to reconstruct prehistoric subsistence strategies. Bio-cultural traits, such as the intentional modification of anterior teeth, can also act to provide clues into people's relatedness and/or movement patterns. This trait is also examined in this project.

1.1 Rationale and Research Focus

Katanga is home to one of the great savannah kingdoms, the Luba, whose roots can be traced back with a reasonable degree of confidence to some time before AD 1700 (Reefe 1981; de Maret 1979). But who are the Luba? And how far back can they trace their origins to central Katanga of the DRC? According to de Maret (1982: 9),
"*The continuity and density of occupation in the Upemba Depression, as well as the persistence of certain customs, link its Early Iron Age inhabitants to the present-day Luba in such a way that the emergence of the Luba political system must now be reconsidered in the light of the new archaeological data*".

This quote from de Maret (1982) implies that the people who established Luba polity in the 18th century were the direct descendants of those who lived during the Kabambian, Kisalian and Kamilambian periods between the 6th and 17th centuries. Luba oral historical traditions, however, do not identify with the human remains buried in the archaeological sites of the Upemba Depression. They, in fact, see them as the enemies of their ancestors, who had arrived from the northeast, bringing new customs (de Maret 1979). So, who are the people buried in these ancient graves? Most of what we know of the early inhabitants of the Upemba Depression has come from the classification of archaeological finds (mainly from graves), especially pottery and metal artefacts, from which scholars have attempted to infer aspects of communities' identities (Nenquin 1963; Huffman 1982, 1989a & 1989b; Maggs 1984; de Maret 1977, 1979 & 1985b; Livingstone-Smith & Viseyrias 2010). However, none of these sites have been excavated to their full extent; Sanga is the most extensively excavated site in the Depression. Even at this site, exploration has not been exhausted. A further compounding issue is the fact that excavation has focussed on graves. It has been difficult to identify settlement areas suitable for excavation. This has limited archaeologists' abilities to develop multi-dimensional reconstructions of these past people's lives.

The archaeology of the Upemba Depression has demonstrated that mechanisms such as independent development, regional continuity, as well as migration of peoples were all involved in shaping the prehistoric culture of this region (Clark 1970; Hiernaux 1968; Reefe 1981; de Maret 1979, 1982; Birmingham 1981; Vansina 1966, 1995;

Nurse *et al*. 1985; Gondola 2002; Mitchell 2002; Phillipson 2005). The emergence of a hierarchical socio-political system by the end of the first millennium AD and the progressive development of inter-regional trade, including various forms of currency, are indeed some of the most interesting aspects of these societies (de Maret 1982).

The impetus for the research undertaken for this thesis was the contradiction between the archaeological evidence pointing towards cultural continuity and the Luba's rejection of ancestral relationships with the skeletal remains found in the Upemba Depression. To date, few studies have shed light on these societies from a biological perspective (Hiernaux 1968, 1976, 1977; Rightmire 1976; Hiernaux *et al*. 1992; Ribot 2002, 2004) (See Chapter 3 for a review). No overall picture exists of the biological variation of these populations, especially in relation to modern Luba. Much is still unknown about the possible interactions between the people, their environment and their neighbours. In the light of modern sub-Saharan African population diversity, the present research proposes to focus on understanding the biological history of the early inhabitants of the Upemba Depression. This research hopes to offer some clarity into the inconsistency between Luba oral history and the archaeological record.

1.2 Aim and Objectives

This project thus aims to evaluate biological variation within the populations living in the Upemba Depression, DRC between AD 700 and 1600, in relation to Luba ancestry.

The **central objectives** of the project were:

a) To assess biological continuity among burials associated with diverse cultural markers, using dental morphological traits

b) To track dietary continuity or change using analyses of stable carbon, nitrogen and oxygen isotopes, tooth-wear, dental diseases and phytoliths from dental calculus, and lastly

c) To evaluate bio-cultural traits, specifically dental modification, and their implication for identifying people's origins and/or relatedness.

Dental traits, rather than ancient DNA or craniometry were chosen as a means of assessing population variation because ancient DNA studies rely on preservation of the DNA molecule in the tissues of the dead. DNA begins to degrade as soon as an organism dies, and the rate of this degradation is strongly affected by environmental factors such as, soil pH; temperature; humidity and post-excavation storage (Höss *et al*. 1996; Pääbo *et al*. 2004; Gilbert *et al*. 2003; Willerslev & Cooper 2005). For example, Edwards *et al*. (2004) were able to amplify and sequence mitochondrial DNA from only 12 of the 101 specimens of archaeological African cow teeth and bones analysed. Methodological limitations are also a real problem when working with ancient DNA (Gilbert *et al*. 2005). In the Upemba Depression where this research is focused, temperature and relative humidity are high, (www.congonline.com; Peel *et al*. 2007); both environmental factors that contribute to rapid postmortem degradation of DNA in dental and skeletal tissues (Höss *et al*. 1996; Burger *et al*. 1999). The likelihood of recovering ancient DNA from the skeletons studied here using currently available techniques is therefore very small. Moreover, exogenous contamination with other human DNA (such as that from excavators, researchers, museum personnel) is very probable and would pose a problem (Binladen *et al*. 2006; Pääbo *et al*. 2004; Willerslev & Cooper 2005; Gilbert *et al*. 2005).

In craniometric studies the focus has been on inter-population variation, with fewer analyses of within-region variation because this technique is not well suited to investigating micro-scale diversity (Howells 1989; Lahr 1996; Froment 1998; Relethford 2001). Gene flow, directed by geographical proximity appears to be the key element in shaping morphological differences between populations, along with ecological and cultural factors (Froment 1998; Relethford 2001; Ribot 2002). In sub-Saharan Africa, cranial morphology has not proved very successful in revealing within-region differences (Relethford 2001; Ribot 2002, 2004). This is partly because of confounding factors that influence cranial variation, i.e. the role played by the environment and climate in morphology (Ribot 2002, 2004).

On the other hand, dental morphology has been shown to be a more robust indicator of population relatedness, since it is less strongly influenced by environmental pressures, sexual dimorphism and age variations (Larsen 1997; Scott & Turner 1997;

Scott 2008). There is a strong genetic component to tooth trait inheritance, suggesting that phenotypic similarity approximates genetic similarity, which subsequently can provide us with biological distances and gene flow patterns of a population under study (Scott & Turner 1997; Hanihara & Ishida 2005; Irish 1997, 1998; Ullinger *et al*. 2005). Several studies have demonstrated successful use of dental morphological traits to illustrate both inter- as well as intra-population relationships (Hanihara 1992; 2008; Hanihara & Ishida 2005; Irish 1997, 1998; Stojanowski 2005; Ullinger *et al*. 2005). Most lines of evidence for the strong heritability of dental traits (twin studies, familial correlations and population variation studies) indicate that genes are a major controlling factor in crown and root development (Bachrach & Young 1927; Montagu 1933; Kraus 1951; Townsend *et al*. 2012).

1.3 Dissertation Format

This dissertation consists of seven chapters. Chapter 1 introduces the proposed research, pointing out its goal and appropriateness. The rationale, aims and objectives of the current research study are also outlined in this chapter. Chapter 2 provides background information on the archaeology of the Upemba Depression and the skeletal remains used in this study. A brief review of the environment (geography, climate, flora and fauna) of the Upemba Depression is given, in order to understand its influence on the ecology of the area and diet of its inhabitants. Next, each archaeological site is described to highlight inter-site similarities and differences.

Chapter 3 reviews the literature on the approaches employed in this dissertation, critically examining current approaches to dental anthropology, biological anthropology, phytoliths, dental health and pathology, dietary stable isotopes and dental modification. Chapter 4 defines and describes the skeletal sample studied for this thesis, listing the numbers and archaeological origins of skeletons, how they were selected and their current locations. In addition, the methods used to examine the skeletal remains are outlined in this chapter, including estimation of age and sex, analysis of dental traits (metric and non-metric), stable isotopes of carbon, nitrogen and oxygen, phytoliths, dental diseases and cultural dental modifications. This chapter also provides a list of samples taken for stable isotope and phytolith analysis. Chapter

5 presents the results obtained in this research. Statistical tests are used to explore the significance, or lack thereof, of any differences or similarities found.

Chapter 6 discusses the results of the current study in three sections. First, it explores the data from dental morphological traits from the Upemba Depression in light of the question about biological continuity. Second, it looks at dietary indicators (dental diseases, phytoliths, and stable isotopes) as clues to dietary homogeneity/heterogeneity through time. Lastly, the use of dental modification is considered as a reflection of social complexity and identity. The findings of this study are compared with other studies in the research area and relevant neighbouring areas in order to put the ancient societies of the Upemba Depression in the wider context of sub-Saharan Africa. Chapter 7 synthesises the totality of the information gathered from dental anthropology, phytoliths and stable isotopes about the biological variation and population affinity of these early farming populations from the Upemba Depression and their relationship to modern Luba.

Chapter 2: ARCHAEOLOGICAL BACKGROUND

In this chapter, I summarise relevant aspects of the archaeological background of the societies living in the Upemba Depression during the Iron Age (AD 700 to 1600). The Upemba Depression (also known as the Kamalondo Depression), is situated in the central part of the Katanga Province in the south-eastern Democratic Republic of the Congo (DRC) (Figure 2.01). Most of what we know of the Iron Age archaeology of the Upemba Depression comes from graves and associated goods. Although habitation levels and fragments of daga were found at all the sites, it was not possible to make any significant reference in terms of settlement structures and way of life because of their poor preservation due to the continuous use of the land (de Maret 1999). Consequently, this kind of evidence is very incomplete, since it depends on what people considered appropriate items to include in the burials. In that respect, it is a very different kind of evidence from the more usual archaeological assemblages obtained by excavating habitation sites and refuse areas.

Since the burials, especially the human remains, excavated from the graves were the focus of this study, their archaeology is reviewed so as to place them in the wider context of the prehistory of south-central Africa. Moreover, in order to explore the biological variation and diet of these early inhabitants of the Upemba Depression, it is necessary to review the geography, climate, flora and fauna of their environment.

2.1 Research Area: Geography, Climate, Flora and Fauna

Geography and climate are important in this dissertation because of their influence on patterns of population distribution, interaction and the spread of genes in these populations. Climate is determined by interaction between temperature, rainfall, solar radiation and altitude (Schulze & McGee 1978). The Upemba Depression lies to the east of the Kibara Mountains, with the Lualaba (Upper Congo) River running approximately through the middle (Figure 2.01). The Depression is about 400 kilometres long and 100 kilometres wide, running from the southwest to the northeast. It is about 1000 metres above sea level at its southwest end, sloping down to 610

metres in the northeast, where it flattens out to a series of approximately fifty lakes and marshes. The largest lake is Lake Upemba (530 km^2) (Kahozi 2002). Of the six archaeological sites that have been excavated and studied in the Depression, Katoto, Katongo and Kamilamba have the highest elevation at ~650m above sea level (asl), Sanga is 600m asl while Kikulu and Malemba-Nkulu lie slightly lower at ~565m asl.

Apart from its richness in natural resources, this part of the DRC is important as the source of the Congo River, which arises from the numerous streams off the Kibara plateau. The Upper Congo or Lualaba River flows through the marshes between and through the lakes, in parts connected by narrow channels. Sources of drinking water for resident populations come from the numerous lakes and streams in the Depression. At Katoto, in the south-western end of the Depression, people obtained their drinking water from the nearby Upper Congo (Lualaba) River, while people at Sanga would have used water from Lake Kisale.

Based on the relationship between precipitation and evapotranspiration, Koppen and his collaborators developed a classification system for world climates, which has been in use for over a century (Peel *et al*. 2007). Using the Koppen-Geiger system, three main climate zones can be identified for the continent of Africa: arid (57.2% of land area), tropical (31.0%) and temperate (11.8%). The current research area falls within the temperate savannah (Cwb) climate zone (Peel *et al*. 2007). It is characterised by dry winters and wet summers, with precipitation of 1200-1400mm per annum. In the south and south-east Katanga, the rainy season begins in mid-October and continues until mid-May (www.congonline.com). Mean annual temperatures are moderate, between 8 and 31°C (www.worldclimateguide.co.uk).

The DRC exhibits high levels of biodiversity at both the ecosystem and species level. According to the floristic divisions by White (1983) and Werger (1978), the Upemba Depression belongs to the Zambezian domain, with a marshy grassland savannah landscape. There is a wide variety of edible plants, both wild and domesticated, available in the Zambezian region. The country is estimated to be the 5th most bio-diverse country in the world (Counsell 2006); current knowledge shows a minimum of 10 531 floral species, of which 1 337 are endemic (Atyi & Bayol 2008).

Termote (2012) reports on wild edible plants commonly found in eastern DRC. This is the most recent ethno-botanical study carried out in the country, and was concerned with the Tshopo District (in the north-eastern Orientale Province) of the DRC. It aimed to make an inventory of wild edible plants for the purpose of promoting them for better nutrition security and poverty alleviation (Termote 2012). Though the Tshopo District has a tropical rainforest climate, the wild edible plants listed from this District still provide the closest and best estimate of the kinds of foods available to populations in the Upemba Depression.

The fauna of the DRC includes at least 4758 wildlife species, namely 456 terrestrial invertebrates, 1782 aquatic invertebrates, 1000 fresh water fish, 1099 birds (22 endemic species) and 421 mammals (15 endemic species) (Anonymous 2009; Atyi & Bayol 2008). The fauna in the research area falls into one region, i.e. the Aethiopian zoogeographical region (Delany & Happold 1979; Werger 1978). Delany and Happold (1979) looked at the distribution of mammals in the savannah regions of Africa and found twice as many species in the wetter savannah region (800-1000mm annual rainfall) as in the drier savannah (350-400mm annual rainfall). This is in part due to the loss of vertical habitats more common in moister areas, so there are fewer primate species in dry savannah, for example. Loss of dense tree cover, however, leads to more grass cover and shrubs, which in turn accommodate diverse populations of hoofed mammals (Delany & Happold 1979).

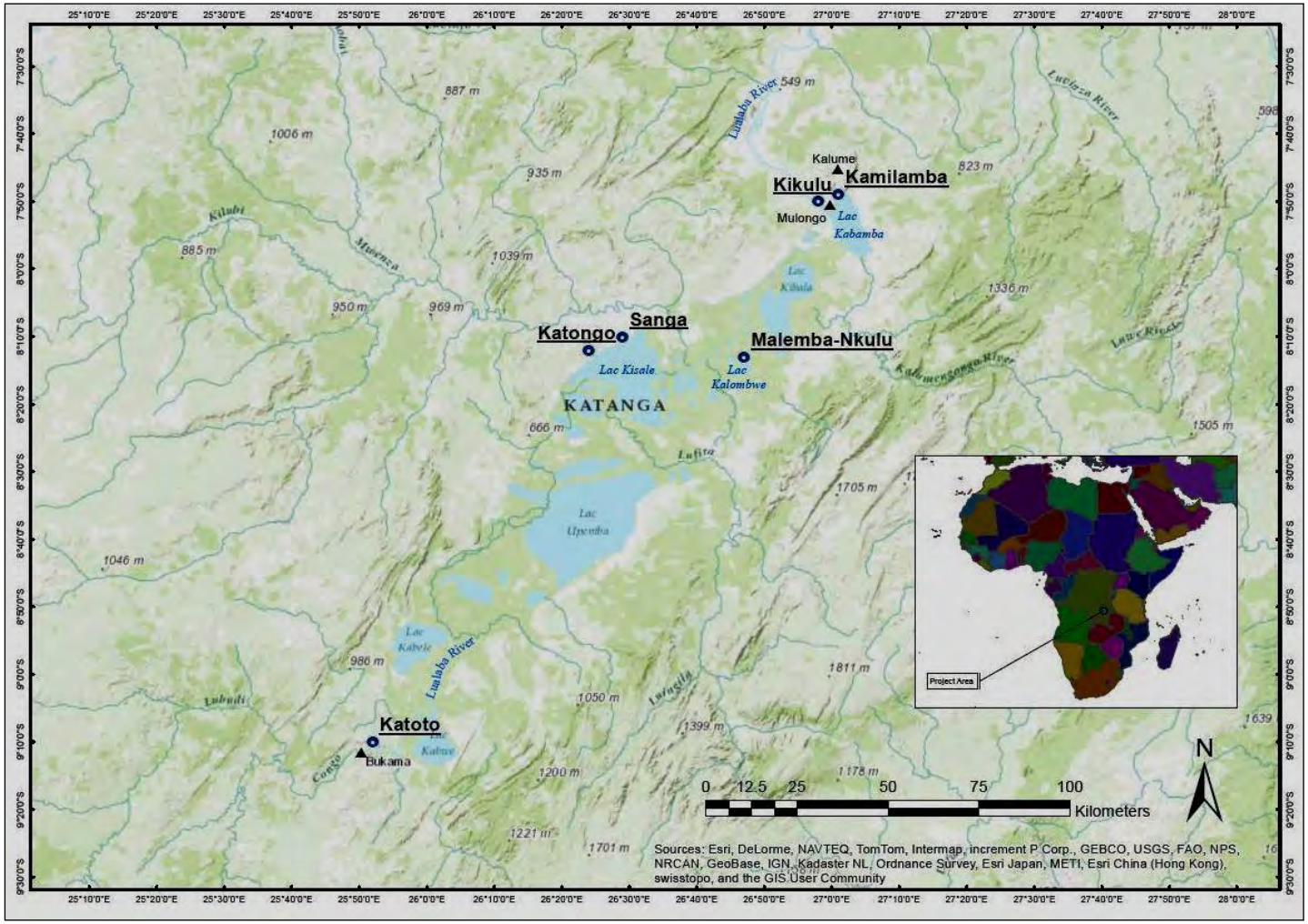


Figure 2.01: Geographical location of the research area in Katanga, DRC, showing positions of archaeological sites. (Map constructed using the following GIS sources: Esri [Japan & China], DeLorme, NAVTEO, TomTom, Intermap, Increment P Corp, GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, Kadasler NL, Ordinance Survey, METI, swisspro, and the GIS User Community).

In addition to the wild fauna, a variety of domesticates have been introduced into south-central Africa over the past few thousand years, including cattle, goats, sheep, chickens and dogs. Cattle herding requires an environment with the appropriate temperature, rainfall and vegetation. Disease vectors also play a major role in pastoralism in sub-Saharan Africa. Tsetse flies live in shaded, moist and warm regions throughout Africa and are a hindrance to cattle keeping in areas of infestation (Smith 1992; White 1984). Tsetse infestation is commonly associated with savannah woodland in the wetter regions (upper limit between 500 and 700mm annual rainfall) and can be found throughout most of the DRC. Cattle pastoralism is therefore not common in the DRC today due to high rainfall and prevalence of tsetse flies. This is likely to have been true during the past two millennia: skeletal remains of goat and chicken were the only domesticated fauna recovered at the sites in the Upemba Depression (van Neer 1978. See section 2.4 below for details). Tsetse flies have less effect on wild bovids, which have evolved resistance to the parasite (Smith 1992). Thus, hunting is still possible in tsetse-infested regions; this is supported by the abundance of wild faunal remains at the Katanga sites (see below for details).

2.2 Archaeology of farming communities in the south-eastern DRC

Between 4,000 and 3,000 years BP, proto-Bantu speaking agriculturalists began to expand southwards and eastwards from their homeland in the region of present-day Nigeria-Cameroon (Diamond & Bellwood 2003). Described as a great complex population movement of linguistic and cultural groups, the Bantu-speakers' expansion has been linked to the spread of farming based on the perceived homogeneity of the material culture of the earliest agricultural groups (Mitchell 2002). Debate over the model of the Bantu-speakers' migration have been put forth, citing arguments such as independent development, diffusion of ideas, and so on, as involved in shaping the prehistoric culture of this region (Vansina 1995). Despite the controversy over the model, spread and timing of this event (Vansina 1995; Chami 1999, 2001, 2007), it remains widely accepted that a great migration took place in sub-Saharan Africa post 4, 000 BC (Ehret 2001; Heine & Nurse 2000; Williamson & Blench 2000; Beleza *et al*. 2010; Huffman 2005, 2007; Phillipson 1995, 2005; Ribot 2011).

Ceramics, which are often found in abundance, have played a major role in interpretations of cultural change or continuity in sub-Saharan Africa. In conjunction

with linguistic data, archaeologists have examined continuities in ceramic and other cultural remains, and models for the Iron Age population movements have been suggested (see Diamond & Bellwood 2003 for a review). Evidence for a settled village life is another distinctive feature of Iron Age sites. Radiocarbon dates indicate that the dispersal started in West-Central Africa, between 4,000 and 1,000 BC (Mitchell 2002; Phillipson 2005).

Closest to the study area, the earliest evidence of a type of agriculture dates to between 300 and 100 BC and is seen at the Ngovo group of sites in the western part of the DRC, and into northern Angola and southern Congo-Brazzaville (de Maret 1986) (Figure 2.02). Carbonised fragments of palm nut (*Elaeis*) and nuts of *Canarium schweinfurthii*, as well as polished stone tools and ceramics were found at these sites. Although the Ngovo sites lack any evidence of metal (iron) use and are thus not regarded as part of the Iron Age, they could indicate the first colonisation of this country by agriculturalists (de Maret 1986).

In the western part of the country, at the site of Sakuzi (Figure 2.02), the earliest evidence of metal use (iron) has been radiocarbon dated to between the mid-first and the early third centuries AD (de Maret 1986). This site is associated with a group of people known as the Kay Ladio, whose pottery shares significant similarities with that of the preceding Ngovo group. Sakuzi also yielded remains of iron-smelting furnaces, hearths, and polished stone tools which could have been used as hoes because of their shape, wear and damage. Once again, as at the Ngovo sites, carbonised remains of the nuts of the oil palm (*Elaeis* sp.) were found in some of the pit features at the site (de Maret 1986).

Overall, archaeological exploration has been limited in central Africa, perhaps due to lack of interest in the African past before independence, and the ongoing challenging political and economic situation of this region of Africa (de Maret 1999). Much remains to be learned about the early history of central African kingdoms. The situation is, however, changing and hopeful. For example, archaeological excavations at Mbanza Kongo, the former capital of the Kongo kingdom, are underway and have indeed proved very fruitful (de Maret 2006; Clist *et al*. 2013a, b).

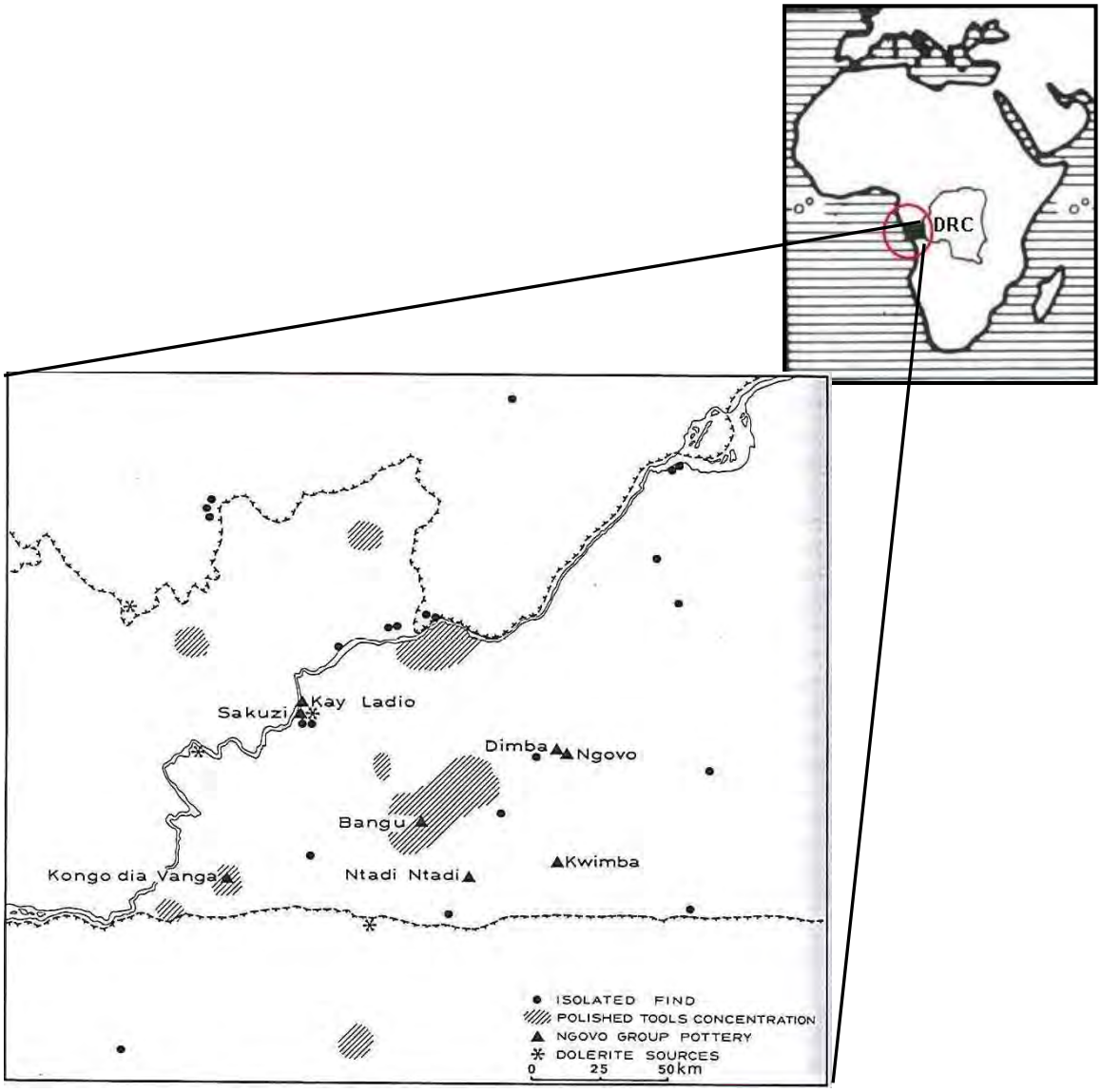


Figure 2.02: Map showing Ngovo and Sakuzi sites (underlined in red) in the western part of the DRC (red ellipse), as well as the distribution of polished stone tools in relation to the Ngovo Group pottery (from de Maret 1986: 126).

In Katanga, the earliest evidence of the Iron Age begins around the seventh century AD at the site of Kamilamba in the northern end of the Upemba Depression. This period is known as the Kamilambian and its ceramic tradition is related to that of the larger Copperbelt Early Iron Age Industry, and constitutes its most northerly point of extension (de Maret 1977, 1982; Phillipson 2005). There is tentative evidence to suggest that the spread of Early Iron Age farmers in this region was north-to-south as indicated by the distribution of archaeological sites (de Maret 1992: 187). All sites that have been dated to the Kamilambian period are restricted to the northern end of the Depression. Most knowledge of the Katangan Iron Age of the first and second millennium AD comes from six cemetery sites located in the Upemba Depression, namely, Sanga, Katoto, Malemba-Nkulu, Kikulu, Kamilamba, and Katongo (Figure 2.01). More than fifty archaeological sites have been documented in this region, but only these six have been systematically excavated. Located on the shores of Lake Kisale, Lake Kabamba and Lake Kalombwe, as well as along the Upper Congo (Lualaba) River, the people living at these sites could make use of ample resources from the lakes and rivers as well as fertile alluvial soils for farming activities (de Maret 1979).

The archaeology of this area has revealed a long sequence of over 1000 years of continuous Iron Age occupation, in a vast region of the savannah (de Maret 1979, 1982). The richness of the artefacts found in the graves and the significant number of radiocarbon dates have enabled us with to place these societies in the wider Iron Age context of south-central Africa. Population growth, continuous occupation, and use of the land for agriculture have, however, caused great disturbance to the deposits at most of these sites. In some cases, the area is still in use today. Thus, very little information about habitation sites or settlement types could be obtained.

The first of the systematic excavations took place in 1957 at the site of Sanga, north of Lake Kisale, and were carried out by a Belgian archaeologist named Jacques Nenquin. Between 1926 and 1955, several discoveries of Kisalian pottery were made by different prospectors, some linked to the Royal Museum for Central Africa in Tervuren (Belgium), and others who were private collectors. These earlier discoveries were collected at the modern villages of Mulongo, Sanga, Kikondja and Katongo, when villagers were digging for clay. Prompted by these earlier discoveries of

Kisalian pottery, Nenquin's expedition aimed to find more graves containing Kisalian ware, and possibly a settlement belonging to this culture, in order to integrate it into the general picture of central African pre-contact cultures (Nenquin 1963). Continuing in the search for Kisalian origins, a further 89 graves were excavated by Jean Hiernaux and De Buyst in 1958, bringing the total number of graves excavated at Sanga to 145 (Hiernaux *et al*. 1971). Some sixteen years later, Pierre de Maret returned to Sanga to excavate a further 31 graves, raising the grand total of systematically-excavated graves to 176 (de Maret 1985a). In that same year, de Maret excavated a new site called Katongo, which yielded 12 graves (de Maret 1985a).

About 130 kilometres south-west of the Depression, another site (Katoto) had been excavated in 1958 by Hiernaux and De Buyst, and produced 47 graves (Hiernaux *et al*. 1967). In 1975, de Maret excavated three more sites with material culture similar to the three already-excavated sites, i.e. Sanga, Katongo and Katoto. The sites of Malemba-Nkulu, Kikulu and Kamilamba produced 37, 27 and 13 graves respectively. Altogether, a total of 308 graves have been excavated at the six archaeological sites from the Upemba Depression. The results of the excavations at all six sites are summarised by year and excavator in Table 2.01.

The three excavators each proposed different chronological groupings of these sites. Nenquin (1963) suggested a three-phase sequence: Kisalian, Mulongo and Red Slip. Hiernaux *et al*. (1967) recognised only Kisalian and Mulongo-Red Slip (contemporary). Nenquin and Hiernaux's sequences were based mainly on ceramic typology. De Maret (1977) also incorporated observations of changes in funerary practices and grave goods, to propose six chronological periods: Kamilambian, Ancient Kisalian, Classic Kisalian and Kabambian A and B (Mulongo and Red Slip cultures grouped into one tradition) (Table 2.02). This sequence is underpinned by 50 radiocarbon and four thermoluminescence dates. All the graves date to between AD 700 and 1800 (de Maret 1979, 1985a, 1992). Radiocarbon dates for skeletons included in the present study are presented in Table 2.03. De Maret's chronology has been widely recognised, and is employed in this dissertation.

Table 2.01: Numbers of graves excavated at the six archaeological sites in the Upemba Depression. Numbers in brackets indicate grave identification numbers from successive seasons of excavation at Sanga.

Year of excavation	Site	Total no. of graves	Reference
1957	Sanga	56 (#1 – 56)	Nenquin (1963)
1958	Sanga	89 (#57 – 145)	Hiernaux *et al*. (1971)
1974	Sanga	31 (#146 – 176)	de Maret (1985a)
1959	Katoto	47	Hiernaux *et al*. (1967)
1974	Katongo	12	de Maret (1985a)
1975	Kamilamba	13	de Maret (1992)
1975	Kikulu	37	de Maret (1992)
1975	Malemba-Nkulu	23	de Maret (1992)
TOTAL	**6**	**308**	**-**

Table 2.02: Chronological sequence of the archaeological phases in the Upemba Depression.

Period	Chronology	Reference
Kamilambian	AD 600 – 700	de Maret (1999)
Ancient Kisalian	AD 700 – 900	de Maret (1999)
Classic Kisalian	AD 900 – 1200	de Maret (1999)
Kabambian A	AD 1200 – 1500	de Maret (1999)
Kabambian B	AD 1500 – 1600	de Maret (1999)
Recent (Luba)	AD 1700 – 1900	Reefe (1981)

Table 2.03: Skeletons studied in this dissertation with direct radiocarbon dates, listed by site. All radiocarbon dates were obtained from human bone collagen. The "T" numbers under each site indicate the grave (or tomb) number from that site.

Specimen	Chronological period	Uncalibrated radiocarbon date	Publication
SANGA			
T176	Kabambian A	(Hv 6615): 495 ± 105 bp	de Maret (1985a)
T153	Classic Kisalian	(Hv 6610): 655 ± 125 bp	"
T172	Classic Kisalian	(Hv 6613): 770 ± 95 bp	"
T175	Classic Kisalian	(Hv 6614): 855 ± 90 bp	"
T160	Classic Kisalian	(Hv 6612): 875 ± 75 bp	"
T10	Classic Kisalian	(B-264): 1070 ± 200 bp	Nenquin (1963)
T173	Classic Kisalian	(Hv 8490): 1110 ± 70 bp	de Maret (1985a)
T149	Ancient Kisalian	(Hv 6609): 1205 ± 105 bp	"
T18	Ancient Kisalian	(B-263): 1240 ± 120 bp	Nenquin (1963)
KATOTO			
A radiocarbon date on charcoal of AD 1190 ± 60 (B-760) makes Katoto contemporaneous with the Classic Kisalian period (Hiernaux *et al*. 1967).			
MALEMBA-NKULU			
T19	Kabambian B	(Hv 8496): 100.1 ± 0.5 bp	de Maret (1992)
T13	Kabambian B	(Hv 8495): 375 ± 40 bp	"
T2A	Kabambian A	(Hv 7506): 420 ± 55 bp	"
T3	Kabambian A	(Hv 7516): 495 ± 55 bp	"
T26	Kabambian A	(Hv 7495): 520 ± 50 bp	"
T10	Classic Kisalian	(Hv 7513): 785 ± 210 bp	"
T35	Kabambian B	(Hv 8497): 860 ± 55 bp	"
T37	Classic Kisalian	(Hv 7499): 1005 ± 65 bp	"
KIKULU			
T1	Recent (Luba)	(Hv 7507): 100.8 ± 1.2 bp	de Maret (1992)
T2	Kabambian A	(Hv 7517): 685 ± 50 bp	"
T13	Atypical	(Hv 7503): 765 ± 60 bp	"
T8	Classic Kisalian	(Hv 7514): 765 ± 50 bp	"
T20	Kabambian A	(Hv 7505): 795 ± 65 bp	"
T19	Kabambian A	(Hv 7515): 920 ± 50 bp	"
T14	Ancient Kisalian	(Hv 8494): 1295 ± 45 bp	"
KAMILAMBA			
T2	Kabambian	(Hv 8491): 155 ± 130 bp	de Maret (1992)
T5	Kabambian A	(Hv 7501): 470 ± 120 bp	"
T7	Kisalian	(Hv 7498): 1105 ± 150 bp	"
T10	Ancient Kisalian	(Hv 8492): 1645 ± 160 bp	"
KATONGO			
T6	Recent (Luba)	(Hv 6617): 190 ± 65 bp	de Maret (1985a)
T8	Kabambian B	(Hv 6621): 250 ± 85 bp	"
T2	Classic Kisalian	(Hv 6616): 660 ±190 bp	"

Since archaeological investigations in the Upemba Depression have primarily focused on burials, relatively little is known of the actual habitation or settlement structures and day-to-day lives of these people. As a result, the archaeology has concerned itself with continuities and changes in ancient burial practices and rituals, subsistence and technological activities, and the symbolic uses of objects found in the burials (Childs & de Maret 1996). The section below briefly discusses the six chronological periods identified for the Iron Age of Central Katanga. In addition, a brief discussion of the Katotian pottery tradition, which developed in the south-western end of the Depression, is provided for comparison with the contemporaneous Kisalian culture. The section ends with a review of the points of contrast between the archaeological evidence and Luba oral history.

A. Kamilambian (AD 600 – 700)

Iron Age villages were established on the shores of the numerous lakes and streams of the Upemba Depression. Some fragments of daga with impressions of branches were collected from the Kamilambian phase, providing evidence for housing structures. Iron objects found in the only grave dating to this period include an axe, barbed arrow heads, a curved knife, a spear head and a hoe. No human remains, however, were preserved in this grave (de Maret 1992, 1999); therefore, nothing can be said of the orientation of the body.

No evidence of copper has been found during this period; copper first appears in the Ancient Kisalian (de Maret 1979, 1982). Grindstones and charred palm nuts attest to an established farming way of life. The single grave from this period indicates that settlements were relatively few in number compared to subsequent periods.

The fragmentary state of the ceramic remains does not allow comparison of the frequency of the different types (bowls, pots, and so on) of vessels. The base is convex without any special characteristics. In some fragments, the shoulder is carinated, while others have a rounded profile between the body and the shoulder. The rims are straight and decorated mainly by comb stamping. The decoration consists of oblique impressions and crosses bordered by horizontal lines. This pottery is similar to that from the Early Iron Age of north-western Zambia; the so-called Western

Stream (Phillipson 1975, 1976) or Early Iron Age Copperbelt Industry (de Maret 1979).

B. Ancient Kisalian (AD 700 – 900)

The Ancient Kisalian, which dates to between the eighth and tenth century AD, succeeds the Kamilambian period. Pottery becomes more elaborate and complex, but not to the same high standard as during the Classic Kisalian period (de Maret 1979). Ancient Kisalian pottery is made of very fine and durable clay, contrary to the usual standards of (Classic) Kisalian ware (de Maret 1985a: 144). Ancient Kisalian vessels have sinuous and elaborate shapes, with distinctive decorations on convex rims. This ware has a darker colouration than the later forms, and a micaceous temper. Grave goods are not as elaborate as in succeeding occupations (de Maret 1982). Large curved knives and spearheads are typical of the Early Kisalian. The spearheads were found in a heap and not hafted, suggesting that they might have been used as currency (de Maret 1999). Iron artefacts were no longer limited to weapons as in the Kamilambian, but include jewellery (bracelets and necklaces), as well items for ceremony and displays of power. It is during this period that we see the earliest evidence of political organization, demonstrated by the presence of a ceremonial axe and an iron anvil, in burial number 7 from Kamilamba (de Maret 1992: 30).

Copper, in the form of hammered bangles, appears for the first time during the Ancient Kisalian and remains rare until the Classic Kisalian. It was probably brought up from the Katangan Copperbelt to the south, where the earliest evidence of its production dates to the fourth century AD (Bisson 1975). Its rarity may mean that there was considerable disparity in access to materials such as copper, and that it was available only to a selected few. This indicates that some degree of socio-political differentiation and ranking was already in place around the ninth century AD (Childs & de Maret 1996). There are not many recorded graves associated with this period probably due to low population density. However, the presence of burials dating to this time at four of five sites in the Depression suggests that people had become well dispersed in the landscape.

With regards to the funerary ritual, there seems to have been a preference (77%) for the north-south orientation of the body (head to the north or north-east) during the

entire Kisalian period, with a few heads rested upon upturned pots. The body was interred most often on its back, with its legs in a flexed position. The pots, which were mostly unused before burial, were generally placed at the back of the deceased, but sometimes formed a half circle by the upper body or complete enclosure around the body (Nenquin 1963, 1967).

C. Classic Kisalian (AD 900 – 1200)

The beginning of the tenth century AD saw the evolution of a new type of pottery that was of such high quality that so far, it remains unique in the Late Iron Age of sub-Saharan Africa. Kisalian pottery is characterized by its complex profile, frequently exhibiting a spout or a handle, as well as contoured shapes (de Maret 1979). The colour ranges from a pale greyish-yellow to a vivid orange-red. The clay is heterogeneous and composed of some rough pieces of 1-5mm quartz (de Maret 1985a: 153, 1992). A typical Kisalian pot has a rounded base, contracted shoulder, outward-flaring neck, and an inward-turning rim (Figures 2.03 and 2.04). The shoulder is often decorated with an incised half-moon motif, the lip is either incised or comb-impressed, or shows a series of horizontal grooves. These pots dominate the assemblage. Other pots have a sharply carinated shoulder, but the body, neck and lip remain the same as the typical form. The bowls, which have the same decoration on the lip as the larger pots, often have a triangular handle or spout. Other unusual types include vases with a human face decoration, and trilobate vessels that first appear at this time (Nenquin 1963, 1967; de Maret 1999). The last vessels were probably used as braziers, as identical ones are used by modern fishermen in central Africa for cooking fish in dug-out canoes. More importance is given to pots as funerary items to the extent of production purely for interment.

This is the period when the Kisalian culture reached its peak and is represented by the largest number of graves known so far in this part of Africa (de Maret 1982). The increased number of burials suggests that there had been significant population growth, accompanied by high infant mortality. The quantity and range of grave goods was markedly greater than in preceding periods. Iron objects found in the graves included objects for agriculture, hunting, fishing, ritual and personal adornment. Copper became common, and was used for both ornamental items (such as necklaces,

belts, bangles and bracelets) and for functional objects (such as spearheads and knives).

Other artefacts found during this period include ornaments of shell, ivory, and bone, including human and animal teeth and complete human jaws, which are discussed in more detail below. Differences in socio-political status were clearly indicated by the unequal wealth found in the graves. Some of the richest burials were of children, suggesting that status was inherited at this time. Miniaturised symbols of power, such as a ceremonial axe, attest to this inherited status (Childs & de Maret 1996). Evidence of materials foreign to the Upemba Depression (copper and cowrie shells), prove that short and long-distance trade was established during this time and largely manipulated by a wealthy minority (de Maret 1999).

D. Kabambian A and B (AD 1200 – 1500 and 1500 – 1600)

At the turn of the thirteenth century AD, a change in burial ritual typified by less consistency in body orientation, a decrease in quantity of grave goods especially of iron objects, and a change in types of objects placed in the graves. Unlike in the preceding Kisalian, during the Kabambian period, the preferred body orientation was south-north (with the head to the south), but north-south orientation is also represented. The body was interred either on its right side or on its back while being fully extended, with the arms stretched along the sides. However, as already mentioned, more variation is seen in the orientation and position of the body during the Kabambian (Nenquin 1963; de Maret 1992). No ritual of resting the head on an upturned pot was encountered at this time. There is no uniformity in the position of the pottery in the graves.

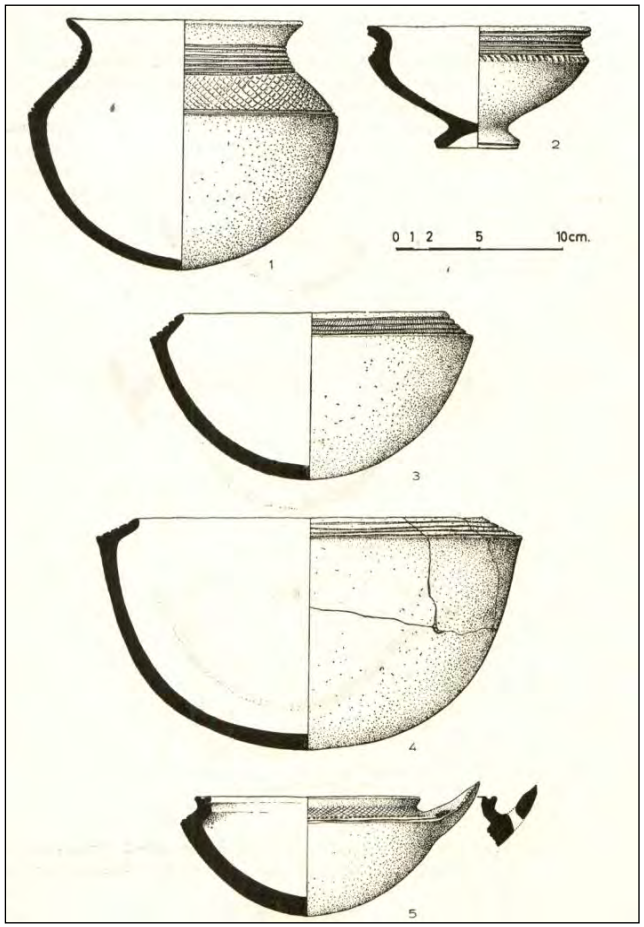
The causes for the shift in customs and rituals from the Kisalian to the Kabambian remain obscure, but could be a result of growing exterior pressures or of population movements. The pottery is less elaborate in form and decoration, and in the second phase, is characterized by a red slip (de Maret 1979). The appearance of a new category of copper artefacts, the copper crosses or *croisettes*, believed to have been used as currency and symbols of wealth and authority, distinguishes the Kabambian from the Kisalian culture. The abundance of copper confirms the progressively

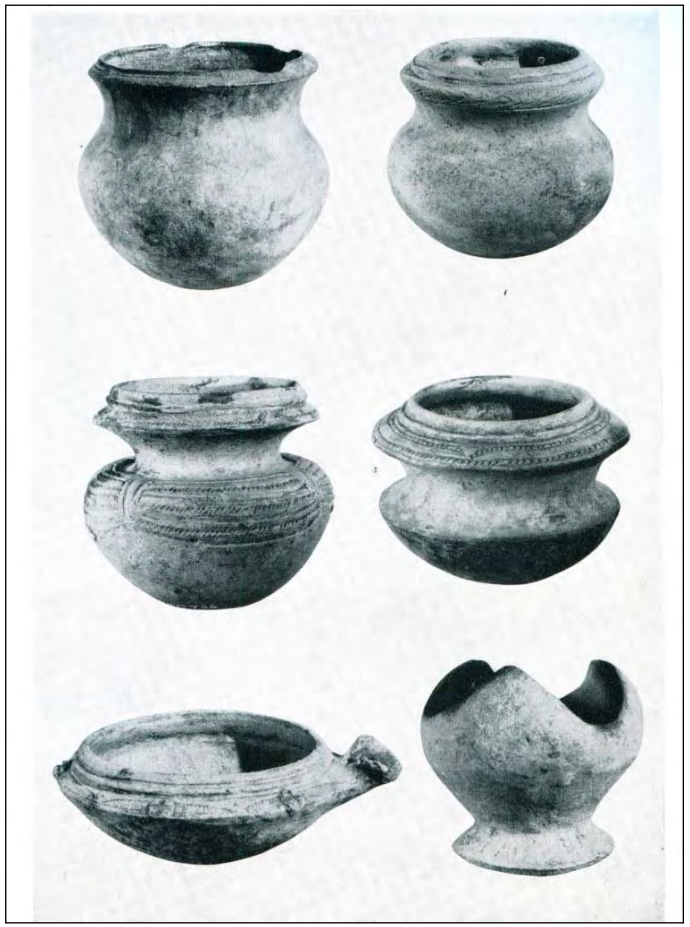
growing trade with the south, i.e. the Copperbelt region of lower DRC and north-central Zambia (de Maret 1979). Of particular interest is the lack of distinct markers of socio-political status, such as ceremonial axes and anvils, in the richest Kabambian burials. This is in sharp contrast to the rituals of the earlier periods in which an emphasis was placed on the association of these artefacts in high-ranking burials.

The Kabambian B period is related to the expansion of long-distance trade with the coastal regions, attested by the presence of cowrie shells and glass beads in the graves. Standardised and smaller in size, the copper *croisettes* during the Kabambian B can be distinguished from the earlier larger and cruder forms. Their decreased size and standardisation were probably related to a decrease in quantity of copper as well as an increase in demand (de Maret 1999; Childs & de Maret 1996). Population density remained high during the Kabambian as in the Classic Kisalian period. This is supported by a large number of Kabambian graves at the sites of Malemba-Nkulu and Kikulu.

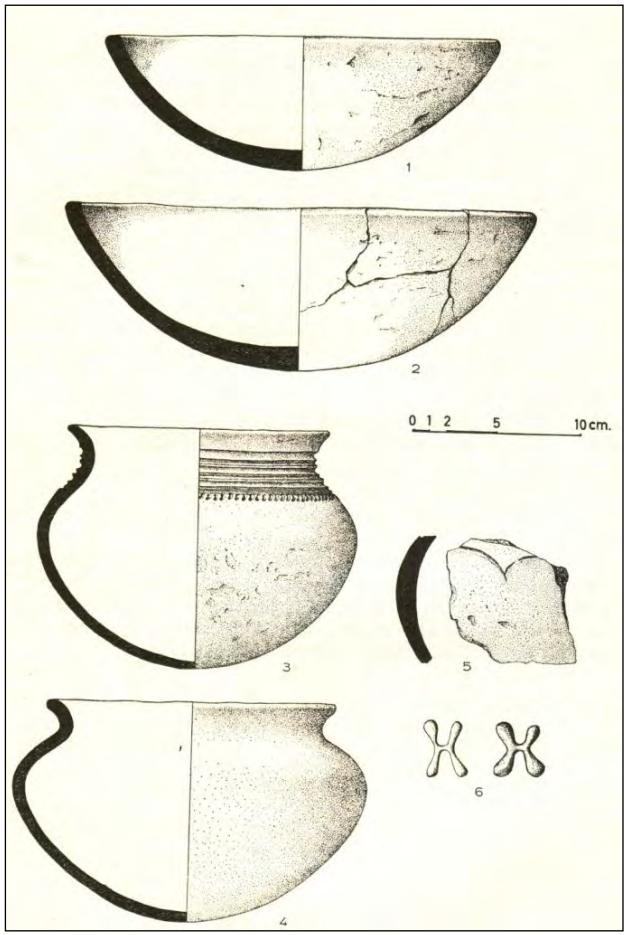
Kabambian pottery differs from the preceding Kisalian ware mainly in its shape and decoration. It has a somewhat flattened aspect, with a wide body, constricted neck and everted rim (Figures 2.05 and 2.06). The shape of the pots is more globular than rounded. Their shape seems to anticipate that of recent Luba ceramics, although they are much more carefully made. Several vessels are decorated with a number of horizontal grooves or incisions around the neck, much more simply than the elaborately decorated Kisalian ware. The trilobate bowls first seen in the Kisalian period are still present, and show little change other than the overall widening trend in the body of the vessels. In the Kabambian B period, a thick shiny red slip covers the outer, and sometimes the inner surface of the pots (Nenquin 1963; de Maret 1992). Akin to Kisalian pottery, Kabambian pottery is also made of coarsely grained clay with some pieces of quartz (de Maret 1985a, 1992).

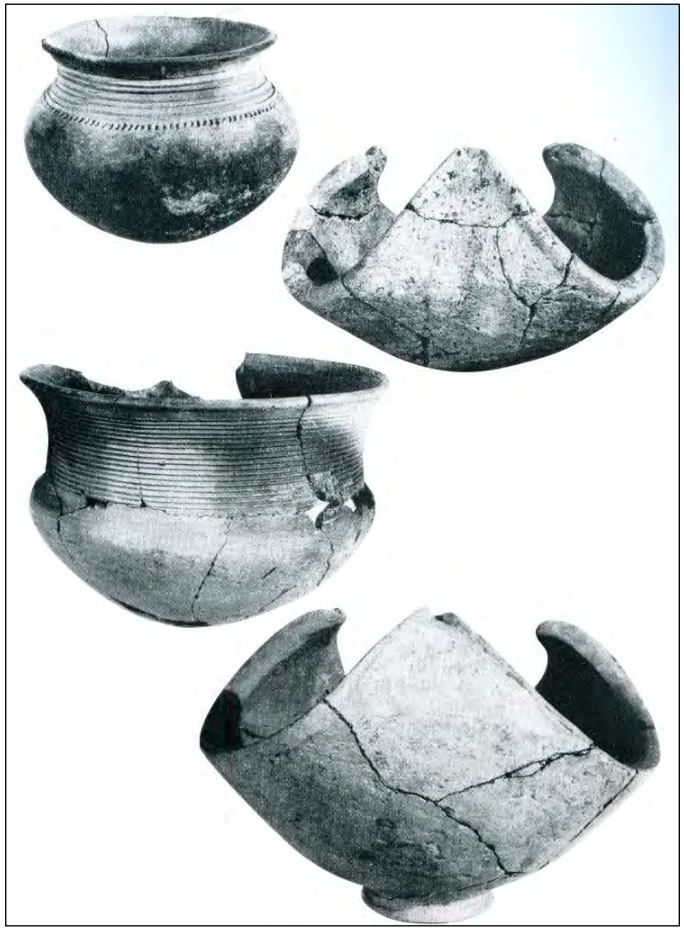
Around the end of the seventeenth century an eastward expansion of a new culture, the Luba Lomami, led to the decline of the Kabambian culture (de Maret 1977, 1982). The emergence of the Luba state is linked with the control of local trade of raw materials such as salt, dried fish and iron (Reefe 1981).





Figures 2.03 and 2.04: Examples of Kisalian pottery from Sanga grave no. 32 (Nenquin 1963: 107). Pots of Kisalian type collected in 1955 by Dr. A. Maesen (Nenquin 1963: Plate XVII).





Figures 2.05 and 2.06: Examples of Kabambian pottery from Sanga grave no. 1 (Nenquin 1963: 22). Typical examples of Kabambian (Mulongo) ware, with deep horizontal grooving on the neck (Nenquin 1963: Plate XXI).

E. Recent: Luba (AD (AD 1700-1890)

The richest information on Luba history and culture has come from oral traditions and ethnohistory, rather than from archaeology. According to Luba oral history, the origins of their sacred kingship is told in an epic narrative that is often referred to as a "genesis myth" in literature. The free-form story begins with a great hunter from the east, Mbidi Kiluwe, who introduced royal bearing and a new political order that was different from the uncouth, cruel rule of Nkongolo Mwamba. Nkongolo's origins are somehow a mystery. The few accounts that have been recorded refer to him as a self-made ruler or a conqueror (*mukalanga*). This title is different from that used for the Luba sacred kings, i.e. *mulopwe* (Reefe 1981). Nkongolo is remembered for his cruelty, for he would cut off the noses, ears, arms or hands of people who displeased him.

Mbidi Kiluwe, also known as Ilunga Mbidi, was a handsome hunter and 'prince' who came from the east. He married one of Nkongolo's sisters and together they produced a son named Kalala Ilunga. Kalala Ilunga grew to become a heroic warrior who defeated and overthrew his maternal uncle Nkongolo and acceded to the throne to establish sacred kingship. Kalala Ilunga is said to have introduced royal manners and rituals, tightly linked to iron working (Reefe 1981; Nooter Roberts & Roberts 1996). It is this political leadership that the Luba become popularly known for, with neighbouring societies looking to the Luba as the source of prestige and glamour (Roberts 1996).

The process by which the ancient Upemba societies transitioned into the Luba Kingdom was gradual and complex. Towards the end of the Kabambian period, the Luba state is known historically to have been a vast, politically and economically dominant entity (Reefe 1981). Their sophisticated political organization led the Luba to become one of the most powerful kingdoms in Central Africa (de Maret 1999). Small chiefdoms associated with the Luba became very wealthy due mainly to the region's mineral wealth. The Luba Kingdom and its allied chiefdoms traded dried fish, salt, iron and copper products, in addition to ivory at the turn of the 19th century (Wilson 1972). Luba traders linked the Congo forest to the north with the mineral-rich region of modern Zambia, the Copperbelt. The trade routes passing through Luba territory were also connected with wider networks extending to both the Atlantic and Indian Ocean coasts. Long-distance trade eventually destroyed the Luba Kingdom as

traders from East Africa began searching for slaves and ivory in the savannahs of central Africa, in the 1870s and 1880s (Reefe 1981).

When we consider Luba ethnicity, it is important to keep in mind that "Luba" is a social identity that encompasses a wide complex of cultures. Moving away from the notion of a centralised "empire" that was perpetuated in the 1970s by colonial preconceptions of African kingdoms, Luba has been shown in recent years to be a loosely constituted group, incorporating numerous territories and ethnic identities into its sovereignty (Figure 2.08). The Luba Kingdom included ethnic groups such as the Lozi, Kunda, Bemba, Kaniok, Hemba, and others, giving rise to the term "Luba-ized" or "*lubaïse*" (Verhulpen 1936 in Reefe 1981; Nooter Roberts & Roberts 1996: 25). The term "Luba-ized" highlights the very powerful mythical ideology of the Luba belief system and religion. "Luba peoples constitute a 'watercolour wash' of overlapping clan and lineage groupings that were consolidated kingdoms and important chiefdoms from around the 17th century as they are to some extent today" (Nooter Roberts & Roberts 2007: 7).

Because of the prestige associated with Luba sovereignty, a large number of small cultures that looked up to the Luba would voluntarily emulate, adopt and adapt this culture. This was done to a point that if men wished to assume more political power, they turned to Luba for their model of authority; sometimes going as far as travelling to the heartland to acquire trappings and potency of sacred royalty (Roberts 1996). In addition, armed raids were performed by Luba warriors on outlying chiefdoms for both defensive and offensive purposes.

Since there is no evidence of a supreme authoritarian rule, the Luba polity constituted a heartland (in central Katanga) of active commerce and political influence. Peripheral chiefdoms affirmed trade networks and political alliances through occasional tribute to Luba kings (*mulopwe*) in the heartland. For the most part, people in these small chiefdoms lived as they did before their incorporation into the Luba kingdom. Often, they were led by a hereditary chief and continued to speak their own languages. In some cases, however, the transformation involved adoption of the Kiluba language (Roberts 1996).

Archaeologically, there is little evidence of the Luba period, mainly because archaeologists have deliberately avoided Luba burials. The few Luba burials that have been excavated have revealed a change in ritual practice from the preceding Kabambian period. Pottery is rarely found in the graves and differs in decoration from earlier forms. Luba pottery lacks the sophistication of craftsmanship seen in the earlier periods. Continuity in overall shape, however, is apparent. Typical of modern Luba ware are carinated pots with a step-like shoulder, which have also been discovered in the Kamilambian through to the Kabambian assemblages.

The most frequently found grave goods are glass beads for personal adornment (anklets, bracelets and belts). In sharp contrast, iron objects and copper crosses abundantly found in Kisalian and Kabambian graves, respectively, are absent in Luba graves (de Maret 1999). Contrary to the extended position of the body in Kabambian burials, the Luba buried their dead in a flexed or foetal position, lying on their sides with the hands positioned by the face. In most cases, the body is orientated towards the east. The Luba graves that have been exhumed are briefly described below under each site from which they were found. The archaeological sequence of the northern Upemba Depression is summarised in Table 2.04 (de Maret 1999: 154), with a brief description of features for each chronological period.

F. Katotian pottery tradition (contemporaneous with the Classic Kisalian; AD 1000 – 1200)

The 325 ceramic objects exhumed from the 47 graves at Katoto are all containers. The majority of the vessels (96.6%) fall into five classes of general shapes, which include: a) vessels with rectilinear, vertical or slightly widened neck; b) vessels with vertically bulged neck; c) carafes with long vertical neck; d) bowls with short vertical neck; and e) dishes with annular foot (Hiernaux *et al*. 1967). The lip is simple and rounded or slightly flat. The shapes *a*, *b* and *d* have a round base, except the one of a bowl, where it is slightly concave, forming a dimple. The base of the carafe *c* is almost flat (Figure 2.07). The colour of the vessels varies from yellow to brick red, an orange coloration being very frequent. Almost all of them have large black stains, a sign of firing in an atmosphere in which oxidation/reduction was poorly controlled. The surfaces are not

polished, and there is no trace of coating or slip. The clay paste is sticky and contains large grains of degreaser (Hiernaux *et al*. 1967: 150).

The ceramics from Katoto have affinities with dimple-based ware from the Great Lakes. Both show decoration that includes rectangular incisions in horizontal bands or in sectors of vertical or oblique lines, triangles filled with incisions, circles and concentric half circles, eight-shaped interlacing lines, rolls, stitches, fish bones, honeycomb (embossed), incision bands and oblique imprints. The Katoto assemblage is much richer in imprints by variety and frequency compared with the dimple-based ware from the Great Lakes. Such a degree of similarity involving a variety of decorative motifs implies either cultural contact or continuity in time. The two sites in Rwanda, Ndora and Ciyamakuza, were occupied considerably earlier than Katoto, with dates of AD 250 ± 100 (B-755) and AD 300 ± 80 (B-758) respectively. The Katoto ceramics also show affinities with the Channelled ware of Kalambo Falls in Zambia, which lies approximately 550km to the east of Katoto, near the southern extremity of Lake Tanganyika. At Kalambo Falls, occupation levels that have yielded Channelled Ware date from AD 550 to 1550 (Clark 1965: 89), making it contemporary with Katoto.

Figure 2.07: Pottery from Katoto (Hiernaux *et al*. 1967: 149, Plate I and II).

Points of difference between the archaeology of the Upemba Depression and Luba oral history

Five points of discrepancy can be identified between the archaeology and oral history-based reconstructions of the Luba past. These centre around questions of cultural continuity and the timing of culturally important events (Childs & de Maret 1996).

1) There is a disagreement about whether or not there was a cultural break at the genesis of modern Luba state. Modern Luba are convinced that there was a cultural break between their ancestors and the earlier people whose remains have been excavated in their heartland, and draw attention to the differences between ancient and Luba pottery. In contrast, the general conclusion from the Iron Age archaeology of the Upemba Depression is that the people who lived during the Kisalian and Kabambian periods were the ancestors of modern Luba.

Though distinct in style, the Kamilambian, Kisalian, Kabambian and even Luba pottery are sufficiently similar that archaeologists conclude they were made by related people. According to de Maret (1979), pottery tradition described from the archaeological sites in Katanga is continuous from the Kamilambian period from around AD 600 to the present. Livingstone-Smith and Viseyrias (2010) report that pottery 'roughing-out' techniques in the Upemba have been fairly stable and similar from Kabambian to modern times. The 'roughing-out' techniques or *chaînes opératoires* they examined involve the processes employed in the primary manufacturing or forming of pottery, which include methods such as coiling, combining flat slabs of clay, pinching or paddling. Using binocular microscopy and radiography to reconstruct the manufacturing technology of the Kabambian pottery, Livingstone-Smith and Viseyrias (2010) were able to conclude that the Kabambian pottery was made by cylindrical coiling with a slab base, in much the same way that Luba pottery is crafted today. They link this stability to deeply rooted forms of identity, in comparison to other aspect of pottery, such as vessel shape and decoration. The implication of their study is that present-day Luba speakers of Katanga can trace their origins back to earlier communities (from the 13th century AD) in the same region (Livingstone-Smith and Viseyrias 2010).

2) The first Luba sacred king, Kalala Ilunga, is said to have introduced iron metallurgy, the use of ceremonial insignia, political leadership linked to iron working, and culturally sophisticated practices like filing teeth (Reefe 1981). These attributes are an important source of pride among the Luba. Their claim that these attributes date to the origins of the Luba is, however, challenged by the archaeological record. The earliest grave goods found in the Depression are iron tools and weapons dating to Kamilambian times, c. AD 600-700. Iron objects were also recovered from Kisalian graves. Their frequency and variety indicate that they were valued objects in the society at the time (Childs & de Maret 1996).

3) According to the oral traditions of the Luba, the relationship between iron metallurgy and political leadership is a strictly Luba phenomenon that developed around the seventeenth century AD at the genesis of their state. The earliest development of political organization, confirmed by the presence of symbolic grave goods such as ceremonial axes and iron anvils, in Ancient and Classic Kisalian graves can be found at the archaeological sites of Katongo and Kamilamba (de Maret 1999, 2012). Political centralization was, therefore, developing as early as the eighth or ninth centuries AD in the Luba heartland. In addition, political leadership was already inherited at this time as attested by the presence of a miniature ceremonial axe in a child burial dating to the Classic Kisalian period.

4) The iron anvil is another symbol of royal authority claimed by the Luba to be a development of their recent polity, although its presence alone is not proof of socio-political importance. Within the archaeological record, an anvil was found in the wealthy grave (number 7) of the same individual from Kamilamba with an elaborate ceremonial axe dating to the Ancient Kisalian period. Two more anvils were also found along with other symbols of political power at Katoto, in the southern end of the Depression. This physical evidence is proof that socio-political importance was bestowed on the anvil long before the Luba began to do so (Childs & de Maret 1996).

5) The claim that the custom of filing the front teeth is of Luba origin is again inconsistent with the archaeology. Skeletal remains from the Upemba Depression dating to the Classic Kisalian period have been found to display filed front teeth.

Therefore, we have clear evidence that this practice dates back at least to the eleventh century AD in the Luba heartland (Nenquin 1963; de Maret 1992).

Figure 2.08: Map showing the Luba-ized region with the heartland (red ellipse) in the middle (after Nooter Roberts & Roberts 1996: 25).

Table 2.04: Archaeological sequence of the northern Upemba Depression, with a summary of features that characterise each chronological period (taken from de Maret 1999: 154).

AD	Phase (no. of graves)	Grave goods	Trade	Population density
500				
600	Kamilambian (1)	Only iron implements and weapons. No pots.	No evidence	Low
700 800	Ancient Kisalian (19)	Few pots, iron weapons, and implements. Copper beads and bangles. Very few ceremonial axes and one anvil as status symbols; ranking instituted. Autonomous leaders.	Copper ornaments. Trade with Copperbelt.	Increasing
900 1000 1100	Classic Kisalian (142)	Abundant pottery in some graves, along with ivory, copper, and iron ornaments. Grave goods differ according to gender, but graves of women and children among the richest; status inherited, but no sharp division between the wealthy minority and the rest. Small discs of shell in strings, used for social payments into associations? High homogeneity in pottery and ritual.	Expansion of trade with Copperbelt. Coastal trade items such as cowries appear.	High
1200 1300 1400	Kabambian A (54)	Metal grave goods decline but copper crosses common. Local variation in pottery and burial ritual more pronounced. No symbols of power except one *Conus* shell disc. Greater contrast between wealthy and poor.	Trade with Copperbelt, mostly unstandardized H-type copper crosses, used as special purpose currency? Long-distance trade expands: cowries, *Conus*, glass beads.	High
1500 1600	Kabambian B (15)	Few pots, with thick red slip. Initially numerous very small H-type copper crosses, decreasing to one or two per grave.	Trade with Copperbelt, H-type copper crosses become smaller and standardized, used as money?	High
1700 1800 1900	Modern Luba (6)	No pots or metal, glass beads only.	Smoked fish exported, Arabo-Swahili, then European traders and raiders. Numerous European glass beads.	High

2.3 Site details:

The following section offers a brief description and excavation history of each of the six sites in the Upemba Depression which have yielded skeletal remains studied in this dissertation.

A. Sanga (GPS co-ordinates: 8°10′S, 26°29′E)

Sanga is one of the largest Iron Age cemeteries ever excavated in sub-Saharan Africa. It lies just beyond the extreme south-eastern corner of the equatorial forest on the northern shore of Lake Kisale. Lake Kisale, with a total area of 300km^2, is the second largest lake in the Depression, after Lake Upemba (530km). The site is one of the best known Iron Age sites in sub-Saharan Africa; for oral traditions have led historians to link Sanga with the origin of the Luba Kingdom to which many chiefdoms of the central African savannah trace their origins (de Maret 1977; Reefe 1981; Nooter Roberts & Roberts 1996). Nenquin and De Buyst, who exhumed 56 graves at Sanga, were the first to excavate this site in 1957 (Nenquin 1963).

In 1958, the Department of Physical Anthropology at the University of Lubumbashi (then Elisabethville) extended the excavations (Nenquin 1963). This second season was led by Hiernaux, Maquet, and De Buyst. A further 89 graves were excavated, reports on which can be found in Hiernaux *et al*. (1971). In 1974, Pierre de Maret completed a third series of excavations at Sanga (de Maret 1977, 1985a). These excavations increased the number of graves studied to a total of 176 and led to a major revision of the Iron Age chronology of the Upemba Depression. In 1988, De Maret went back to Sanga to excavate a few additional graves. The details of this expedition are not well known since no published reports exist. Some information was obtained from personal communication with De Maret (pers. comm, de Maret 2010) and there is some mention of this work in Childs & de Maret (1996).

The majority of the graves excavated at Sanga date to the Kisalian period (mainly Classic Kisalian). Altogether, 136 of the 176 (77.3%) graves excavated at Sanga date to the Kisalian period (Ancient and Classic). There is discrepancy to do with the classification of the Recent (Luba) graves at this site. Grave T23, excavated in 1957,

was classified as modern or recent by Nenquin (1963: 70); but De Maret (1992: 189) has put this grave into the Atypical category. This grave yielded glass beads and cowrie shells – typical of Recent (Luba) burials. In this dissertation, the incomplete skeletal remains from this grave were studied and classified as Recent (Luba). Grave T48 is another Recent (Luba) burial that was included in this study (Nenquin 1963). Lastly, grave T101, discovered by Hiernaux and his team in 1958, also belonged to the Recent (Luba) period. This burial was 'abandoned' during the 1958 excavations, and hence no skeletal remains were exhumed from it (Hiernaux *et al*. 1971: 82). Therefore, only graves T23 and T48 belonging to the Recent (Luba) period were exhumed at Sanga.

Some unusual finds of human dental artefacts were recovered at Sanga, as well as at Katongo and Katoto. Perforated human teeth and jaws were found attached to metal belts or earrings of what appears to be high-status individuals (Hiernaux *et al*. 1967; Nenquin 1963; de Maret 1999) (Figure 2.09). The individuals who wore these dental artefacts included both adults (males only) and children. These items raise some interesting questions about those wearing them and those whose remains these belonged. Only the jaw found with Sanga T53 (Figure 2.09) was studied and analysed (for dental traits, but not sampled for isotope analyses) with the rest of the sample. None of the other perforated human teeth and jaws from Katoto and Katongo were found at the holding institutions.

Figure 2.09: Partial view of Sanga T53, showing a human maxilla with filed teeth, attached to a belt (Nenquin 1963: Plate X).

B. Katoto (GPS co-ordinates: 9°11′S, 25°52′E)

Discovered and excavated in 1958, after the second season of excavations at Sanga, the site of Katoto lies on the banks of the Lualaba River close to Bukama, approximately 130km southwest of Sanga (Hiernaux *et al*. 1967). This site has not been relocated since its excavation by the late Jean Hiernaux, despite attempts by De Maret to do so (personal communication, de Maret, October 2009). Katoto is the only site of this type that has been systematically excavated in the Upemba Depression, despite the discovery of four other sites with the Katotian tradition (Luangwe, Makombe/Mukombe, Maleo, and Muyumbwe) (de Maret 1992). It is interesting to note that the development of the Katotian tradition is restricted to the southern half of the Depression below Lake Upemba (de Maret 1992: 187). This is in contrast to the more widespread distribution of the contemporaneous Kisalian tradition, with sites extending west of the Lovoi River and as far south as the Copperbelt (de Maret 1992: 187: Figure 48).

In 1958, Hiernaux, Maquet and De Buyst unearthed forty-seven graves at Katoto, which dated to about the twelfth century AD (Hiernaux *et al*. 1967). This makes the Katotian contemporary with the Classic Kisalian tradition, which continued until the thirteenth century AD. The orientation of the body is variable. The two most frequent orientations of the body are north-west and east, but all the others are also represented. Of the cases in which the position of the body could be determined, 44% rested on their backs, 38% on their left side, and 18% laid on their right side.

Apart from the pottery, other economically important artefacts recovered at Katoto include quartz grinding stones, a large collection of spears, hoes, fish harpoons, etc. Faunal remains are scant, but consist of fish, bird, and small bovid bones (Hiernaux *et al*. 1967). Items of personal adornment include copper pendants with “punched dots”, objects made of ivory, necklaces, bracelets, anklets, and belts made of iron, brass, shells, and marine shells (cowrie and *Conus*).

As far as we can tell from the limited archaeological research done at this site, Katotian culture resembled Kisalian in many ways, except for a distinct pottery tradition and some unusual iron tools (Hiernaux *et al*. 1967). Evidence for contemporaneity of these two traditions is also found in the presence of a few

Katotian pots in Kisalian graves and vice versa. Judging from the small number exchanged pots, contacts between the two traditions appear to have been limited (Childs & de Maret 1996).

C. Malemba-Nkulu (GPS co-ordinates: 8°3′15″S, 26°47′40″E)

The discovery of Malemba-Nkulu was a result of local people alerting Mr. G. De Plaen to the presence of ancient pottery and *croisettes* on the right bank of the Lualaba (Upper Congo) River. Situated upstream of the modern village of Kibuwa/Kalala-Mwele, the site of Malemba-Nkulu has yielded burials that predominantly date to the Kabambian A and B periods (AD 1300 to 1600), with a few dating to the Kisalian period (de Maret 1992). No recent (Luba) graves were excavated at this site. The cemetery extends for about 200 metres along the river bank, and was subjected to regular flooding from the river. It extends towards the north-west as attested by the presence of more Kabambian graves where trial excavations were done.

The density of the graves is extremely high: all 37 were recovered in only 3 trenches designated A2, A4 and A5. Some of the Kabambian graves were disturbed, probably as a result of digging of later graves. There are many graves of very young children at this site compared with other sites in the valley. Like all the other systematically-excavated sites in the Depression, Malemba-Nkulu was also only partially excavated (de Maret 1992).

D. Kikulu (GPS co-ordinates: 7°50′35″S, 26°58′40″E)

While de Maret and his team were excavating at Kamilamba in 1974, local people from nearby villages informed them of another site south-west of the village of Mulongo. The site of Kikulu is located on the left bank of the small Bombo River flowing into Lake Kabamba, where the lake begins to flow out into the Lualaba River. A total of 27 graves were excavated at Kikulu, extending across most of the chronological periods outlined above (i.e. Ancient Kisalian, Classic Kisalian, Kabambian A, Recent and Atypical) (see Figure 2.10). No Kabambian B graves were found at this site. None of the graves yielded small *croisettes*, only the large ones characteristic of the earlier Kabambian A period (de Maret 1992). The majority of the

graves belonged to the Kabambian A period, with 15 of the 27 graves (55.5%) classified into this period. Only two graves, T1 and T17, belonged to the Recent (Luba) period. These graves were studied in this project. It appears that there is no concentration of graves from any period in any particular area of the cemetery.

It is at this site that the only concrete evidence of cultivation of domesticated crops has been found. Carbonised remains of finger millet (*Eleusine* sp.) were found adhering to a hoe in a pot buried in grave number 3 (de Maret 1992). Based on the pottery style, this grave belongs to the Kabambian A period (AD 1200 to 1500). No radiocarbon date was obtained for this burial.

E. Kamilamba (GPS co-ordinates: 7°49′S, 27°01′30″E)

After having bought some ancient pottery at the modern village of Kamilamba, 4 km from another archaeological site called Mulongo, the next expedition of excavations started in the following year (1975). The site of Kamilamba is situated on the northern banks of Lake Kabamba between the modern villages Kia and Kalume (de Maret 1992: 183). Thirteen graves were excavated; their chronology spans the entire sequence found at neighbouring sites (i.e. Kamilambian, Ancient Kisalian, Classic Kisalian, Kabambian A, and Recent).

Kamilamba has yielded the only grave that probably dates to the beginning of the Iron Age in this region, i.e. the eponymous Kamilambian phase dating to AD 600 (see Figure 2.10). At other sites, such as at Sanga, the Kamilambian is poorly preserved due to disturbance by subsequent occupations (de Maret 1992). Because of the intentional avoidance of Recent (Luba) graves during the archaeological excavations in the Depression, only very few graves of this period were exhumed. At Kamilamba, the only Recent grave to be exhumed during the 1975 excavations was grave no. 9. The skeletal remains from this grave were, however, not included in the current study because of their poor state of preservation (de Maret 1992: 37).

F. Katongo (GPS co-ordinates: 9°11′S, 25°52′E)

The first mention of the site of Katongo appears in Nenquin (1958, as mentioned in de Maret 1985a: 195), in which he described the pottery collected at this site by A. Maesen in 1955. The site is situated on an alluvial fan that descends from Mount Kibala Kimbwi to the lake. Situated on the northern shore of Lake Kisale, Katongo

lies approximately 10 km from the archaeological site of Sanga and 400 metres from the modern village of Katongo. Excavations at the archaeological site of Katongo were carried out in 1974 (de Maret 1985a) when the villagers from Katongo discovered the ancient graves while digging for clay. The site consists of graves spanning a distance of more than 200 metres along the northern shore of Lake Kisale.

Compared with Sanga, the archaeological site at Katongo presented the great advantage of being located outside the modern village. While excavating at the cemetery by the lakeshore (section 1), the villagers came to sell Ancient Kisalian pottery to the archaeologists. These vessels originated from an erosion gully in the north west of the village, and prompted a second series of excavations, in which a habitation layer was identified.

Altogether, twelve graves were excavated at this site. Graves 1 to 9 were excavated from the area close to the lakeshore, while graves 10 to 12 came from a second area (the erosion gully by the river) in the north west of the modern village. These last burials were very disturbed and damaged by erosion, leading to preservation of only a few fragments of human remains. The Kabambian A and Atypical periods are not represented at this site. Four graves belong to the Ancient Kisalian period, three are from the Classic Kisalian, and four belong to the Kabambian B. Grave number 6, which was studied in this research, is the only burial that belongs to the Recent (Luba) period.

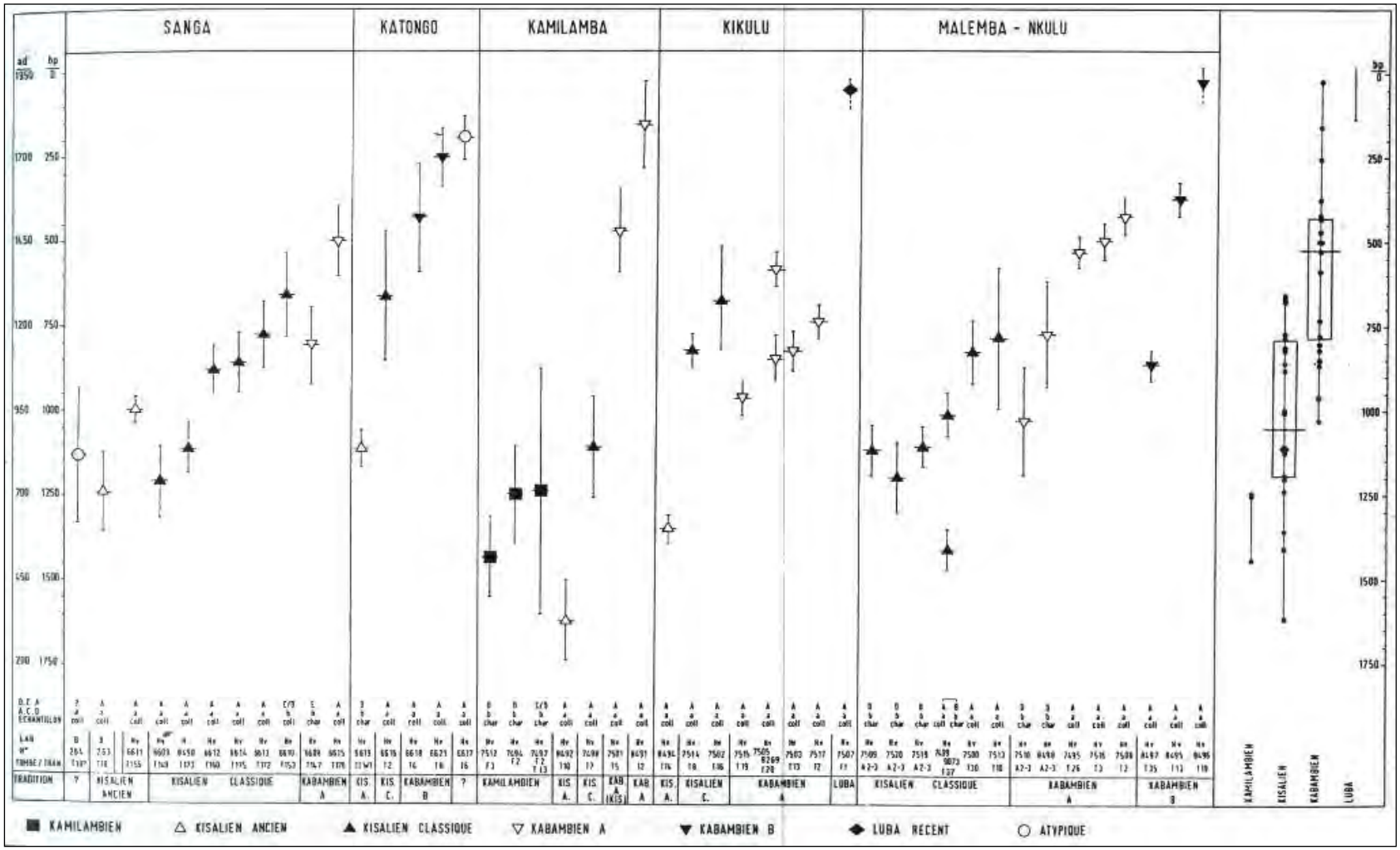


Figure 2.10: A graphic distribution of the uncalibrated radiocarbon dates (BP ± 2 sigma) from Sanga, Katongo, Kamilamba, Kikulu and Malemba-Nkulu, showing the chronology at each site (after de Maret 1992: 205).

2.4 Archaeological evidence of the diet and economy of the early inhabitants of the Upemba Depression

The manuscripts published by the three excavators of the six sites in the Upemba Depression provide considerable detail on the archaeological finds from these sites (Nenquin 1963, 1967; Hiernaux *et* a*l*. 1967, 1971; de Maret 1985a, 1992), especially those by Pierre de Maret. For descriptions of the cultural remains recovered from these sites, I refer the reader to these works, since this dissertation does not focus on material culture. Here, I summarise the available archaeological evidence for diet and economy in the Upemba Depression, in order to inform interpretation of the patterns of dental disease and tooth wear and the isotopic analyses described in Chapter 6.

Table 2.05 provides a list of archaeological fauna and flora recovered from the sites in the Upemba Depression. Some of these specimens were sampled for stable isotope analysis. The faunal remains provide direct evidence of the types of animals consumed, but is by no means a full representation of the wide spectrum of fauna available in the region. It should be remembered that these remains were interred as grave goods, so that profiles of which species are present or absent, and in what proportions, are not directly comparable to faunal assemblages recovered from refuse middens in living sites.

As mentioned above, the presence of tsetse fly means that this area was probably unsuitable for cattle pastoralism. Indeed, no bones that could confidently be identified as cattle were found at these sites (Nenquin 1963; Hiernaux *et al*. 1967, 71; de Maret 1985a, 1992, 1999). It is likely that the bovid bones recovered are from wild animals. Small stock was found only at Sanga. It is not clear whether this is a result of sample size or whether there was some special preference for these animals at this site. The former scenario seems more probable as Sanga is the most extensively excavated site. Of the 176 graves excavated at Sanga, only 17 contained skeletal remains of goats (*Capra* sp.) (Nenquin 1963; Hiernaux *et al*. 1967; de Maret 1985a, 1992; van Neer 1992).

Apart from a different pottery tradition, there is no obvious differentiation in the economically important artefacts from Katoto and the other five sites in the northern

end of the Depression. Fragments of quartz grinding stones were recovered at Sanga and Malemba-Nkulu, as well as at Katoto. The scarcity of these important agricultural artefacts is likely because these are cemetery sites as opposed to settlement sites, thus providing only a limited glimpse into the lifeways of these people. Nonetheless, their presence confirms the exploitation of grain crops or farming; along with indirect evidence of cultivating squashes and gourds as indicated by the presence of ceramic pots in the shape of these cultigens (de Maret 1985a, 1992). Kisalian pots, from Kamilamba grave number 1 and 7, in the shape of a calabash demonstrate the presence of *Lagenaria* sp. (de Maret 1979: 234, 1992: 160).

The presence of spears, iron points, and fishhooks provide support for the importance of hunting and fishing in the economy. Fish was undoubtedly an important food source, as well as a significant trade item. There are more fish bones at these sites than there are mammals or birds (Nenquin 1963; Hiernaux *et al*. 1967, 1971; de Maret 1985a, 1992). The relative importance of the different aspects of subsistence, i.e. fishing, farming, hunting, and gathering of wild plant foods cannot, however, be reconstructed from the archaeology. These are better revealed by analyses of stable isotopes, dental disease patterns and phytoliths, as employed in this project.

Very few archaeological remains of plant foods were found at the sites in the Upemba Depression. This is not surprising, considering that tropical environmental conditions are unfavourable for preservation. Even when flotation was used, at the sites of Sanga, Katongo, Kamilamba, Kikulu and Malemba-Nkulu, plant remains were still not recovered (de Maret 1985a, 1992); a large proportion of the fish, bird and mammal remains from these sites was recovered by flotation (van Neer 1978). Some remains of *Elaeis* sp. and *Eleusine* sp. were recovered at Sanga and Kikulu, respectively. These are the only archaeo-botanical evidence of plant food consumption and domestication of crops found at these sites (Table 2.05).

Table 2.05: Archaeological faunal and floral remains recovered from sites studied in this thesis. X indicates presence (van Neer 1978, 1992; Hiernaux *et al*. 1967).

FAUNA & FLORA	Sanga	Katoto	Malemba-Nkulu	Kikulu	Katongo	Kamilamba
Mammals						
• *(Artiodactyla) Bovidae* gen. sp.		X	X	X	X	X
Capra aegragus (f. *hircus*)	X					
Cephalophinae	X					
Cephalophus sylvicultor	X					
Hippotamus amphibius	X					
Kobus sp. (vardoni or lechwe)	X					
Oreotragus oreotragus	X					
Rhinoceros sp.	X					
• *Canidae* gen. sp.		X				
• *Mustelidae* gen. sp.						
Lutra maculicollis	X					
• *Rodentia* gen. sp.			X	X		X
Aethomys sp.						X
Praomys sp.	X					
Reptiles						
Crocodilus sp.	X					
Pelusios sp	X		X		X	
Varanus sp.	X					
Fish						
Clarias sp.	X		X	X		X
Heterobranchus sp.	X					
Percomorphi gen. sp. (*Cichlidae* or *Lates nilotus*)	X		X	X		X
Polypterus sp.	X		X	X		X
Protopterus sp.	X		X			
Synodontis sp.	X		X	X		X
Birds						
Gallus sp.	X	X				
Aves sp.		X				
Molluscs						
Achatinidae	X	X	X			X
Aspatharia rubens			X			
Aspatharia sp.	X		X			
Cypraea annulus		X	X			
Cypraea sp.	X					
Limnicolaria sp.			X			
Flora						
Elaeis sp.	X					
Eleusine sp.				X		

Chapter 3: LITERATURE REVIEW

This chapter provides the background information on the approaches employed in this research. Essentially, the information given here lays the foundation from which to interpret the data from this study and how they compare with those from other studies in Africa and elsewhere.

3.1 Dental anthropology: non-metric and metric traits

A. Introduction

The arrangement of teeth, their complex and species-specific morphology, as well as their development timing imply strict regulatory mechanisms, making teeth an important model for several scientific disciplines. The strong genetic control of tooth development ensures that we all have a similar dentition with distinct morphological features and size. Despite this similarity, however, all dentitions are unique. A large part of this uniqueness is caused by genetic factors. Dental anthropology pays attention to this variation with the aim to understand population history, which pertain to the current research (Dahlberg 1945; Irish 1993; Scott & Turner 1997; Hanihara 2008). So, how can dental variation help to identify local population change in a small area like the Upemba Depression and what are the possible problems in interpretation that may occur? In trying to answer these questions, the genetic background and related complications of dental morphological traits are provided. Then, a discussion of some successful examples of using dental traits to understand population relatedness is presented.

B. Genetics/Inheritance of tooth traits

Non-metric morphological dental traits provide useful means for evaluating biological relationships between different populations (Hanihara 1992, 2008; Scott & Turner 1997; Irish 1997, 1998; Stojanowski 2005; Ullinger *et al*. 2005; Taylor & Creel 2012; to mention a few). Dental morphological traits are known to be under relatively strong genetic control and that the effects of the environment are thought to

be less important (Scott & Turner 1997). However, closely similar phenotypes do not necessarily have the same genotype; they could be caused by alterations in different genes but also environmental factors (Mikkola & Thesleff 2003; Brook 2009). Epigenetic factors, which can be defined broadly as alterations in gene expression without changes in nucleotide sequencing, have been shown to play a critical role in tooth development (Brook 2009). Phenotypic expression is, therefore, a result of genetic, epigenetic, and environmental factors (Mayhall 1999).

Most dental traits are considered to be related to genes in several loci and follow a non-Mendelian or multi-factorial inheritance. More than 300 genes have been identified as involved in dental development (http://bite-it.helsinki.fi/; Thesleff 2006). The polygenic nature of dental characters, and the varying environments in which teeth grow, produce *continuous variation* within a range. Hence, dental traits are not observed as either present or absent (as in Mendelian inheritance), but rather as a continuous range of variation in form when present (Grüneberg 1952; Hillson 2005).

In order to show how much of the observed variation could be attributed to genetic contributions, estimates of heritability are calculated for morphological features within human populations. Heritability estimates for most non-metric morphological traits are moderate to high with a range from 40 to 80%, although Carabelli's trait has been shown to be highly heritable with about 90% genetic input (Mizoguchi 1977; Townsend *et al*. 1992, 2009, 2012). Other dental traits such as overbite and overjet have relatively low heritability estimates (53% and 28%, respectively). These estimates are much higher than those for cranial traits (average heritability estimate = 36%), which makes dental morphology a better tool for estimating genetic relatedness of populations (Carson 2006; Relethford 1994).

The influence of non-genetic factors (epigenetic, maternal and environmental) on phenotype is clearly demonstrated in twin studies. Several studies that have revealed the strong heritability of morphological traits have compared selected features between monozygotic (MZ) and dizygotic (DZ) twins (Hughes *et al*. 2007; Kabban *et al*. 2001; Townsend *et al*. 1992; Mizoguchi 1977). Assuming that environmental effects are similar in each zygosity group, comparisons between MZ and DZ twin pairs allow for an estimate of the genetic involvement to be made. Since MZ twins share 100% of their genes and are thus expected to be 100% alike (phenetically), any

discordances or differences can be explained by post-genetic factors (Townsend *et al*. 2005, 2012). For example, there was evidence of at least one missing upper I2 or PM2 in 24 of the 278 MZ pairs (8.6%), with 21 of these 24 pairs (87.5%) showing discordant expression. Furthermore, nine of the 278 MZ pairs (3.2%) displayed evidence of supernumerary teeth, with eight of these nine pairs (88.9%) being discordant.

Given the strong underlying genetic basis to tooth size, shape and number, the finding that such a high proportion of MZ twin pairs were discordant for these features supports the view that epigenetic factors have an important role in dental development. Because of the discordance observed between MZ twin pairs, some scholars have suggested that the role of genes has been overestimated (Boruchov & Green 1971), while others consider heredity as the most important factor but emphasise the variable expression and low penetrance (Gravely & Johnson 1971; Townsend *et al*. 1995; Townsend *et al*. 2005). Nevertheless, it must be kept in mind that heritability is a population concept that refers to the proportion of genetic variation within a given population at a particular time (Sesardic 2005).

In trying to understand how the different factors affecting tooth development work, studies such as those of twins reared apart (Bourchard 1984; Boraas *et al*. 1988); MZ half-sibling (Potter 1990); MZ co-twin (Townsend *et al*. 2005); and DZ opposite sex (Dempsey *et al*. 1999), offer some clarity. The overarching theme of all these studies is that the factors affecting tooth development are neither purely genetic nor environmental (Martin *et al*. 1997; Hughes & Townsend 2012). 'Nature via nurture' has been proposed as a more suitable phrase (Ridley 2003) from the popular one of 'nature versus nurture'.

C. Degree of trait expression

As far as trait expression is concerned, there is general recognition that an insignificant relationship exists between the degree of expression and presence of a particular trait. In other words, it is considered that whether a trait is expressed mildly or markedly is not important; its presence is what matters. This is based on the assumption that "there is only a single genotype for any specific trait and that when present, the tooth showing the highest degree of expression is the more accurate

indicator of the genotype" (Turner *et al*. 1991: 30). This view assumes that trait morphology that appears similar at the outer enamel surface in different teeth is the result of developmental processes that are similar enough to allow valid comparisons within and between groups. However, according to Skinner *et al*. (2009), different developmental processes can result in similar morphology at the outer enamel surface; thus confounding the comparison of trait morphology between groups. Based on the results from their study, Skinner *et al*. (2009) have shown that the presence and degree of morphological expression of cusp 6, cusp 7, trigonid crest and the protostylid are instructed primarily by the enamel-dentine junction; thus proving that the outer enamel surface is not the best for assessing and comparing trait morphology between groups.

Trait expression can also inform about geographical origin of an individual or population. For example, upper incisor shovelling attains a frequency of about 100% in living Southwest American Indians (Sinodonts) and less frequent in other world populations (Scott 2008). However, sub-Saharan Africans also exhibit this trait, though expressed mildly in comparison to those seen in Sinodonts (Irish 1993, 2013; Hanihara 2008; Scott & Turner 1997). Thus, consideration of the degree of trait expression is essential for the correct estimation of an individual's or population's geographic origin.

Furthermore, it has been argued that the degree of trait expression could be telling us something about adaptability or evolutionary changes that correlate with different diets and environmental niches (Sperber 2006). "The genetics underlying phenotypic dental characteristics that are directly observable has enabled rates and degrees of gene flow to be calculated and genetic drift to be estimated in divergent populations. Mutations may be traced in this manner, and the selective advantages of particular dental conformations might account for dental micro-evolution" (Sperber 2006: 121). Despite evidence for strong genetic regulation of morphological traits (Dempsey & Townsend 2001; Townsend & Martin 1992), there is still a great deal to learn about phenotypic variation in the human dentition, both within and between populations (Hughes & Townsend 2012).

D. Geographical distribution of tooth traits, with a focus on sub-Saharan Africa

Early studies in dental anthropology focussed on describing the nature and extent of variation observed in the human dentition to explain population affinities and migratory patterns (Scott 2008). This led to the establishment of dental complexes that served to characterise human populations on a worldwide geographical scale (Scott & Turner 1997). For the purpose of this review, it is important to note only that sub-Saharan Africans are disparate from all other populations, and that they show the highest intra-population variation (Hanihara 2008; Irish 1998; Scott & Turner 1997). The high within-group variation has been explained as indicative of large effective population sizes or long-range gene flow for sub-Saharan Africans (Relethforth 1994). It can also be interpreted as suggestive of great time depth of separation from other groups (Turner 1987).

On the African continent, the Sahara Desert has played a major role in shaping the biological variation of the people to its north and south. North Africans, for example, are dentally more similar to their northerly neighbours from Europe than they are to the Africans south of the Desert (Irish 1993). Much like their European relatives, North Africans are characterised by simplified dental morphology, with low or no occurrences of the following traits: upper canine mesial ridge, deflecting wrinkle on lower M1s, cusp 7 on lower M1s, and five-cusped upper M1s, as well as high incidence of M3 reduction or absence.

In contrast, sub-Saharan Africans are characterised by size-additive traits, which result in complex dentitions (Irish 1993, 1997, 1998; 2013; Irish & Guatelli-Steinberg 2003). Sub-Saharan Africans are shown to exhibit high frequencies of the following nine traits: mesial ridge on upper canines, two-rooted upper P1s, Carabelli's trait on upper M1s, three-rooted upper M2s, Y-groove pattern on lower LM2s, cusp 7 on lower M1s, Tome's root on lower P1s, two-rooted lower M2s, and upper M3 presence (Irish 1993, 1997, 2013). Low frequencies of double shovelling of upper I1s and enamel extension on upper M1s were also observed. This suite of nine high- and two low-frequency traits that characterises sub-Saharan Africans is now known as the Afridonty (previously sub-Saharan African Dental Complex) (Irish 2013), and differs from patterns seen in other large geographic populations (i.e. North Africans,

Europeans, Native American Indians/Sinodonts, Southeast Asians/Sundadonts and Northeast Asians/Sinodonts).

The dental complexes described above have been useful in our understanding of gene flow (of the recent past) on a global scale. There are shortcomings, however, with using large-scale complexes to characterise human variation. There is the limitation of overlooking diversity at a micro or regional level. One of the concerns with the large-scale complexes (Sundadonty, Sinodonty, Afridonty, and so on) is their inclusion of all population groups from as large a geographical area as sub-Saharan Africa, for example. The range of variation within regions is greater than between regions (Hanihara 2008), and this deserves more attention than offered by the current complexes. In his most recent report on the Afridonty, for example, Irish (2013) briefly mentions intra-regional variation, citing an example of a range from 0% to 36% for lower P1 Tome's root in eastern Africa. It seems, therefore, that more data highlighting intra-regional variation in sub-Saharan Africa (and elsewhere) could be helpful in understanding population history at a micro scale.

In addition, all the dental complexes were established using both historical and modern populations. This approach fails to take into account the impact of recent genetic admixture between local and extra-local populations, which has undoubtedly been greatly sex biased in most regions (Beleza *et al*. 2005; Berniell-Lee *et al*. 2009; Pereira *et al*. 2002). In the sub-Saharan African context, for example, it is well known that late historic and modern populations have had modest to substantial genetic admixture with outside populations of Eurasian origin (Beleza *et al*. 2005; Berniell-Lee *et al*. 2009; Pereira *et al*. 2002).

Using skeletal populations, Irish (2013) has explored this issue and his results have shown no differences in dental morphological traits in the ancient (Late Pleistocene to Holocene) samples compared with historic-modern samples. On the other hand, a recent study of archaeological Iron Age populations from southern Africa did find that the pre- and post-colonial populations differed in dental morphological traits (Warren 2013). Warren's (2013) results are supported by genetic studies that have demonstrated admixture between Bantu speakers and Europeans (De Filippo *et al*. 2011; Wood *et al*. 2005). Thus, it is argued here that the use of historic and modern populations as reference for inferring genetic history of populations in antiquity must

be done with caution, and that prehistoric populations would make a better reference for the understanding of population relationships.

Regardless of all the complications mentioned above, dental morphology still provides a very useful and reliable tool for assessing inter- and intra-population variation. Examples of studies that have successfully used dental traits in addressing questions of population relatedness are numerous (Jackes *et al*. 2001; Coppa *et al*. 1998; Stojanowski 2004; Delgardo-Burbano 2007; Sutter 2005). In an attempt to figure out where the genes of modern Europeans came from, Jackes *et al*. (2001) used seven dental traits to compare morphological variation in Neolithic and Mesolithic samples from western Iberian. Although a Neolithic genetic contribution had been demonstrated in more easterly areas of Europe, the contribution in western Iberia was shown to be insufficient to change indigenous genotypes. Their findings demonstrated little evidence for population discontinuity in the prehistoric populations (Jackes *et al*. 2001).

Still in Europe, the work by Coppa *et al*. (1998) demonstrated that dental traits in the Iron Age populations of central-southern Italy cluster according to chronological age instead of geographical proximity; in contrast to the hypothesis that the Apennine Mountains might provide a significant barrier for gene flow. In south-central North America, dentitions of hunter-gatherer populations were compared with those of adjacent groups of agriculturalists in order to evaluate biological relationships between the two groups (Taylor & Creel 2012). Non-metric dental traits showed little morphological similarity between hunter-gatherer and farming groups, and hunter-gatherers were more similar to each other than to agriculturalists. This suggested that there was relatively little gene flow between hunter-gatherer and farming populations during the Late Prehistoric period (Taylor & Creel 2012).

However, fewer studies of this kind exist for African populations. Most of the earlier work done on African populations report on single dental crown features (Shaw 1931; Shapiro 1949; Tobias 1972; Jacobson 1982) instead of assessing variation within and between groups of people. Other studies focused on comparisons of tooth sizes between groups, such as the San and Bantu speakers (van Reenen 1964; Drennan 1929; Sperber 1958; Haeussler *et al*. 1989). In addition, these studies were largely centred on a classificatory or descriptive standpoint, instead of genetic and

phenotypic variation. In essence, it was the pioneering work of Irish (1993) that put sub-Saharan Africans on a global map of dental morphology. The situation is changing; new research on dental morphology and size is being undertaken. These studies are aimed at addressing questions of population or genetic change of prehistoric-to-modern African populations, as well as understanding regional or geographic relations. Most recently, work by Warren (2013) revealed a temporal difference in dental and cranial traits from Early Iron Age to modern populations from southern Africa. Of particular interest is the lack of genetic and phenotypic change in populations from the Early to the Late Iron Age (Warren 2013), in contrast to the implied population changes suggested by the change in material culture between these two periods (Huffman 2007).

E. Crown morphology and tooth size

When it comes to the relationship between crown morphology (non-metric traits) and size (metric diameters), the question is whether larger teeth tend to have more complex morphological traits than smaller ones. Examples of size-additive traits include Carabelli's trait, protostylid, greater cusp number, parastyle, UC mesial ridge, and so on. Reduction in tooth size does not have to be paralleled with a simpler morphology (Jackes *et al*. 2001; Scott & Turner 1977), as has been argued for by some scholars to explain patterns of traits seen in smaller dentitions (for example, see Garn *et al*. 1966; Harris 2007; Williams & Corrucini 2007). In essence, size and morphology vary independently. Therefore, it is reasonable to say that both tooth morphology and size can be used independently to relate populations (Scott & Turner 1997; Hillson 2005).

In the same way as non-metric morphological traits have been used to reconstruct population history, odontometric traits have also been shown to be powerful tools in the understanding of inter-population relationships (Hanihara & Ishida 2005; Kabban *et al*. 2001; Liu *et al*. 1998; Scott & Turner 1988). There is, however, more variation in dental dimensions than in non-metric traits (Mayhall 1992), likely a reflection of other factors such as sexual dimorphism and fluctuating asymmetry (Townsend *et al*. 2003; Hanihara & Ishida 2005). Generally, studies among first-degree relatives indicated a significant genetic contribution to mesiodistal and buccolingual

dimensions, but heritability estimates vary. Some studies have suggested low heritability as well as greater size variability for late-developing teeth, suggesting that the environmental impact is considerable in determining the size of these teeth (Sofaer *et al*. 1970). However, heritability estimates from twin studies have not supported small heritability for the size of the later-developing teeth (Dempsey & Townsend 2001). Based on data from monozygotic (MZ) and dizygotic (DZ) twin studies, the genetic contribution for crown diameters of permanent posterior teeth accounted for 40 to 70% of size variation, while the effect of the environment ranged from 8 to 29% (Dempsey & Townsend 2001; Harris 2005; Townsend *et al*. 2009). Heritability of dental metric traits is thus slightly lower than that estimated for non-metric traits (see above), but sufficiently strong to make the study of biological relationships and micro-evolutionary trends appropriate.

F. Geographical distribution in tooth size

Odontometric diversity among human populations of major geographic regions has been investigated in order to understand the patterning within modern populations (Harris & Rathburn 1991; Hanihara & Ishida 2005). In summary, the largest teeth (megadonts) are found among Australians, followed by Melanesians, Micronesians, sub-Saharan Africans, and Native Americans. Groups with intermediate overall tooth size (mesodonts) include East/Southeast Asians and Polynesians. Lastly, Philippine Negritos, Jomon/Ainu, Western Eurasians, and southern African Khoesan have small teeth (microdonts) (Hanihara & Ishida 2005).

In a study that compared mesiodistal crown diameters of four human populations from different geographical areas and time periods, Brook *et al*. (2009) demonstrated that not only do the modern Southern Chinese have larger crown dimensions than the other three groups, but that they also had larger posterior teeth in comparison to anterior ones. The modern British of European ancestry in this study had the largest incisors compared to their posterior teeth (Brook *et al*. 2009). This suggests, therefore, that there are patterns within the observed overall size differences between the major geographical populations.

G. Tooth size reduction in modern populations

Since the beginning of the Upper Palaeolithic, reduction in tooth size has been noted in populations worldwide (Hanihara & Ishida 2005; Hillson 2005; Williams & Corrucini 2007). The evolutionary processes leading to this reduction are not clear. One of the most popular hypotheses is the Probable Mutation Effect, which argues that the reduction is a result of a lack of selective pressure for larger teeth because of more sophisticated food preparation and cooking (Brace *et al*. 1991; Hanihara & Ishida 2005). This hypothesis, along with others that have been put forward, has been met with criticism mainly because they make a weak argument for a strong selective advantage (Calcagno & Gibson 1988; Hillson 2005). Brook *et al*.'s (2009) study also failed to support this. They found that a Romano-British population dating to AD 200-400 showed smaller mesiodistal (MD) diameters than modern populations. It was proposed that their smaller tooth size was likely a result of poor environmental conditions and developmental insults (Brook *et al*. 2009). We may conclude that different proportions of genetic and environmental influences lead to variations in tooth size within and between populations.

3.2 Anthropometric and genetic studies in relation to the expansion of Bantu-speakers

In sub-Saharan Africa, previous anthropometric and genetic research is dominated by studies of the Bantu-speakers' migrations (Ribot 2002, 2011; Pereira *et al*. 2001; Froment 1998; Hiernaux 1974, 1976; Rightmire 1976) (see Chapter 2 for a brief review), which took place from around 3,000 BP when proto-Bantu speaking agriculturalists began to expand southwards and eastwards from their homeland in the region of present-day Nigeria-Cameroon (Diamond & Bellwood 2003). These early western Africans moved across the subcontinent exchanging and contributing to the gene pool of existing groups. Today, the majority of Africa's Bantu-speaking peoples are descendants of these early migrants (Ehret 2001; Greenberg 1966; Heine & Nurse 2000; Williamson & Blench 2000). In terms of genes, the Bantu-speakers' migrations led to homogeneity of sub-Saharan Africans due to a founder effect (Wood *et al*. 2005; Tishkoff & Williams 2002; Tishkoff *et al*. 2009). In addition to the genetic exchange within Bantu-speakers and between other indigenous groups, as well as

with incoming populations from other parts of the world (especially in the last five hundred years), have influenced variation among modern sub-Saharan Africans (Berniell-Lee *et al*. 2009; Beleza *et al*. 2005; Pereira *et al*. 2002; Soodyall *et al*. 1996; Cavalli-Sforza *et al*. 1994).

According to the craniometric analyses of Froment (1992, 1998, 2002), southern Bantu-speaking groups show low biological distances between each other and marked differences from neighbouring Khoesan people. He argues that this could reflect two major micro-evolutionary processes: firstly, a progressive homogenisation of the Bantu speakers due to population admixture through adoption of agriculture; and secondly, a retention of early differentiation through isolation and retention of a foraging way of life for the Khoesan. These phenomena related to the changes in subsistence patterns probably occurred during the expansion of Bantu speakers and subsequently shaped the present biological diversity in sub-Saharan Africa. Therefore, Froment's work provides indirect supporting evidence for the expansion of Bantu speakers, since no marked differences within Bantu-speaking populations were noticed (Froment 1992, 1998, 2002).

Using the largest sample of metric data available, Ribot's (2002, 2011) work on craniometric variation in modern and prehistoric Africans is invaluable to the study of cranial morphology as the outcome of a complex process of diversification, related to the expansion of Bantu speakers. After analysing 957 skulls with the aid of multivariate analysis (fourteen cranial variables and five for the mandible), Ribot was able to demonstrate that patterns of variation left traces of morphological homogeneity due to a common origin resulting from the Bantu-speakers dispersal (Ribot 2004, 2011). She, however, cautions the interpretation of the craniometric results in relation to the effects of only one historical event as other sources of diversity (geographical barriers, recent population admixtures, nature and size of sample) likely played a part.

Very little morphometric work has been done on the inhabitants of the study area. The work of Hiernaux (1968, 1974, 1976; Hiernaux *et al*. 1992) has provided some insights into the biological relationships of the early inhabitants of Katanga and the Luba. Based on anthropometric data, the Luba of Katanga (along with the Basa of

Cameroon, the savanna Bira in eastern Congo, the northern Fang in southern Cameroon, the Ewondo of Cameroon, and the Nyamwezi in western Tanzania), show the lowest mean distance to the groups of Bantu speakers in the 'Bantu' nucleus in present-day Nigeria-Cameroon. Hiernaux (1968) interprets this as an indication of their close affinity, and that relatively little morphological (and genetic) change has occurred since their departure from the nucleus. In another study, Hiernaux *et al.* (1992) demonstrated that modern (Ba)Luba share morphological affinities with the prehistoric populations from Sanga and Katoto in the Upemba Depression. This affinity was expanded to include the rest of modern-day central Africans (Ribot 2002, 2004).

Finally, we take a look at other biological studies that have contributed information on the lives of past populations in the sub-continent. Studies on health and lifestyle of prehistoric sub-Saharan populations have been indirectly useful in our understanding of people's movements, as well as cultural and biological exchange. Although these studies looked at health and lifestyle, their findings have taught us a great deal about micro-evolutionary processes and adaptation, as well as the complex nature of human interaction (Morris 1992; Steyn 1994; Murphy 1996; Mosothwane 2003; Dlamini 2006; to mention a few). For example, Morris (1992) who analysed proto-historic populations from the Northern Cape and western Free State of South Africa revealed that social status played an important role in the process of genetic exchange in this contact frontier of indigenous Khoesan foragers and herders, Bantu-speaking agriculturalists, and European colonists. Steyn's (1994) work on the health status and physical characteristics of the archaeological populations from Mapungubwe and K2 was insightful in unravelling the complexities of Iron Age farmers' social structure, and its consequences for health, at the turn of the second millennium AD. There are also differences in health status in different ecological zones and over time: early farmers in the dry savannah areas were healthier, on average, than those from wetter environments (Dlamini 2006).

3.3 Oral health and pathology

Information presented in Chapter 2 summarises the characteristics of the subsistence economy in the study area. The Iron Age inhabitants of the Upemba Depression were moderately reliant on agriculture with a combination of subsistence farming, fishing, and a minor component of herding contributing to their diet. They can thus be referred to as agro-pastoralists or as having a mixed economy.

Agriculturalists, pastoralists and/or agro-pastoralists have been analysed for variations in health and disease prevalence. Populations in southern and central Africa have shown a tendency for lower frequencies of dental caries and lower parasite burdens among pastoral people, but with an increased risk of exposure to zoonotic diseases (Morris 1992; Sealy *et al*. 1992; Larsen 1997; Peckmann 2002). On the contrary, agriculturalists tend to have higher parasite loads and to suffer more from infectious diseases, with a rise in caries rates mainly as a result of their subsistence strategy, as well as their lifestyle (Steyn 1994; Murphy 1996; Mosothwane 2003). Studies of living populations show that under circumstances of increased population size and overcrowding, conditions that are conducive to the maintenance and spread of infectious diseases are established (Larsen 1997; Lewis 2002). This is the case with most agricultural societies, past and present. Variations in health and diet based on the different subsistence strategies of living hunter-gatherers, agricultural, and pastoral populations provide the basis for the exploration of similar differences in prehistoric populations.

Dental diseases are inter-related; for example, when the incidence of caries rises, antemortem tooth loss and abscesses also rise. Dental caries are used here as the starting point from which to review the literature, but related oral conditions will be considered as part of the same 'package'.

3.3.1 Caries and related oral conditions (AMTL; wear and abscesses)

A. Aetiology of caries

Dental caries or tooth decay is a progressive disease characterised by the focal demineralisation of the inorganic portion (enamel and dentine) and subsequent

destruction of the tooth. The aetiology of caries is complex and requires understanding of all factors, biological (genetic, hormonal, structural, and so on) and behavioural, which play a role in their development. The aetiology of tooth decay is thus multifactorial, but bacterial fermentation that produce organic acids from dietary carbohydrates, is at the basis of the tooth-decay process (Larsen 1997; Aufderheide & Rodriguez-Martin 1998; Burns 1999; Hillson 2005). Factors that promote the development of caries include tooth morphology; wear; processed starchy foods; trauma; calculus; and female sex hormones. Extrinsic factors, such as food composition and texture; frequency of exposure; caries-promoting behaviours, are more variable within and between populations. As a result, they generally influence caries development more than intrinsic factors, such as physiology; genetic predisposition or immunity; and tooth morphology.

B. Carbohydrates and caries

In agricultural societies, diets with foods rich in processed carbohydrates are the most common cause of dental caries (Larsen *et al*. 1991; Larsen 1998; Cucina *et al*. 2003; Temple & Larsen 2007; Hillson 2008). The adoption of an agricultural way of life frequently meant a narrowing of diet, often involving reduced availability of animal protein in combination with an increased reliance on a limited number of domesticated plants, which may offer a poor nutritional base. The result is a tendency for high levels of dental diseases, iron-deficiency anaemia and more morbidity in children (Larsen 1997, 1998; Cohen & Armelagos 1984; Stuart-Macadam & Kent 1992; Steckel & Rose 2002; Mensforth *et al*. 1978). However, it is worth noting that all these studies are based on maize agriculture. Maize is cariogenic because it is high in sugar and tends to stick on tooth surfaces when ground and gelatinised (Lingström *et al*. 2000). Not all agricultural (starch) products have the same cariogenic potential. For example, rice is much less cariogenic than maize. In Japan, some rice farming communities from the Yayoi period demonstrated caries frequencies far below the range previously reported for farming societies (Temple & Larsen 2007; Tayles *et al*. 2000).

The link with caries development is the high sugar content found in most agricultural foods, especially when processed, that provides a prime environment for bacteria to

grow and multiply. Softer processed foods exacerbate the problem, as they tend to stick on and between teeth. Since the main constituent of dental plaque is bacteria, the risk of enamel demineralisation depends on the capacity for the bacteria to convert dietary sugars or gelatinised starches into organic acids (Lingström *et al*. 2000). Thus, without sugary carbohydrates in the oral cavity, bacterial acidogenesis is minimal.

Since oral diseases, especially caries, are closely linked to diet, they are often used in anthropological studies as a means to categorise human populations on the basis of subsistence patterns. Although standard ranges are useful in providing guidelines for interpreting different subsistence strategies on a global scale, they are simplistic and assume that subsistence strategies are uniform worldwide (Turner 1979). The ranges do not consider other factors that influence dental caries differences such as cultural behaviours, the nature, type and preparation of foods consumed, and so on. For example, foraging communities from the Jomon period have much higher caries rates than the Japanese rice farmers cited above (Temple & Larsen 2007; Tayles *et al*. 2000). These patterns demonstrate that every situation is unique and should be dealt with in its own context and not simply on broad prescribed categories of subsistence (Tayles *et al*. 2000). As a result, standard ranges of dental caries frequencies to classify different subsistence strategies are not employed in this study.

C. Caries and dental wear

Dental wear or attrition can be explained as the loss of hard tissue (enamel and dentine) during day-to-day processes of mastication and swallowing, as well as when teeth are used as tools (Aufderheide & Rodriguez-Martin 1998). Although dental wear is a normal physiological process rather than a disease, it is necessary to assess it when comparing dental pathologies between populations. Severe dental wear can predispose a tooth to cariogenesis and possible abscessing; whereas moderate wear can be beneficial in deterring caries as it smoothes out the tooth surface where caries usually occur (Powell 1985; Hillson 1986; Roberts & Manchester 1995). Differences in the severity of wear can therefore affect the prevalence of dental pathological conditions between populations. Dental wear can also reflect differences in dietary behaviour and lifestyles between past and living populations.

Among human populations worldwide, there has been a secular trend in the reduction in severity of occlusal surface wear (Powell 1985; Larsen 1997, 2002). This trend has been largely attributed to the shift in subsistence strategies from foraging to farming economies. The characteristics of food, such as its consistency and texture as well as the manner in which it is prepared, highly influence the wearing of tooth surfaces. Thus, differences in subsistence economies would tend to produce different degrees of severity of dental wear. These differences would also be further influenced by local behavioural or cultural practices (Larsen 1997; Eshed *et al*. 2006).

In general, foraging populations have more severe dental wear than agricultural societies (Eshed *et al*. 2006; Larsen 1997; Morris 1992; Sealy *et al*. 1992; Powell 1985). The reason for this is that hunter-gatherer diets usually consist of tougher, fibrous foods that also contain more exogenous abrasive substances. Foods consumed by agriculturalists on the other hand, tend to be softer and more processed (Larsen 1997). However, this is not always the case since some processing techniques may actually introduce abrasive elements that encourage tooth wear. For example, Pfeiffer's analyses of skeletal material from the Iron Age agriculturalists in Nigeria have indicated relatively heavy dental wear on the teeth of these people (Pfeiffer 1988). She attributes this to the processing of cereal grains with grinding stones, contributing to the overall grittiness of the diet.

D. Biological influence on caries

The development of dental caries is also influenced by intrinsic factors, which include tooth morphology, genetic and physiological factors. The grooves and pits of molars and premolars provide a haven for cariogenic bacteria to flourish, which can lead to higher occurrences of carious lesions in cusped teeth compared with flatter teeth (incisors and canines) (Larsen 1997; Aufderheide & Rodriguez-Martin 1998).

There is no doubt that caries development is highly influenced by lifestyle (behavioural) factors. At the root of the causes for caries is the consumption of processed carbohydrates high in sugar (Lingström *et al*. 2000). However, when it comes to biological effects, some debate arises. There is a physiological or hormonal influence on the distribution of caries between sexes. According to clinical and anthropological research, females of reproductive age have been shown to be more

susceptible to dental caries, especially during pregnancy (Lukacs & Largaespada 2006; Lukacs 2008, 2011). This has been related to a reduction in salivary flow, lower oral pH and increased cariogenic oral bacteria during pregnancy. During the first (sometimes, into the second) trimester of pregnancy, morning sickness and vomiting are common ailments that can increase gastric acid in the oral cavity. Because gastric acid can erode dental enamel, pregnant women are at a higher risk of tooth decay. This, in addition to sugary dietary cravings, and limited attention to oral health, makes women of childbearing age more susceptible to developing dental caries (Hey-Hadavi 2002; Silk *et al*. 2008).

Conflicting views on these findings express concern that the condition should be a universal trend of elevated caries frequencies in females than in males, if the hormonal hypothesis should hold (Temple & Larsen 2007). They argue that female caries rates rise due to their greater consumption of cariogenic agricultural products (Larsen 1998; Larsen *et al*. 1991). But there is substantial empirical evidence that at a population level, more females are affected by dental caries compared to males, regardless of their dietary choices (Walker & Hewlett 1990). Moreover, a specific cause alone is not sufficient to explain the sex related caries patterns, especially since every situation is unique. The hormonal influence on dental caries is, in essence, a predisposing factor that could explain the observed higher caries prevalence in females. Like any other predisposing factor, an environmental stimulus is often necessary to trigger the onset of any disease. In this case, a cariogenic diet, trauma, cultural behaviours need to be present for cariogenesis.

E. Caries and antemortem tooth loss

Antemortem tooth loss (AMTL) can result from carious lesions, excessive tooth wear, periodontal disease, trauma and intentional (cultural) evulsion. Exposure of the pulp cavity through cariogenesis, excessive wear or trauma can lead to bacterial infection and subsequent abscessing of the surrounding alveolar bone that could result in loss of a tooth (Burns 1999). Diet has been implicated in the prevalence of AMTL in past and contemporary populations (Cassidy 1984; Hartnady & Rose 1991; Larsen 1997; Patterson 1984; Walker & Hewlett 1990). Contrary to the decline in occlusal wear, the shift from foraging to farming economies was accompanied by an increase in

tooth loss. Both minimal and severe dental wear have been associated with high incidences of caries and tooth loss. Rapid and heavy wear, often noted in the dentition of foraging people, has been shown to cause loosening of the teeth in their sockets and can result in loss of healthy teeth.

Other factors such as stagnation of bacteria on the tooth surfaces or periodontal tissues are involved in promoting oro-dental disease processes. For example, in the case of reduced dental wear as observed in many agricultural populations, the grooves or fissures present in the posterior teeth provide ample loci for caries-causing bacteria to grow (Larsen 1997). Thus, dental caries as a disease process are the main cause leading to tooth loss; and reduced dental wear only provides opportunities for the caries to develop. Furthermore, since agricultural foods often stick in stagnant areas of the tooth and have a high starch or sugar content, dental caries proliferates through consumption of such foods. High incidences of AMTL can be expected, therefore, in populations that rely heavily on agricultural foods.

3.3.2 Calculus and periodontitis

Dental calculus is composed of a variety of organic and inorganic substances from bacterial, salivary and dietary origin within a matrix of calcium phosphate (White 1997; Kani *et al.* 1983). In humans, calculus development involves plaque calcification or mineralisation. Plaque biofilm development involves adsorption of pellicle proteins onto the enamel surface, followed by bacterial adhesion. In the absence of mechanical cleaning and an alkaline oral environment, plaque absorbs calcium and phosphate salts from the saliva and in time becomes hardened (White 1997; Kani *et al*. 1983). However, the aetiology of dental calculus formation is multi-causal and not fully understood. For example, it is not clear what type of diet causes an alkaline oral pH. Some scholars argue that calculus deposition is associated with the consumption of protein-rich foods, which produce ammonia that causes a rise in alkalinity (Dawes 1970; Lieverse 1999). On the other hand, others defend that diets rich in carbohydrates can promote calculus deposition because of elevated microorganisms associated with high carbohydrate consumption (Littleton & Frohlich 1989; Hillson 1996). Therefore, assessment of calculus deposition can provide useful information regarding dietary habits of (past or present) people.

Although other factors, such as, salivary flow rate, the composition of oral fluids, oral microorganisms, and oral pH are important for calculus to develop, the presence of calculus indicates long-standing plaque accumulation, suggesting infrequent mechanical cleaning of the teeth (Hillson 2008). Calculus is, therefore, indicative of an individual's or population's oral hygiene or lack thereof.

Invasion of plaque by pathogenic bacteria can lead to inflammation of the periodontium and surrounding soft tissues (gingiva). The inflammation of the surrounding soft tissues is an immune response triggered by toxins produced by bacteria present in dental plaque (Marsh & Martin 1999; http://www.perio.org/consumer/2a.html). This chronic, slowly progressive and destructive inflammatory disease process is known as periodontitis, which subsequently leads to the resorption and destruction of the alveolar bone, as can be seen on skeletal samples (Hillson 1986, 2008). Closely linked with calculus deposition, periodontitis can therefore be used as an indicator of dietary patterns.

Periodontitis, however, has also been associated with pregnancy (Lukacs 2008, 2011; Silk *et al*. 2008). Vascular and hormonal changes that occur during pregnancy are related to an inflammatory response that affects oral health (Clothier *et al*. 2007; Laine 2002). Loss of bone mineral density, which is a common malady in menopause, has been extended to include alveolar bone loss (White & Rudolph 1999; Jeffcoat *et al*. 2001).

Furthermore, gingivitis, which is inflammation of the superficial gum tissue, is the most common oral disease in pregnancy. The combination of increased and fluctuating levels of oestrogen and progesterone, changes in oral flora and a decreased immune response results in a high prevalence (60 to 75%) of gingivitis in pregnant women (Silk *et al*. 2008). The mechanism by which oestrogen and progesterone affect the soft tissues surrounding the teeth has been linked to increased vascular permeability of these tissues as early as the onset of puberty, and exacerbated in pregnancy when these hormones are at much higher levels (Mealey & Moritz 2003).

As with dental caries and antemortem tooth loss, periodontitis increased markedly in populations that consumed large quantities of plant carbohydrates and processed

foods (Cohen & Armelagos 1984; Hillson 1986; Larsen 1997). Once again, the link from several anthropological studies is plaque development, which they attribute to the sugar content in most starchy foods that constitute the diets of agricultural populations (Brothwell 1981; Lukacs 1989; Cassidy 1984). In general, agricultural populations exhibit a higher calculus rate than hunter-gatherer populations (see Cassidy 1984 for example). However, calculus is not necessarily diet-related and other factors such as oral hygiene and culturally derived behaviours cannot be neglected (Lieverse 1999).

3.3.3 Evidence from studies of dental diseases and stable isotopes

In reconstructing past diets, a combined approach using oral pathologies, stable isotopes and other techniques, such as analyses of phytoliths, starch granules, and dental micro wear, is more powerful than the use of these analyses independently. Studies that have combined oral pathologies and stable isotopes have indicated a close relationship between dental caries and certain kinds of diets, particularly those high in carbohydrates (Gilbert 1995; Ambrose *et al*. 2003; Schollmeyer & Turner 2004; Kusaka *et al*. 2010; Valentin *et al*. 2006; Gil *et al*. 2009). For example, in Cikobia (northern Fiji), investigations of stable carbon and nitrogen isotopes and oral pathologies of individuals dating to the late prehistoric/historic period (around AD 1850), showed that males and females had similar diets, and that the proportion of marine resources was low in comparison to the proportion of vegetal food. The evidence from oral pathologies indicated low dental wear, a high caries rate (15%) and calculus, suggesting a diet relying mainly on vegetal food with limited shellfish consumption (Valentin *et al*. 2006).

On the contrary, the complementary studies of Kusaka *et al*. (2010) and Temple and Larsen (2007) on the diets of prehistoric Jomon period foragers and Yayoi period agriculturalists in Japan, challenge the widely accepted pattern of high caries rates among agricultural groups. In these studies, the lack of significant differences in caries rates between the these groups suggested that the rice eaten by the Yayoi farmers, though a high-carbohydrate staple, was not more cariogenic than the mixed diets (marine protein resources and terrestrial C_3 plant carbohydrates) consumed by the Jomon foragers (Temple & Larsen 2007). This confirms that archaeological

evidence of agriculture alone is not adequate to presume a certain pattern of disease and health in prehistoric populations. The actual contributions of each mode of subsistence, and the nature and preparation of foods consumed, become crucial factors to consider in palaeodietary studies. It is through such studies that heterogeneity within similar diets may be found (Schoeninger 2009).

3.3.4 Previous non-clinical studies of dental disease in Africa

As mentioned above, studies that compare patterns of diseases (and health status) in different subsistence economies are common. Studies of contemporary people are valuable because they provide us with information that is clear and unambiguous. Walker & Hewlett (1990) compared Bantu agriculturists from central Africa with their hunter-gatherer neighbours. The farmers had diets that comprised mainly manioc, plantains, maize and rice, and they suffered more dental caries (8% of teeth) than the hunter-gatherer groups (Mbuti, Efe, and Aka) who consumed more meat and less carbohydrates in comparison. The incidence of caries amongst hunter-gatherers ranged from 5.1 to 5.8%.

Archaeological evidence of the disparity in oral diseases between hunting-and-gathering people and farmers has been reported in studies such as those by Morris (1992); Sealy *et al*. (1992); and Peckmann (2002). Proto-historic foraging-pastoral (Kakamas and Riet River), and farming (Griqua) groups living in the Northern Cape and western Free State of South Africa, depicts this picture clearly (Morris 1992). The Kakamas and Riet River people subsisted on wild plant food, wild (and occasionally domestic) fauna, milk and honey. The occurrence of caries is low, especially for the Kakamas people (1.3%; Riet River had a rate of 4.3% teeth affected). The higher rate of caries in the Riet River sample has been attributed to the inadequate amount of fluoride in the ground water of this area (Morris 1992). The relatively disease-free condition of the Kakamas people's teeth is consistent with a hunter-gatherer or 'specialised' pastoralist diet (Morris 1992). In contrast, the Griqua had a mixed diet of wild and domestic fauna, wheat, milk and vegetables; 5.2% of their teeth were affected by dental caries (Morris 1992). The Griqua caries rate is comparable to that of other archaeological farming groups, such as for the Mtemankhokwe sample (5.2%) in Malawi (Morris 1993).

Differential rates of caries are also reported for hunting and gathering groups from the Holocene in South Africa. The overall caries rate among hunter-gatherers of the south-western Cape coast is 2.6% of total teeth examined. However, the marine-resource dependent foragers from Oakhurst have surprisingly high rates of dental caries that is inconsistent with most foraging populations. The high caries rates seen among these foragers were attributed to low concentrations of fluoride in drinking water, and extreme dental wear that caused pulp exposure predisposing the teeth to caries (Sealy *et al*. 1992).

Examining the occurrence of caries in historic rural agriculturists versus urban people in South Africa, Oranje *et al*. (1935) found double the number of individuals affected by caries in urban (68%) compared with rural (33%) areas. The 'rural diet' of wild plants, milk and stone-ground corn was better for deterring caries than the 'urban diet' with refined sugars and finer machine-ground corn (Oranje *et al*. 1935). Ethnographic evidence for the differing occurrence of caries between urban and rural populations is also found in Varenne *et al*.'s (2004) study of children and adults from Burkina Faso. In the rural groups, 32% of children aged 6 years were affected by dental caries, while 46% of those in urban areas were affected. Once again, these studies emphasise the significance of the consistency and quality of food in the aetiology of caries, with a striking contrast associated with high-sugar carbohydrate consumption.

Previous investigations of some of the archaeological skeletons from the Upemba Depression (Sanga, Katoto, and Malemba-Nkulu) revealed high rates of dental diseases in comparison to other contemporaneous populations in southern Africa (Murphy 1996; Dlamini 2006). Thirty-six of 439 teeth (8.2%) were affected by dental caries in the Upemba Depression, compared with only 3.7% among farmers from the dry savannah areas of South Africa (Dlamini 2006).

In Murphy's study of prehistoric subsistence of Iron Age populations in central and southern Africa, no differences in dental caries were seen between the groups with a heavier reliance on animal products (Kgaswe and Taukome in Botswana) compared with those who ate more agricultural foods (Isamu Pati, Simbusenga, Ingombe Ilede, in Zambia and Sanga, Katongo, Kikulu and Malemba-Nkulu in the DRC) (Murphy 1996). Among the herders, 9.0% of all teeth studied were affected by caries, while

only 5.0% were diseased among farming groups (Murphy 1996). This is in contrast to the patterns often seen between farmers and herders. It must be pointed out that the herders in Murphy's study, however, were not 'specialised' pastoralists with a heavy reliance on meat, but rather had a mixed subsistence economy.

In summary, caries development is largely influenced by the consumption of processed carbohydrates high in sugar and that tend to stick to tooth surfaces with a longer clearance time in the oral cavity. Secondary to that, the morphology of the teeth, tightly linked to dental wear, play a great role in caries formation. Caries presence and prevalence, therefore, can tell us a lot about an individual's or population's diet and the manner in which it was prepared, as well as their behavioural activities.

Lastly, the multi-disciplinary approach into the study of past people's diet is more holistic than looking at these techniques independently. Combining oral diseases, analyses of stable isotopes and phytoliths, with the evidence from archaeology proves a formidable tool in the understanding of ancient diets.

3.4 Phytoliths

Phytoliths are microscopic particles of silica that range in size from 2 to 100µm, deposited in the intracellular or extracellular spaces of cells of many different higher plants (Armitage 1975; Cummings 1994; Lalueza Fox *et al*. 1996; Piperno 2006; Henry & Piperno 2008). They are produced by many plant taxa, but are especially abundant, diverse and distinctive in grasses (Poaceae sp.) (Figure 3.01). Soluble monosilicic acid (H_4SiO_4) is absorbed by roots and carried up to the plants' aerial structures through transpiration. Some of the silica is laid down as solid silicon dioxide (SiO_2) in the cells of aerial structures and occasionally in underground organs. The shapes can be diagnostic of specific plant taxa down to species level. The family of squashes (Curcubitaceae), for example, make diagnostic spheroid echinate phytoliths from all parts of the plant (Figure 3.02).

In addition to SiO_2, phytoliths are composed of 5-15% water and trace elements such as Mg, Ca, K, Fe and Al. Plants are thought to make phytoliths for different functions, such as 1) to increase the plant's rigidity or strength (structural); 2) to mitigate the toxic effects of aluminium and other heavy metals ingested by plants (physiological),

and 3) to increase resistance to herbivores and pathogenic fungi (protective) (Lalueza Fox *et al*. 1996; Piperno 2006; Henry & Piperno 2008).

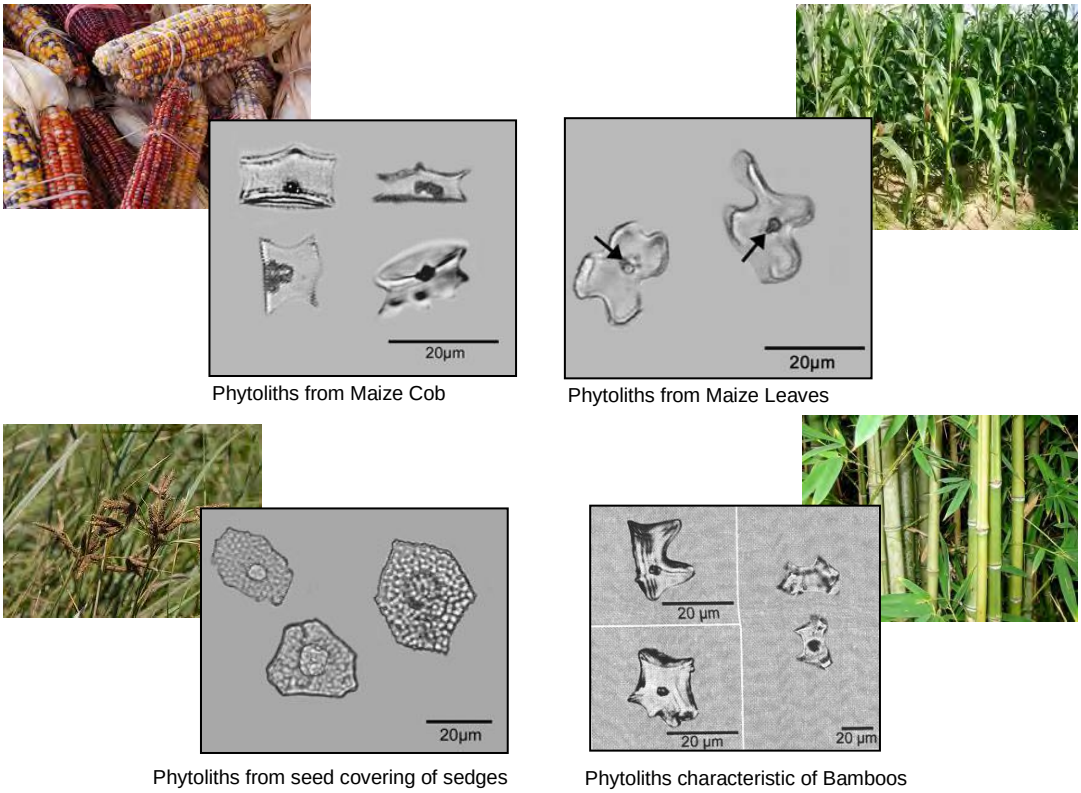
Phytoliths are very durable and can last for many years, hence making them valuable tools for reconstructing palaeoenvironments and diet (Cummings 1994; Piperno 2006). Phytolith analyses have played an important role in palaeoecology by providing a record of the plants that grew in an area. Phytoliths produced in grasses have been studied intensively, especially economically important grasses such as maize (*Zea mays*) and bamboo (Bambusoideae) (Figure 3.01).

During the formation of dental calculus, food particles, including phytoliths, may be trapped in the matrix of calcium phosphate (White 1997). Once in the mineralised calculus, phytoliths are protected and can be recovered to provide a direct record of plants consumed or orally manipulated. In archaeology, phytoliths have been used to reconstruct diet by identifying plants consumed by past people (Lalueza Fox *et al*. 1996; Henry & Piperno 2008). Phytoliths provide information about the vegetable part of diet in an unbiased way that can complement other dietary analyses of past diets such as stable isotopes, dental micro wear and dental diseases. Other uses of phytoliths in archaeology include the timing of plant exploitation (domestication) by humans or origins of agriculture (Piperno *et al*. 2009; Mbida *et al*. 2000; Lejju *et al*. 2006), as well as dating of archaeological sites (Piperno 2006).

Phytoliths and starch granules have been successfully isolated and identified in dental calculus of many archaeological populations (Holt 1993; Middleton 1993; Lalueza Fox *et al*. 1996; Reinhard *et al*. 2001; Boyadjian *et al*. 2007; Henry & Piperno 2008; Hardy *et al*. 2009; Menéndez *et al*. 2009; Wesolowski *et al*. 2010). Using calculus from teeth dating to the third millennium BC (Tell al-Raqā'i, Syria), Henry and Piperno (2008) were able to conclude that individuals from this site consumed a variety of plants, and that domesticated cereals such as barley and wheat contributed an unexpectedly small portion of their diet. Starch granules and phytoliths from *Dioscorea* (yam) and *Araucaria angustifolia* (Paraná pine) were found in dental calculus of the prehistoric sedentary fishing and gathering people of the Brazilian coast who left behind mega shell middens or *sambaquis* from around 3800 to 1200BP (Wesolowski *et al*. 2010).

The majority, if not all, of these studies come from outside of Africa. In the African continent, few studies on phytoliths have been done, and most of them have focused on palaeoenvironmental reconstructions instead of diet (Alexandre *et al*. 1997; Mworia-Maitima 1997; Mercader *et al*. 2000; Runge 1999; Barboni *et al*. 2007). These studies show that phytolith data from lake cores, soil sediments and archaeological sites record both regional and local variations in plant cover and are useful in discriminating most vegetation zones on the African continent. On the palaeodietary front, even fewer studies exist. These studies are dominated by investigations into the cultivation and use of domesticated tropical crops. For example, banana (*Musa*) phytoliths recovered at numerous archaeological sites in West and central Africa have been used as evidence for banana cultivation in prehistory (Mbida *et al*. 2000; Lejju *et al*. 2006; De Langhe 2009). These studies have recovered phytoliths from soils instead of dental calculus.

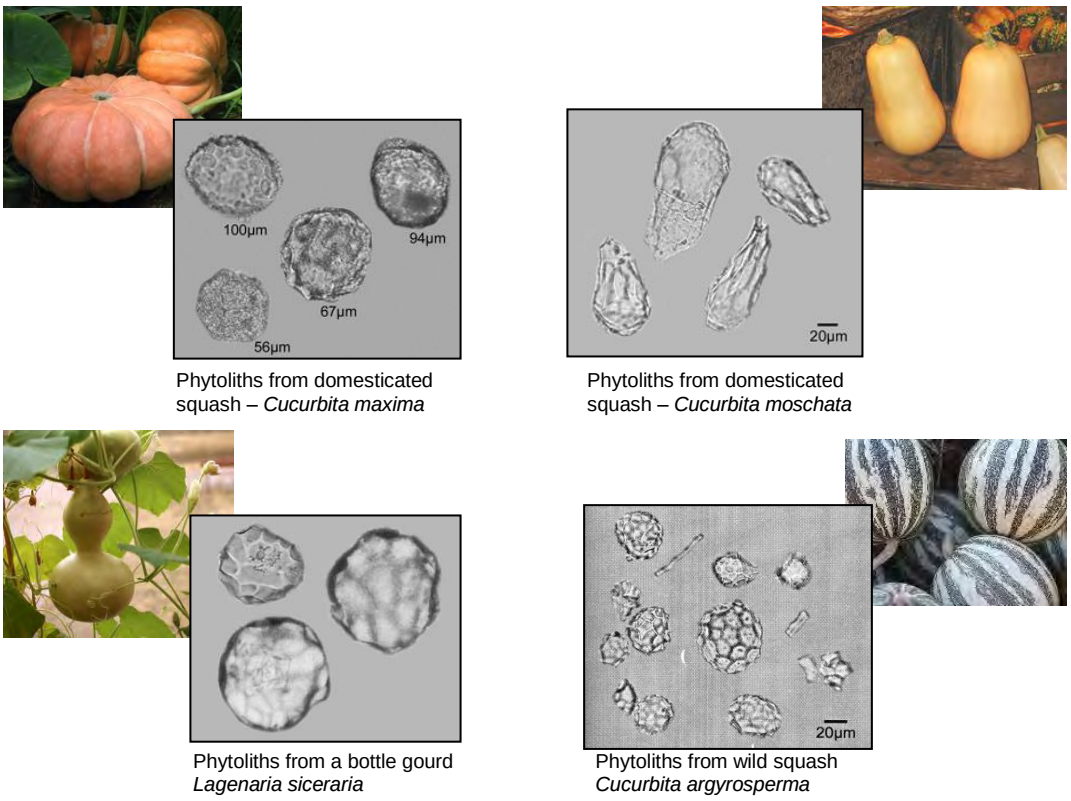
As far as the literature is concerned, the only study from Africa that mentions using phytoliths from dental calculus is that by Henry *et al*. (2012). Based on the findings of Henry *et al*. (2012), there is now evidence that *Australopithecus sediba* had a more diverse diet, which possibly included fruits, leaves and bark, as well as grasses and sedges. In contrast with available dietary data on other hominins (van der Merwe *et al*. 2003), the authors were able to show that *A. sediba* preferred C_3 foods instead of C_4 resources that were widely available in its environment (Henry *et al*. 2012). With the exception of this work by Henry *et al*.(2012), the current research is one of the first in Africa to analyse phytoliths from dental calculus recovered from archaeological humans to reconstruct past diets.



Phytoliths from Maize Cob | Phytoliths from Maize Leaves

Phytoliths from seed covering of sedges | Phytoliths characteristic of Bamboos

Figure 3.01: Some examples of phytoliths from common Poaceae (grasses) plants (photographs of phytoliths from Piperno 2006; photographs of plants and fruits from Wikipedia).



Phytoliths from domesticated squash – *Cucurbita maxima* | Phytoliths from domesticated squash – *Cucurbita moschata*

Phytoliths from a bottle gourd *Lagenaria siceraria* | Phytoliths from wild squash *Cucurbita argyrosperma*

Figure 3.02: Phytolith diversity in the Curcubitaceae family (squashes and gourds) (photographs of phytoliths from Piperno 2006; photographs of plants and fruits from Wikipedia).

3.5 Dietary stable isotopes

Isotopes are forms of the same element that differ in nuclear mass, but contain the same number of electrons and protons (Sharp 2007). The element carbon, for example, has three principal isotopes; two of which are stable (^{12}C and ^{13}C) and one that is unstable (^{14}C). Stable isotopes are named so because they maintain constant concentrations over time, while unstable, or radiogenic, isotopes undergo radioactive decay at predictable and measurable rates (Hoefs & Hoefs 1987). Most elements have two or more stable isotopes, with the lightest occurring in much greater abundance than the other(s). For example, the global average ratio of carbon isotopes ^{12}C: ^{13}C: ^{14}C is about 98.93: 1.07: 10^{-10} (Berglund & Wieser 2011). However, this ratio has been somewhat altered by nuclear-weapon testing and by the combustion of fossil fuels (Telegadas 1971; Bischof *et al*. 1985; Levin *et al*. 1987).

Isotopes differ in their thermodynamic and kinetic properties because of the difference in their nuclear mass, which makes them react at different rates in chemical reactions. The heavier isotope tends to react more slowly than the lighter one in mass-sensitive kinetic reactions. The end result is a product with different proportions of the light and heavy isotopes compared with the substrate. This is known as 'fractionation' and provides a means for tracing biological and geological processes in the environment (Schwarcz & Schoeninger 1991; Lee-Thorp 2008).

Isotopic abundance in a substance is expressed in the delta (δ) notation, which compares the isotope ratio (R) in a sample with that in a standard:

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

where R is the ratio of the heavier to the lighter isotope in a sample or standard. Since the observed fractionations during chemical reactions are very small, they are measured in parts per thousand or per mille (‰). The standards are internationally accepted standard materials; for example, when measuring carbon, the standard is a marine carbonate from the Pee Dee Belemnite (PDB) formation in South Carolina, USA (Craig 1957; Hoefs & Hoefs 1987). The δ values of standard materials are, by definition, 0‰, so the $\delta^{13}C$ value of PDB is 0‰. Most living organisms contain less

^{13}C than the PDB carbonate and hence have negative $\delta^{13}C$ values. The internationally accepted standard for nitrogen isotope measurements is atmospheric nitrogen (AIR).

The use of stable isotopes as a means to reconstruct past diets requires an understanding of how isotopes are naturally distributed in the environment and how they are incorporated into the tissues of living organisms, including humans. The following sub-sections deal with how stable isotopes are used in dietary reconstruction. Each section begins by explaining basic principles of the carbon, nitrogen and oxygen cycles, outlining how these elements circulate between the atmosphere and biosphere. Details of the mechanisms involved in the transfer and fractionation of these isotopes within the bodies of consumers, such as humans, are also provided. Lastly, previous studies are reviewed in order to provide examples of the use of stable isotope techniques in palaeodietary reconstructions, as well as for tracking the movement and origins of people (and animals) in the past.

3.5.1 Stable carbon isotopes

The carbon cycle begins with plants, whether on land or in the oceans, converting atmospheric carbon dioxide into carbohydrates. These carbohydrates are then eaten by consumers, moving up the trophic levels of the food chain, finally returning to the ecosystem with the death and decay of living organisms (Ehleringer 2006). Two dominant photosynthetic pathways exist in higher land plants, i.e. the C_3 or Calvin-Benson pathway and C_4 or Hatch-Slack pathway (named after the number of carbon atoms fixed in the first product of photosynthesis, i.e. 3-phosphoglyceric acid or oxaloacetate, respectively). During carbon dioxide fixation, plants discriminate against the heavier isotope (^{13}C). In C_3 photosynthesis, a strong discrimination against ^{13}C by the RuBisCO enzyme (ribulose-1,5-biphosphate carboxylase oxygenase) results in more negative $\delta^{13}C$ values of the plant, with $\delta^{13}C$ values ranging from -24 to -36‰ (mean = -26‰). Plants that follow the C_4 pathway have specialized bundle-sheath cells that concentrate CO_2 before releasing it into the carbon-fixation cycle and all of the CO_2 is converted into carbon compounds (Slack & Hatch 1967). As a result, plants that follow the C_4 pathway discriminate less strongly against ^{13}C: $\delta^{13}C$ values range from -9 to -16‰ (mean = -12.5‰).

Plants that follow the C_3 pathway include most trees, woody shrubs, herbs, vegetables and temperate grasses. Tropical grasses and other plants in (sub)-tropical zones have adopted the C_4 pathway. While C_3 plants are largely found in temperate and other cooler ecological zones, C_4 plants tend to be in environments with higher temperatures and lower partial pressure of atmospheric CO_2; thus suggesting an adaptive response by plants to these conditions (Collatz *et al*. 1998). The variability in $\delta^{13}C$ observed in C_3 plants is influenced by light intensity, temperature, humidity, moisture and recycling of atmospheric CO_2 (Smith & Epstein 1971; van der Merwe & Medina 1991; Diefendorf *et al*. 2010; Kohn *et al*. 2010).

The incorporation of carbon into animal (and human) tissues is achieved only via consumption of food. The isotope ratios recorded in primary producers (plants) are incorporated into the tissues of consumers, with some additional fractionation. Most of the organic carbon in bone is in collagen. **Collagen** is a complex protein molecule that consists of three helical peptide fibrils joined together by cross-linkages. It is the main structural protein of bone, constituting about 20% of fresh bone by weight (Hare 1980). Calcium phosphate (apatite) crystals are packed around the collagen framework to give bone its strength and rigidity. Bone is a living tissue that remodels throughout normal life (Hedges *et al.* 2007). As a result of bone turnover or remodelling, isotope ratios of collagen reflect dietary carbon (and nitrogen) accumulated over long periods (decades) of the lifetime of the individual (Bell *et al*. 2001; Ubelaker *et al*. 2006; Hedges *et al*. 2007).

The fractionation of carbon during collagen formation leads to an enrichment of about +5‰ compared with the food that the animal eats (Vogel 1978; Cerling & Harris 1999; Howland *et al*. 2003). Thus, the bone collagen $\delta^{13}C$ of an herbivore browsing purely on C_3 foliage can be expected to be on average -21.5‰; while that of a pure grazer feeding only on C_4 grasses should be about -7.5‰ (van der Merwe & Vogel 1978; Cerling *et al*. 2003). In subsequent steps of the food chain, further enrichment of between +1 and +2‰ is observed among omnivores and carnivores, including humans (Lee-Thorp 2008).

One of the crucial aspects of measuring carbon isotopes in collagen for palaeodietary construction is to understand the contribution of the different dietary components

(carbohydrates, fats, or proteins) in the formation of collagen. According to the 'direct routing' model proposed by Krueger & Sullivan (1984), amino acids used in the synthesis of collagen come from the protein component of the diet. Experimental studies of rats and gerbils fed controlled diets initially appeared to support this model (Ambrose & Norr 1993; Tieszen & Fagre 1993). However, it has since been demonstrated that the model is not that straight forward and that a significant proportion of the carbon in collagen may be obtained from dietary carbohydrates and fats (Howland *et al*. 2003).

It has been shown that collagen is useful for palaeodietary reconstruction because it is relatively resistant to alteration in the post-mortem and post-burial state and can survive for up to 100 000 years in ideal conditions, i.e. cold and dry environments (Bocherens *et al*. 1991). Though a stable molecule, collagen can however be altered in the burial context and its isotopic integrity compromised. Hot, wet and/or acidic environments tend to exacerbate the degradation of collagen. With that said, preservation and recovery of collagen from archaeological remains in sub-tropical environments is still possible, and valuable information on past diets can be obtained. Quality control criteria have been established to evaluate the preservation of collagen and the likelihood that it has maintained its *in vivo* isotopic ratios (Ambrose 1990; van Klinken 1999). If extracted collagen has atomic C:N ratios in the range of 2.9 to 3.6, %C in the range of 10.3 to 39.3 and %N in the range of 3.4 to 14.0 (Ambrose 1990; van Klinken 1999), then it is accepted as sufficiently well-preserved to have maintained its isotopic integrity.

As already mentioned, the other molecule commonly used in palaeodietary studies is **hydroxyapatite** ($Ca_9[(PO_4)_{4.5}(CO_3)_{1.5}](OH)_{1.5}$), found in bone and tooth enamel. This contains a small amount of carbonate (Hoppe *et al*. 2004) which yields a $\delta^{13}C$ value, while the carbonate oxygen yields $\delta^{18}O$. Unlike bone, teeth do not remodel. Accordingly, stable isotopes assimilated into dental tissues (especially tooth enamel) reflect isotope ratios of the diet during the period of growth and development of the tooth. Since different tooth types form at different times during an individual's life, their isotope ratios can provide us with dietary information at specific times of an individual's life. For example, the crowns of the permanent first molars (M1) form between age one and three years; while the permanent second molars (M2) form from

age four to seven years of life (Buikstra & Ubelaker 1994; Hillson 2005). These teeth, therefore, will record isotope values at their respective times of formation. It may thus be possible, by analysing several teeth from one individual, to understand migration and where people spent their childhood versus adulthood, and if they moved from one isotopic zone to another.

The fractionation between carbon isotopes in the diet and apatite is much greater than that between diet and collagen. Depending on body mass and dietary physiology, the fractionation factor ranges from +11 to +13.5‰ (Krueger & Sullivan 1984; Lee-Thorp *et al*. 1989; Ambrose & Norr 1993; Cerling & Harris 1999; Passey *et al*. 2005; Kellner & Schoeninger 2007).

Unlike collagen, carbon in apatite originates from all components of the diet, i.e. carbohydrate, proteins, and fats (Lee-Thorp *et al*. 1989; Ambrose & Norr 1993; Kohn & Cerling 2002; Howland *et al*. 2003). Apatite isotope ratios have, therefore, been useful in demonstrating the total contribution of C_4 plants in the diet, where these contribute energy but not protein. In such cases, $\delta^{13}C$ measurements of collagen underestimate this component (for example, see Ambrose *et al*. 2003).

Currently, there are no quality-control criteria for enamel apatite as there are for collagen. That said, enamel apatite has a high crystallinity and density that renders it relatively immune to post-mortem and post-burial diagenesis (LeGeros 1991). The bonds in biogenic PO_4 and CO_3 are strong in comparison to those in exogenic carbonates, so that pre-treatment with dilute acetic acid removes contaminants. Stable isotope measurements on samples prepared thus are generally accepted as reliable (Kohn & Cerling 2002). In environments with C_4 grasses, the expected separation in $\delta^{13}C$ between browsers and grazers is maintained even in samples that are millions of years old (Cerling & Harris 1999; Lee-Thorp 2000; Lee-Thorp *et al*. 1989; Lee-Thorp & van der Merwe 1987; Sponheimer & Lee-Thorp 2003): a clear indicator of the preservation of *in vivo* isotope ratios.

The trend in studies of collagen-apatite spacing has been to compare $\delta^{13}C$ values of bone collagen with bone apatite, rather than with enamel apatite (Lee-Thorp *et al*. 1989; Ambrose & Norr 1993; Hedges 2003; Jim *et al*. 2004). As a result, we know a limited amount about the spacing between bone collagen and enamel apatite; but the

situation is changing (Krigbaum 2003; Loftus & Sealy 2012; France & Owsley 2013). Life history trajectories, whereby stable isotope ratios of enamel apatite are compared to those of bone collagen, offer a method of tracking dietary changes in an individual's life.

3.5.2 Stable nitrogen isotopes

Two isotopes of nitrogen exist in atmospheric nitrogen gas: ^{14}N and ^{15}N. As with carbon isotopes, the lighter ^{14}N is the more abundant (99.636%), while ^{15}N comprises only 0.364% (Berglund & Wieser 2011). Most living organisms cannot directly fix nitrogen gas. Atmospheric nitrogen (N_2) is assimilated by nitrogen-fixing bacteria (largely found in the roots of legumes) to produce ammonium (NH_4^+), which is further nitrified into absorbable nitrites (NO_2^-) and nitrates (NO_3^-). In the reverse process called denitrification, fixed nitrogen (NO_2^-, NO_3^-) is converted by bacterial action into N_2 gas and returned to the atmosphere (Lewis 1986). During all of these steps, nitrogen is fractionated, with particularly strong fractionation during denitrification, leading to enrichment of the heavy ^{15}N isotope in the residual pool of reactants.

Atmospheric nitrogen is used as an international reference standard for $^{15}N/^{14}N$ ratios, and has a $\delta^{15}N$ value of 0‰ (Heaton 1987; Keegan 1989; Ambrose 1993; Schoeller 1999). Soils and terrestrial plants usually have $\delta^{15}N$ values higher than that of atmospheric N_2, by about +1 to +4‰ depending on aridity, leaching caused by high rainfall, salinity and anoxia (Heaton 1987; Hobbie *et al*. 2000; Pate & Anson 2008).
In marine ecosystems, the overall ratios of $^{15}N/^{14}N$ exceed those found on land, with a large amount of variation. $\delta^{15}N$ values can vary from near 0‰ for nitrogen-fixing organisms to as much as +20‰ for top consumers. This disparity between terrestrial and marine environments is mainly because the twice as much denitrification occurs in the sea as on land (Wada *et al*. 1975). Since denitrification favours ^{14}N, the oceans are left significantly enriched in ^{15}N. In addition, the oceans receive terrestrial runoff that contains isotopically enriched nitrogenous compounds.

With regards to freshwater systems, as they pertain to the current research area along the lakes and rivers in the Upemba Depression, $\delta^{15}N$ values in freshwater ecosystems

tend to be higher than those in terrestrial systems. It is expected, therefore, that the people living along these freshwater bodies and subsisting on freshwater resources would have high $\delta^{15}N$ (Dufour *et al*. 1999; Katzenberg & Weber 1999; van der Merwe *et al*. 2003).

A significant stepwise enrichment of approximately +2 to +4‰ in $\delta^{15}N$ exists as one moves up the trophic levels in terrestrial food chains, from plants to herbivores to carnivores (Ambrose 1991; Tieszen & Fagre 1993; Sponheimer *et al*. 2003; Robbins *et al*. 2005; Hedges & Reynard 2007). This stepwise increase is due to fractionation favouring the incorporation of heavier ^{15}N during protein synthesis while the lighter ^{14}N is preferentially excreted (Schoeller 1999). Due to this trophic shift, stable isotope analyses can be used to differentiate between herbivores and carnivores, as well as to reconstruct the contributions of animal protein in ancient human diets (Schoeninger & DeNiro 1984; Kellner & Schoeninger 2008).
In hot and dry environments, however, the effect of climate on nitrogen isotopes obscures the distinction between herbivores and carnivores (Ambrose 1991). This is possibly related to the excretion of higher concentrations of urea by animals, in an attempt to conserve body water in arid conditions and under water stress. Urea, which is the main end product of protein metabolism, is excreted from the body through urine and faecal matter of animals. A small quantity of nitrogen is lost through sweat. Because urea is depleted in ^{15}N compared to the diet, animal tissues are enriched in ^{15}N (Ambrose & DeNiro 1986; Hedges & Reynard 2007). Therefore, the high variation in $\delta^{15}N$ values of herbivores observed in different environments, led to the consideration of other factors influencing nitrogen isotopes in bone collagen (Sealy *et al*. 1987). Heaton *et al*. (1986) pointed out that $\delta^{15}N$ values in herbivores and prehistoric humans in areas of southern Africa receiving less than 400mm of annual rainfall are enriched, suggesting a relationship between $\delta^{15}N$ and climate.

The model for nitrogen isotope enrichment with trophic level predicts that humans eating only plant protein will have $\delta^{15}N$ values similar to herbivores and that those feeding on herbivore protein will have $\delta^{15}N$ values similar to herbivores plus enrichment of between 3 and 5‰. For example, the $^{15}N/^{14}N$ ratios of pastoralists in east African savannah and the nineteenth century Griqua in the Orange Free State, South Africa, were ≥ 13‰ (Ambrose 1986). In contrast, the Kikuyu in Kenya and the

Later Iron Age communities of the northern Transvaal, South Africa, had $\delta^{15}N$ values of ≤10‰ (Ambrose 1986). Although this may likely be an aridity effect, the more enriched values of the pastoralists may be reflecting higher trophic levels related to an emphasis on animal foods. It is important to note that these nitrogen isotope distinctions between farmers and pastoralists are not always achieved. Firstly, $\delta^{15}N$ values of cereals and legumes that humans feed on might be significantly different from $\delta^{15}N$ values of herbivore diets. Secondly, metabolism and physiological challenges of nitrogen assimilation and excretion between herbivores and humans might result in different $\delta^{15}N$ values between the two (Hedges & Reynard 2007). Mechanisms responsible for variations in nitrogen isotopes in mammalian food webs are not well understood (Pate & Anson 2008; Hedges & Reynard 2007). High protein diets are thought to result in ^{15}N-enriched consumer tissues. However, it is unclear whether increased protein intake results in increased protein metabolism and urea production (Hedges & Reynard 2007).

Marine and freshwater plants have higher $^{15}N/^{14}N$ ratios than terrestrial plants (Ambrose 1991) and these differences are carried up the food chain (Schoeninger *et al*. 1983; Schoeninger & DeNiro 1984; Hedges & Reynard 2007). Freshwater fish $\delta^{15}N$ values are 3-6‰ enriched while marine fish $\delta^{15}N$ values are ~8‰ more positive than values for terrestrial meat and milk (Schoeninger & DeNiro 1984; Hedges & Reynard 2007). Thus, it is expected that the humans sampled in this thesis might show increased $\delta^{15}N$ due to the consumption of freshwater resources (fish and reptiles) as supported by the archaeological record (see Chapter 2 for details).

3.5.3 Stable oxygen isotopes

Oxygen has three stable isotopes, of which two are important to palaeodietary studies: ^{16}O and ^{18}O, with abundances of 99.757% and 0.205% respectively (Berglund & Wieser 2011). Oxygen isotope ratios in water vary according to differences in the physical and biological environment and local meteoric precipitation (Dansgaard 1964; Luz *et al*. 1984; Kohn *et al*. 1996). Geo-physical factors have also been shown to affect the $\delta^{18}O$ of meteoric precipitation. An inverse relationship exists between $\delta^{18}O$ of meteoric precipitation and distance from the sea, altitude and low temperature (Yurtsever & Gat 1981). Oxygen isotopes in animals (and humans) have most

frequently been measured in bone and enamel apatite in either phosphate (PO_4) or carbonate (CO_3). $\delta^{18}O$ of both phosphate and carbonate correlate with that of body water (Luz *et al*. 1984; Iacumin *et al*. 1996), although $\delta^{18}O_{carbonate}$ is significantly more enriched than $\delta^{18}O_{phosphate}$. In animals, drinking behaviour, diet, body temperature, respiration, urination, defecation and sweating affect the oxygen isotope composition of their tissues. All these processes together determine the total $^{18}O/^{16}O$ ratio of an animal's body water (Kohn 1996; Sponheimer & Lee-Thorp 1999; Lee-Thorp 2008; Dupras & Schwarcz 2001). Water lost in liquid form as in urine, faeces, and sweat has an isotopic composition similar to body water, whereas water lost as vapour is depleted in ^{18}O (Wong *et al*. 1988).

In the food chain, carnivores are generally more depleted in ^{18}O than herbivores. It is not completely understood why this is the case, but there is some evidence to suggest that proteins are less enriched in ^{18}O than carbohydrates (Tredget *et al*. 1993; Kohn 1996). Other scholars have suggested that the body water of the ingested prey may be depleted in ^{18}O compared to plant water ingested by most herbivores (Sponheimer & Lee-Thorp 2001). Browsing herbivores are more enriched than grazers because plant leaves tend to be more enriched in ^{18}O than stems or roots (Kohn *et al*. 1996; Cerling *et al*. 1997; Sponheimer & Lee-Thorp 1999). Most browser species are less dependent on drinking water as they get much of their moisture from their food, while grazers drink more water in comparison. The oxygen isotope composition of both food and drinking water is highly variable, but tends to track local $^{18}O/^{16}O$ ratios of environmental (meteoric or recycled) water. For these reasons, oxygen isotopes can be used to trace ecological origins or migrations of animals and humans. The potential for oxygen isotopes as tracers is, however, complicated by the behaviour and nature of water, i.e. sources and movements of water are complex (Dansgaard 1964; Kohn *et al*. 1996). $^{18}O/^{16}O$ ratios are presented using the delta (δ) notation, and the international standards used are VSMOW (Vienna Standard Mean Ocean Water) and PDB.

Expected $\delta^{18}O$ ratios from the current study area: The physical environment of the study area has been described in Chapter 2. Based on the characteristics of the Upemba Depression, $^{18}O/^{16}O$ ratios are expected to be low as the archaeological sites are more than 1400km from the sea, with an elevation of more than 600m above sea

level. The (mean annual) temperatures are moderate to high, and ranging from 8°C to 30°C (Hughes *et al*. 1992; www.worldclimateguide.co.uk). Using a Regionalized Climatic Water Isotope Prediction (RCWIP) approach, based on the Global Network for Isotopes in Precipitation (GNIP), to predict point- and large-scale spatiotemporal patterns of the stable isotope compositions of water (δ^2H, $\delta^{18}O$) in precipitation, the predicted amount-weighted $\delta^{18}O$ of annual precipitation for the southern part of the DRC ranges between -5.9 and -3.0‰, relative to VSMOW (Terzer *et al*. 2013).

3.5.4 Applications of stable isotopes to palaeodiets in Africa

Archaeological remains from early Iron Age sites in Africa indicate evidence for a variety of subsistence strategies including farming, herding and/or foraging, but the relative contributions of any one of these economies is still unclear. For example, some of the distinctions often made based on evidence from archaeology and ethnography are those between Western and Eastern African farming groups (de Maret 1982, 1985a, Fagan *et al*. 1969; Inskeep 1978; Mitchell 2002; Phillipson 1995, 2005). Agricultural groups from West Africa were thought to rely more on wild resources, including fishing and hunting, as well as gathering and cultivating yams and legumes. Groups from East Africa, on the other hand, supposedly relied more heavily on domesticated livestock (sheep, goats, and cattle), and agricultural crops (such as millet and sorghum); while wild resources were exploited to a lesser degree (Stahl 1984; Phillipson 1995).

So, how do we go about reconstructing actual diets of past peoples? The use of stable isotope analysis in archaeological human skeletal remains has greatly enhanced our ability to characterise past human diets on a more direct individual level, compared to the general, group-oriented evidence provided by archaeological material remains (Ambrose 1993; Larsen 1997, 2002). Stable isotope research in East and southern Africa has made significant contributions to our understanding of the subsistence of prehistoric peoples in these regions (Ambrose 1986; Sealy 1986, 2006, 2010; Sealy & van der Merwe 1985, 1986, 1988; Lee-Thorp *et al*. 1993; Gilbert 1995; Cerling *et al*. 2003; Murphy 1996; Kiura 2008; Mosothwane 2010; Ribot *et al*. 2010; to mention a few).

In addition to stable isotope analyses of archaeological remains, results from ethnographic investigations have offered insights into past human diets. The potential to reconstruct and interpret past diets from archaeological remains depends on our ability to interpret them, at times, using known examples from ethnographic and experimental studies (Kiura 2008; Ambrose 1986; Froment & Ambrose 1995; Codron *et al*. 2008). For example, in a project that combined ethnographic and stable isotope study of hair samples from three modern groups in northern Kenya, Kiura (2008) was able to establish a carbon and nitrogen isotope framework within which to interpret the dietary behaviour and subsistence strategy of Holocene people living in Koobi Fora. With their varied diets, the Dassanech (animal husbandry, farming and fishing); Gabra (pastoralists); and El-molo (fishermen) people in the Marsabit District east of Lake Turkana provided an excellent example of people exploiting different resources in the same area. The ethnographic data of their diets were well matched by the data from stable isotopes of the hair (Kiura 2008).

The first surveys that applied stable isotopes to southern African Iron Age humans were those of Ambrose (1986) and Lee-Thorp *et al*. (1993). Lee-Thorp *et al*. (1993) found considerable variability in $\delta^{13}C$ and $\delta^{15}N$ values of bone collagen, which reflected adaptations to local environments by Iron Age farmers and that Iron Age diets were not uniform (Lee-Thorp *et al*. 1993). Comparing between two Middle Iron Age sites from the same biome also showed distinct results; people at Skutwater (-11.3‰ ± 0.8, n = 5) had a heavier reliance on C_3 resources (probably from wild game) when compared to those from Bambandyanalo (-10.4‰ ± 1.3, n = 13) (Lee-Thorp *et al*. 1993). Another example from the Iron Age of southern Africa, involves an investigation into the diets of early farming and herding peoples in Botswana and Zambia (Murphy 1996). The surprisingly minor differences in the bone collagen and apatite isotope values from all the sites indicated that both herders and farmers relied heavily on C_4 resources, most likely domesticated cereals such as sorghum and millet and animal products from grazing animals. While no sites had evidence of specialised pastoral adaptations, some sites in Botswana (Kgaswe and Taukome) showed heavier reliance on animal products than others (Isamu Pati, Simbusenga, Ingombe Ilede in Zambia) (Murphy 1996).

Setting out to investigate the "Kalahari Debate", which argues that some Later Stone Age (LSA) hunter-gatherers altered their mode of subsistence from hunting and gathering to farming as they were incorporated into farmers' settlements, Mosothwane (2010) used stable isotope analyses to assess prehistoric dietary changes in the Kalahari. Individuals who shifted from hunting and gathering to farming were expected to have more negative (from C_3 sources) enamel apatite $\delta^{13}C_{ap}$ values and less negative (from C_4 sources) bone collagen $\delta^{13}C$ values. Of the 81 humans analysed for dietary change, only four indicated a shift from foraging to farming. The results of this study offer some support for the argument that some LSA hunter-gatherers had adopted a farming way of life (Mosothwane 2010).

Lastly, dietary differences between men and women are known to exist in contemporary African populations (Carr 1991; http://www.diet.com/g/african-diet). Evidence of sex-based differences in diet has come mainly from dental diseases (caries, AMTL and periodontitis), with females frequently showing higher rates than their male counterparts (Walker & Hewlett 1990). These differences have been linked to sexual division of labour, which intensified with the adoption of agriculture (Larsen *et al*. 1991. See section 3.4 above for more details of this argument). To date, no studies have reported evidence of this discrepancy from stable isotope analyses of agricultural populations in Africa. Examples of isotope studies showing differences between sexes do exist elsewhere (Kusaka *et al*. 2010; Ambrose *et al*. 2003). For example, the community at Cahokia Mound 72 (ca. AD1050-1150) showed significant differences in $\delta^{13}C$ and $\delta^{15}N$ values for the low-status females buried in mass graves when compared to the high-status males in this site (Ambrose *et al*. 2003). Based on apatite carbon isotopes, the females in mass graves had around 60% more maize and less animal protein in their diets than the high-status individuals.

3.5.5 Use of stable isotopes in tracking movement patterns and origins

Since the current research was concerned with investigating people's migratory patterns and origins, it is necessary to review studies that have successfully distinguished locals from non-locals using analyses of stable isotopes. In essence, most (if not all) of the stable isotopes commonly used to reconstruct diet (carbon, nitrogen and oxygen) can also be used to trace movement or origin of an animal or

human, if the individual has moved from a habitat (or diet) with one isotopic 'signature' to another that is significantly different. Such changes can be recognised by comparing isotope ratios of tissues formed at different stages of life. Examples include collagen from cancellous bone (recently formed) and cortical bone (averaged over a longer time period) or bone collagen and enamel apatite (Sealy *et al*. 1993, 1995; Cox *et al*. 2001; Hobson 1999; Dupras & Schwarcz 2001; Tafuri *et al*. 2006; Laffoon *et al*. 2013; and Goodman *et al*. 2004), and bone density fractionation (Bell *et al*. 2001). This study uses bone collagen and enamel apatite of early- and late-developing teeth to determine isotopic life trajectories in order to differentiate locals from non-locals.

3.6 Dental Modification

Dental modification is the intentional alteration of the natural shape or appearance of teeth, achieved by removing parts of or an entire tooth. Modifications are largely restricted to the anterior teeth (incisors and canines), for obvious reasons such as easy access for manipulation and because they are the most visible teeth when the mouth is opened.

A. Archaeological evidence of tooth modification

Intentional dental decoration and modifications on anterior teeth have been have been a feature of a great variety of cultures worldwide. Examples of such interventions in prehistory exist in southeast Asia (Hudson 2003), Africa (Finukane *et al*. 2008), pre-Columbian America (Rubín de la Borbolla 1940; Romero 1970; Tiesler 2002; Williams & White 2006), and Europe (Arcini 2005) (see also Milner & Larsen 1991 for a review). Mayan tooth modifications consisted of surface grooves, occlusal notches and filings, and inlays of jade, turquoise or pyrite. This practice dates from AD 500-900 (Rubín de la Borbolla 1940; Romero 1970; Tiesler 2002; Williams & White 2006). In Halin (Burma) in the 7th century AD, there is a burial in which the upper incisors were decorated by the insertion of several golden inlays into small perforations cut into the enamel (Hudson 2003).

In Africa, this practice existed in the third millennium BC in West Africa (Finukane *et al*. 2008). Four females from the site of Karkarichinkat in the southern Tilemsi

Valley of Mali exhibit upper incisors and canines filed to points. This is the earliest known evidence of modified human teeth from West Africa (Finukane *et al*. 2008). An earlier case of possible intentional extraction of central maxillary, and occasionally mandibular, incisors comes from North African sites assigned to the Later Stone Age (between 40 000 and 5 000 BP). Skulls recovered from several areas including the Magreb, Afalou and Mechta show signs of intentional evulsion (Briggs 1955). Though inconclusive, it appears that intentional tooth extractions came before filing or chipping.

More examples of this practice in prehistoric Africa come from skeletal populations from archaeological sites such as K2/Mapungubwe (Steyn 1994), KwaGandaganda and Nanda (Morris 1993) in South Africa, Mtemankhokwe in Malawi (Morris 1993), Sanga and Malemba-Nkulu in the DRC (Murphy 1996; Dlamini 2006), Ingombe Ilede and Isamu Pati in Zambia (Murphy 1996), and Toutswe in Botswana (Mosothwane 2003). Both tooth extractions and filing or chipping were commonly done in these societies. Extraction of all lower incisors appears to have been the preferred style in South Africa and in the DRC (Dlamini 2006). In Zambia and Malawi, extraction of the upper incisors was favoured (Morris 1993; Dlamini 2006). Filing of teeth into points was common in South Africa and in the DRC. At Ingombe Ilede in Zambia, filing of the mesial corners of the upper central incisors was the style of choice (Dlamini 2006). Therefore, it is reasonable to say that a wide variety of forms of tooth modification were practised in prehistoric Africa.

B. Distribution of historical and modern practices

Dental modification is particularly variable in the historic period in the DRC, as noted by Konnild (1987: 115) during his travels in that part of the continent between 1950 and 1960: "A special concentration of all types of dental mutilations is to be found in Zaïre, the former Belgian Congo". In his ethnographic surveys from the DRC, Starr (1909) recorded 102 different styles of tooth modifications (Figures 3.03 to 3.05). This survey covered nearly 900 people from more than 20 different ethic groups, spread over all eleven districts/provinces of present-day DRC. Starr reported that the practice of tooth modification was less common among the Bakongo of the lower Congo River in the northwest part of the country. It was ubiquitous and diverse

among most tribes in the upper Congo River. There appears to be no obvious pattern to the geographical distribution of styles, although some neighbouring groups share similar styles. For example, style 73 (Figure 3.05) occurred among the Bwaka of the Ubangi region in the northwest, among the Baluba of the southeastern Katanga Province and among the Wangata of Equateur District in the northwest.

Although Starr (1909) recorded 102 different styles, many were variations of a similar theme. He noted that the combination styles (a mix of extraction and filing or chipping) were usually found among the peoples in the same districts where parts of their elements occur alone. Among the Baluba, who are a central focus in this study, Starr (1909) recoded as many as 19 different styles. These include extraction styles 1; 3; 4 (Figure 3.03); chipping or filing styles 16; 17; 25; 26; 35; 36; 37; 44; 51 (Figure 3.04); and combination styles 63; 65; 68; 70; 72; 73; 76 (Figure 3.05).

The archaeological record of Katanga has demonstrated that the practice of modifying teeth can be traced back as far as the 8th century AD. Skeletal remains of individuals dating to the Ancient Kisalian (AD 700 – 900) period at Sanga and neighbouring sites exhibited teeth that were intentionally chipped, filed, or extracted during life (Nenquin 1967; de Maret 1985a, 1992). Of the 19 different styles observed by Starr (1909) in 1905-6 among the Baluba, only three have been recorded in the archaeological remains from the Upemba Depression (Dlamini 2006). These include the chipping or filing into points of all upper or all lower incisors (Styles 37, 44 and 70 in Figure 3.04), and the extraction of all lower incisors (Styles 4, 7 and 10 in Figure 3.03) (see also Dlamini 2006).

The styles seen in Katanga are, however, not unique to the Baluba or even the other groups in the DRC. Other groups elsewhere in Africa and beyond very often share them. In fact, these and other similar styles have been seen throughout the world where dental modifications have been observed. In Africa, for example, groups that file their teeth to points are so numerous that the majority of populations could very well have performed the style. They have been seen among the M'baka, Houssa of West-Central Africa (Konnild 1987; dianabuja.wordpress.com); the Wakamba, Wawiya/Mawiya, Zanaki, Makonde of East Africa (Konnild 1987); and the Chokwe, Lamba, Luvale, Mbunda, Zulu, Xhosa of southern Africa (Jones 1992; van Reenen &

Briedenhann 1986; Shaw 1931). Farther afield, the same style of filing teeth to points has been recorded among the pre-Columbian inhabitants of Central America (Romero 1970; Rubín de la Borbolla 1940), and the Mentawai people of Indonesia (www.nativeplanet.org).

According to Starr's encounters in the Congo, the practice of modifying teeth was done predominantly by men and occasionally done by women. Demonstration of bravery was cited as one of the reasons for men to modify their teeth, especially extractions or evulsions. Contrary to Starr's observation, the practice of modifying teeth appears to be equally performed in both men and women. Among the Nilotic peoples of Sudan, Kenya, and Uganda, it is the general rule that the incisor teeth of both sexes are extracted before puberty (Konnild 1987). In an essay on "the cultural history of tooth mutilation in Africa", 55 groups were found to perform 'mutilations' on both men and women, in one only men were treated, and in two women only were affected (Hownam-Meek, n.d).

C. Reasons for modifying teeth

One of the biggest challenges of studying tooth modifications in archaeological remains is the difficulty of knowing the reasons for practising this custom. Extensions of modern cultural practices onto ancient cultures provide some possible answers, though they cannot be conclusive. One certainty is that the practice of tooth modification does not have a single universal explanation. Its diversity and wide global distribution make this custom a likely candidate for dispersal through cultural or linguistic diffusion, as well as spontaneous innovation at different places around the globe (Jones 1992).

According to Alt and Pichler (1998), reasons for modifying teeth can be divided into two categories, i.e. those of fashion or popular beliefs (active) and those sanctioned by society (passive). Those sanctioned by society tend to be enduring and conservative since they become part of the social structure. They can also be the most reliable for tracing relationships between people of different cultures (van Reenen 1978). In contrast, fashion-driven reasons are subject to rapid change and high variability. One of the examples of reasons sanctioned by society include tribal or

ethnic markings, which was the primary concern for this study in using tooth modification to distinguish locals from outsiders in the Upemba Depression. If tooth modifications were used as ethnic markers, one would expect uniformity in style, and consistency across all members of the group. Exceptions have also been encountered; for example, royal family members among the Shilluk are exempt from removing their lower incisors (Konnild 1987). Van Reenen's (1986) work on the modern tribes of Namibia provides a classic example of tooth modification as tribal marker. Groups such as the Chokwe, Wanyemba, Ovambo and Herero (to mention a few) adopted individual styles to differentiate themselves from their neighbours.

Another example of a socially-driven reason for modifying teeth is linked to language. Some Nilotic speakers such as the Dinka, Nuer and Shilluk maintain that extracting their lower incisors (and sometimes canines) is done in order to speak their languages 'properly' (Konnild 1987). A more recognized reason influenced by society involves initiation rituals or rites of passage, which are usually performed in large groups. Among the Moru, Pojulu, Kuku, Bari (and other) tribes of south Sudan, both girls and boys remove their lower teeth around puberty, for reasons ranging from fear of growing up sterile to sexual attraction and bravery (Konnild 1987). This is tightly linked to the timing of when the modifications are done. Depending on the reason behind the modifications, the timing of the operation varies from childhood to adulthood. Most society driven modifications are done at a younger age in comparison to those that are individually motivated (Starr 1909; Konnild 1987).

On the contrary, more actively pursued modifications are done predominantly as a fashion statement - an individual caprice. These can be performed at any time, but mainly before marriage as a form of beautification. According to the Ntumba (Bantomba) men of the Equateur Province in the DRC, the modifications are done because "no girl would marry them unless their teeth were made beautiful" (Starr 1909: 116). This is similar to what the Lokele of the Ubangi district (DRC) say about their modifications, i.e. they are done around the time of courting (Starr 1909). Both these groups have a wide spectrum of styles, confirming the individuality of the practice.

Looking at the historic-modern Baluba of Katanga in the DRC, the most probable reason for tooth modification seems to be fashion. The diversity of styles seen by Starr (1909) is suggestive of a people who practise this custom for aesthetic purposes. The notion of beautification is important among the Baluba: Nooter Roberts & Roberts (2007) describe how, in Katanga province, their elaborate *coiffure* or hairstyles were a well known trademark of these people. These styles were so elaborate that they required copper hairpins similar to examples recovered from Iron Age graves in Katanga (de Maret 1985a, 1992).

The second most probable reason for dental modifications among historic-modern Baluba, is as part of a rite of passage. Starr (1909) mentions that the modifications were performed in early manhood to demonstrate a man's disregard for pain and were thus a sign or test of bravery. This lends some support to the rite of passage model. Starr (1909) does, however, have this to say about the custom of tooth modification in the Congo as a whole: "It is generally considered a 'tribal mark' but it seemed to us to be often a family custom, or even an individual caprice" (Starr 1909: 115).

Tooth modifications are still practiced by present-day South Africans in the Western Cape (Friedling & Morris 2005, 2007). These take the form of tooth evulsions, most commonly involving all four upper incisors. The least frequent style is the extraction of only the central lower incisors. Reasons range from peer pressure and fashion statement to gangsterism and medical purposes (Friedling & Morris 2005, 2007).
Although true that the practice of tooth modification is diminishing, it is interesting that in majority of places where the practice has been found in antiquity or historically, it has not entirely died out. With the exception of the Maghreb in North Africa - where the earliest evidence for tooth extraction is found – no other area has revealed complete obliteration of the custom (see Gould *et al*. 1984 for examples in the 20th century). Overall, tooth extraction has been the most affected by the declining trend of tooth modification. This has been attributed to the loss of formal social sanctions in place of personal preference for the practice (Jones 1992).

So common is the practice that it is represented even in art. At the ethnographic exhibition at the Museum for Central Africa, Tervuren, a number of masks and figurines belonging to a wide variety of ethnic groups from the DRC show dental

modifications of one kind or another (personal observation; Tervuren, Brussels 2009). Konnild (1987: 126-129) also points to the ethnographic representation of tooth modification in the masks of some Congo groups seen at the Royal Museum for Central Africa in Tervuren. Once again, this is not only restricted to the people of the Congo, but also noted among the Zezuri and Mbunda of the Zambezi area (Konnild 1987: 140-141). Therefore, the broad distribution and diversity of the styles complicate the use of this practice as a means to identify people. However, examples of successful use of tooth modification in distinguishing locals from non-locals exist (Cox & Sealy 1997; Cox *et al*. 2001; Tiesler 2002; Haour & Pearson 2005).

Using stable isotope analyses and tooth modification, Cox *et al*. (2001) were able to distinguish between foreign and local people buried in Cobern Street, an 18-19th century cemetery in Cape Town. They concluded that individuals with modified teeth had come from tropical regions, likely Mozambique, as indicated by their enriched $\delta^{13}C$ values in body tissues that record childhood diet, and distinct tooth modifications resembling those of African populations targeted by slavers: namely the Makua, Yao and Maravi people (Cox *et al*. 2001). This study also uses tooth modification to assess the biological continuity or relatedness of the people living in the Upemba Depression between AD 700 and 1800.

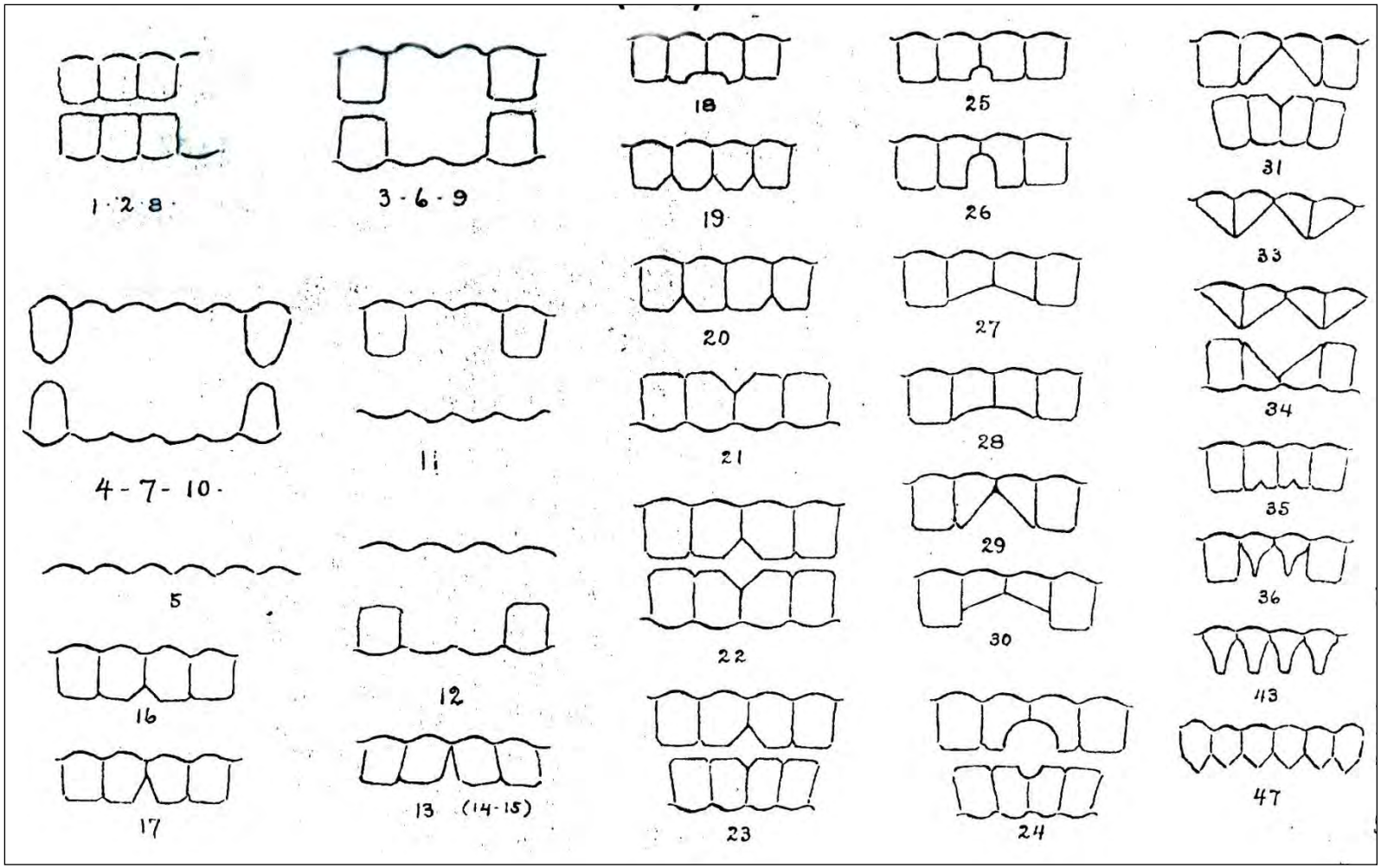


Figure 3.03: Dental modification styles seen and recorded by Frederick Starr in the DRC (formerly the Congo Free State) in 1905-6 (Starr 1909: 119).

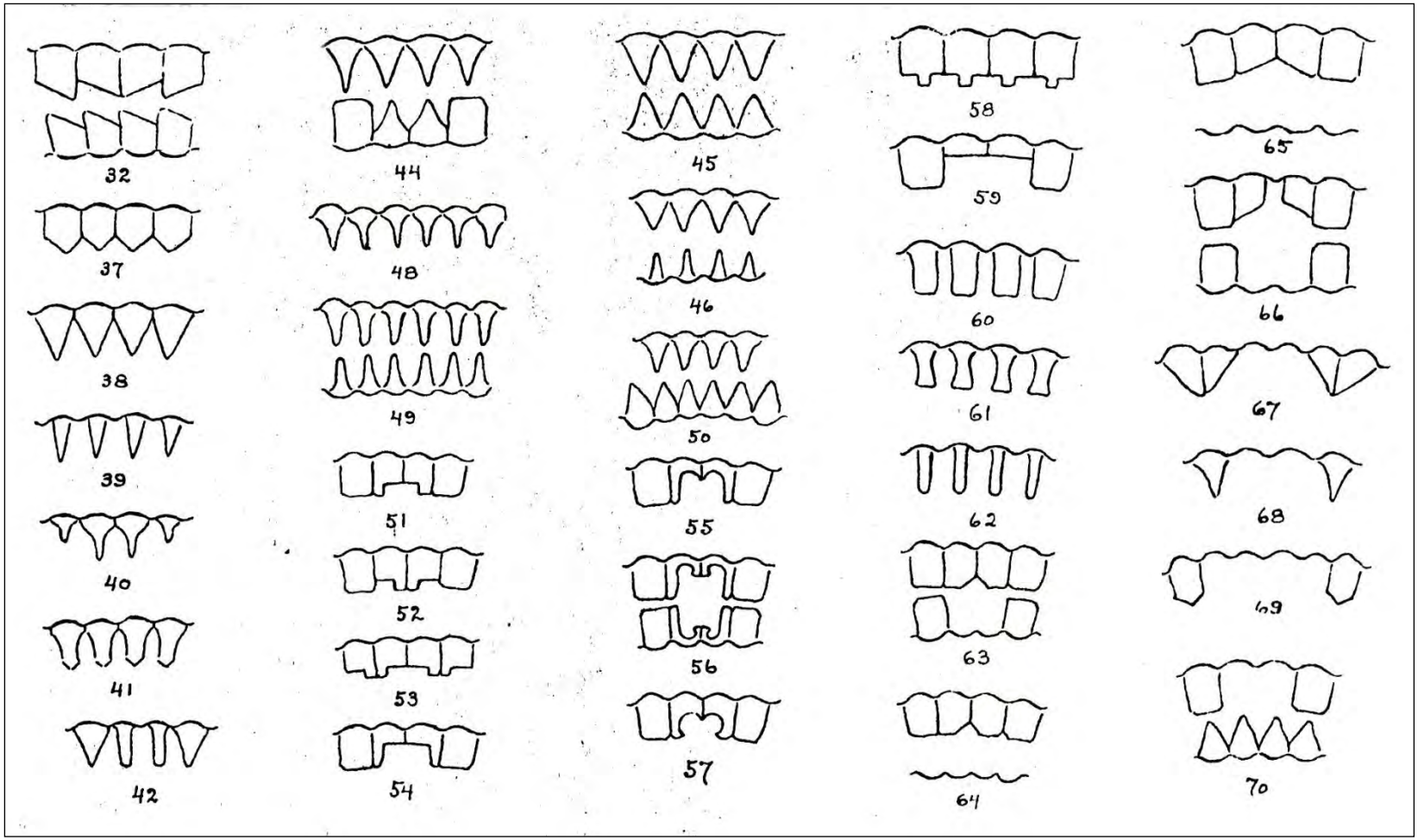


Figure 3.04: Dental modification styles seen and recorded by Frederick Starr in the DRC (formerly the Congo Free State) in 1905-6 (Starr 1909: 121).

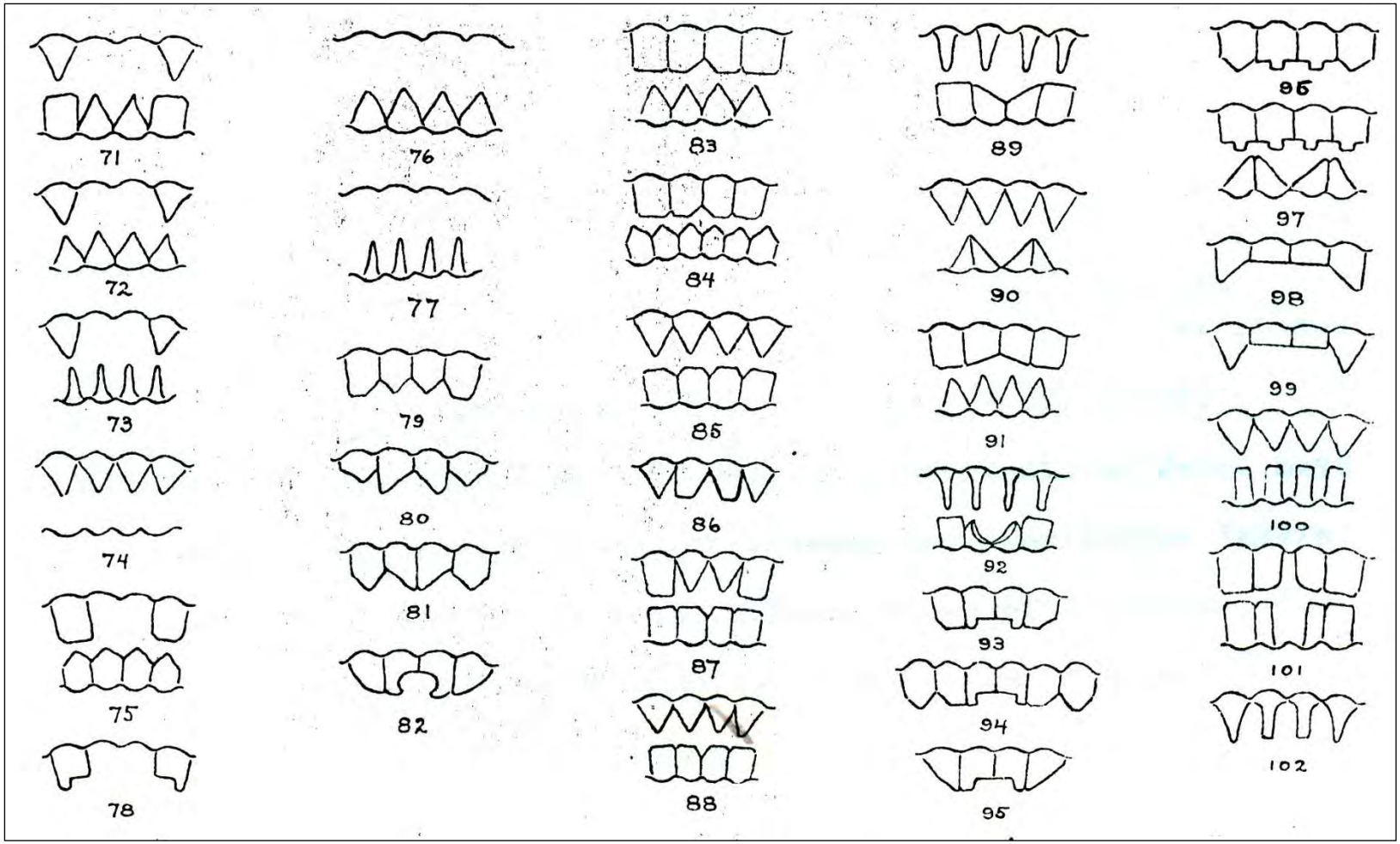


Figure 3.05: Dental modification styles seen and recorded by Frederick Starr in the DRC (formerly the Congo Free State) in 1905-6 (Starr 1909: 123).

Chapter 4: MATERIALS & METHODS

The archaeological context of the human skeletal remains examined in this study is given in Chapter 2. The first part of this chapter describes the sample of human remains chosen for inclusion in this study, and explains how they were selected. Not all individuals were suitable for all aspects of this project, so the factors involved in taking samples for analysis of stable isotopes and dental calculus are outlined. The second part outlines the methods used to examine the skeletal remains. First, sex and age were estimated for each skeleton, except for fragmentary or incomplete remains. This was followed by recording and scoring for dental diseases, sampling and preparation of dental calculus for phytolith analysis, as well as sampling and preparation of skeletal tissues for carbon, nitrogen and oxygen isotope analyses.

4.1 The human skeletal sample

The sample consists of early and late farming communities (Iron Age) from six archaeological sites in the Upemba Depression, in the Katanga Province of the Democratic Republic of Congo (DRC). The sites are located along the confluence of the Upper Congo River and its associated lakes. The skeletal remains date to between AD700 and 1800, and were excavated by several different archaeologists (Table 4.01; see Chapter 2 for details). The sample is divided into six chronological periods based on the archaeology and funerary practices (Table 4.02; see Chapter 2 for details). 31 of the 145 skeletons studied here were directly dated by radiocarbon dating of bone (see Table 2.03 in Chapter 2); a few additional dates were obtained from samples of excavated charcoal. Stratigraphy, and associated cultural artefacts such as pottery, was used to date the rest of the burials.

Most of the excavated human remains are curated at three institutions in the DRC and in Belgium: the National Museum of Lubumbashi (NML) in the DRC, the University of Brussels (ULB) and the Royal Belgian Institute for Natural Sciences, Anthropology and Prehistory (RBINS) in Belgium. A few fragments of human remains were found amongst some of the cultural material at the Royal Museum for Central Africa (RMCA) in Tervuren, Belgium. Artefacts from the excavations are stored at the

RMCA and at the NML, in the DRC. The NML curates most of the pottery from the sites, while the RMCA houses the majority of the metal artefacts, mainly from De Maret's excavations. These artefacts were not the focus of this study, but were examined for any associated human and faunal remains.

4.2 Sample size

308 graves were excavated from the sites of Sanga, Katoto, Malemba-Nkulu, Kamilamba, Katongo and Kikulu (Nenquin 1963; Hiernaux *et al*. 1967, 1971; de Maret 1985a, 1992). Some contained more than one skeleton, while others yielded no preserved remains (de Maret 1985a, 1992). The total number of individuals excavated was 317. Table 4.01 shows the number of excavated graves at each site, the number of skeletons exhumed and the number included in the current study.

In some cases, the remains were not sufficiently well-preserved to be included in this study. Some skeletons have lost some skeletal parts post excavation, i.e. while in curation or during post-mortem handling. The latter can clearly be seen when comparing photographs of the *in situ* burials from De Maret's excavations with those taken during the current study (Figures 4.01 and 4.02). Figures 4.03 and 4.04 demonstrate the variability in preservation at Sanga. Both individuals date to the Classic Kisalian period. Less than half of the excavated skeletons were sufficiently well-preserved for inclusion in the current research (Table 4.01).

After the removal of skeletons that did not meet minimum preservation requirement, data were collected from 145 human skeletons curated at the Royal Belgian Institute for Natural Sciences (RBINS), the University of Brussels (ULB) in Belgium, and the National Museum of Lubumbashi (NML) in the Democratic Republic of the Congo (DRC) (Appendix 1, Table 4.01 and 4.02). The majority of the skeletons came from Sanga (n = 64, 44.1%), followed by Katoto (n = 30, 20.7%), Malemba-Nkulu (n = 25, 17.2%), Kikulu (n = 14, 9.7%), and Katongo and Kamilamba (both at n = 6, 4.1%). The details of each site and its particulars can be found in the publications by Nenquin (1963), Hiernaux *et al*. (1967, 1971) and De Maret (1985a, 1992); a summary is also provided in Chapter 2. Details of the steps taken to track down the Upemba Depression human remains and their current locations are presented in Dlamini (2013).

The chronological grouping of the skeletons studied is presented in Table 4.03. The largest proportion of skeletons studied dated to the (Ancient and Classic) Kisalian period (n = 85, 58.6%). Skeletons belonging to the Kabambian (A and B) period made up 28.3% (n = 41) of the total sample. Only five of the 145 (3.4%) skeletons studied belonged to the Recent period. 9.7% of the skeletons included in this study belonged in the Atypical category, which means that they could not be assigned to any time period (de Maret 1985a).

Table 4.01: Excavated graves compared with number of skeletons exhumed at each site. (+17)* refers to skeletons from Katoto that were sampled for isotope analysis, but were not studied in other ways.

Site	No. of excavated graves	No. of skeletons recovered	No. of skeletons included in this study	References
Sanga (1957)	56	56	25	Nenquin (1963)
Sanga (1958)	89	89	25	Hiernaux *et al.* (1971)
Sanga (1974)	31	33	14	De Maret (1985a)
Katoto	47	47	30 (+17)*	Hiernaux *et al.* (1967)
Katongo	12	12	6	De Maret (1985a)
Kamilamba	13	13	6	De Maret (1992)
Kikulu	23	27	14	De Maret (1992)
Malemba-Nkulu	37	40	25	De Maret (1992)
TOTAL	**308**	**317**	**145 (+17)***	**-**

Table 4.02: Number of skeletons in this study held at different institutions, listed by site.

Holding institution	Sanga	Katoto	Malemba-Nkulu	Kamilamba	Katongo	Kikulu	TOTAL
RBINS, Belgium	16	0	0	0	0	0	16
ULB, Belgium	12	0	25	6	6	14	63
NML, DRC	36	30 (+17)*	0	0	0	0	66 (+17)*
TOTAL	**64**	**30 (+17)***	**25**	**6**	**6**	**14**	**145 (+17)***

*Seventeen individuals from Katoto were sampled for isotope analyses only.

Table 4.03: Skeletal remains included in this study, grouped chronologically.

Chronological period	Sanga	Katoto	Malemba-Nkulu	Kamilamba	Katongo	Kikulu	TOTAL
Kisalian	42	30 (+17)	3	4	3	3	**85 (+17)**
Kabambian	8	0	22	2	2	7	**41**
Recent	2	0	0	0	1	2	**5**
Atypical	12	0	0	0	0	2	**14**
TOTAL	**64**	**30 (+17)**	**25**	**6**	**6**	**14**	**145 (+17)**

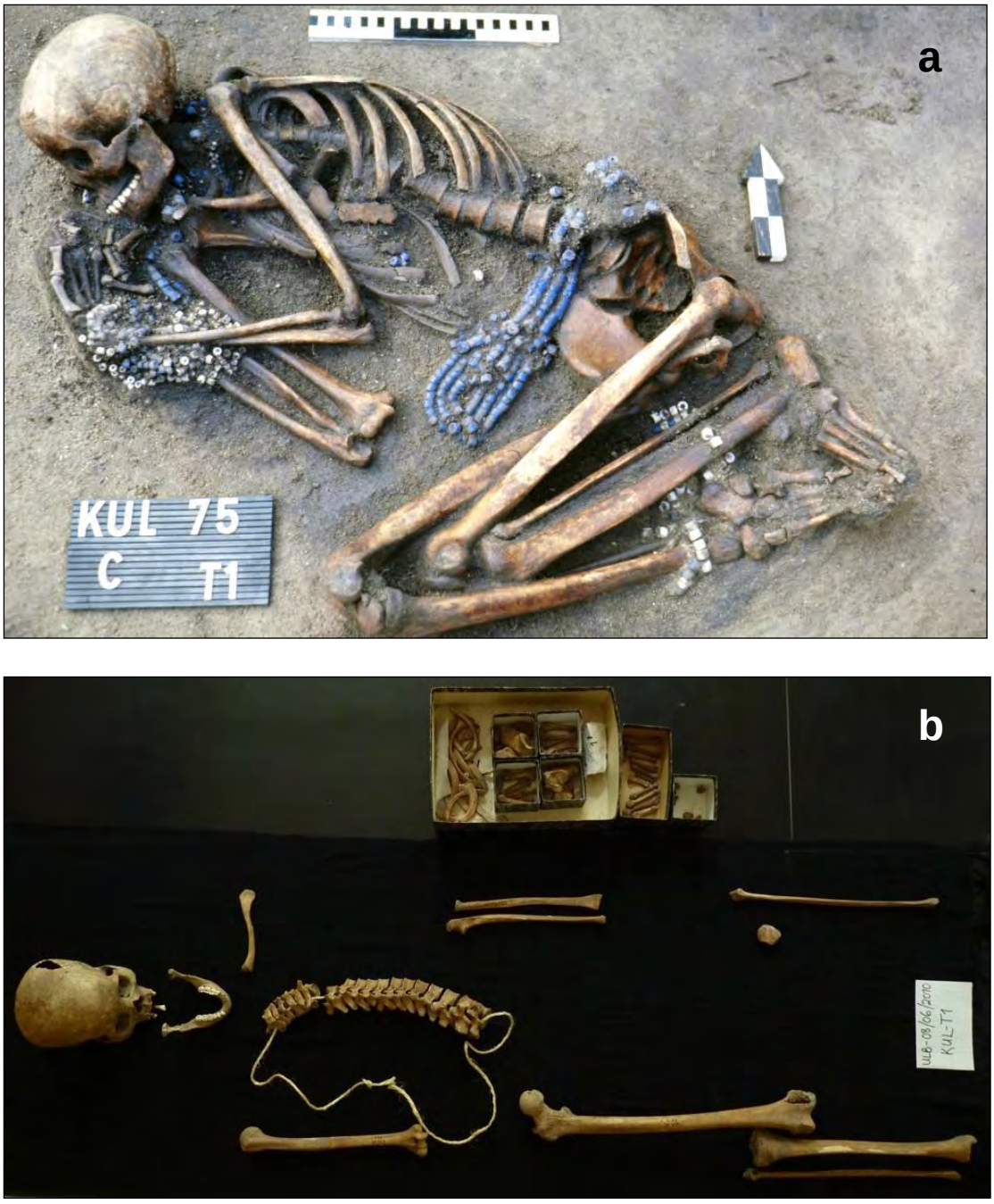


Figure 4.01a & b: (a) Kikulu grave T1 *in situ*, photographed during excavation in 1975 (photograph used with permission from Pierre de Maret), (b) skeletal elements of this individual present at ULB in 2010.

Figure 4.02a & b: (a) Malemba-Nkulu grave T35 (B1) *in situ* photographed during excavation in 1975(photograph used with permission from Pierre de Maret), (b) skeletal elements of this individual present at ULB in 2010.

Figures 4.03 and 4.04: Variation in preservation of human remains seen at Sanga. Grave T172 (left) is very well preserved compared with T175 (right). Both date to the Classic Kisalian. (Photographs used with permission from Pierre de Maret).

4.3 Selection criteria

Teeth were the primary factor for the inclusion or exclusion of skeletons in this project. Individuals were selected, therefore, based on the presence of at least some dental material, i.e. only individuals with teeth were chosen for study. The least complete individual studied was a child aged 3-5 years at death, who was represented by a few loose deciduous and permanent teeth (see Chapter 5 for a description of completeness and preservation). More complete skeletons that could be sexed and aged, as well as provide a large portion of the data required to answer the research questions, were given preference over less complete ones. The skeletons selected include both mature and immature individuals.

4.4 Preservation and completeness

The preservation and condition of each skeleton was recorded in order to cross-check data after recording and before analysis. Clearly, if any data had been recorded for dental and skeletal elements that were missing or damaged, those observations must be in error. Detailed photographic records were also made for the same reason. An adaptation of the method proposed by Bello *et al*. (2006) was used to score the preservation of skeletal parts per skeleton, as follows:

0: absent/missing
1: 5 – 25 % present
2: 25 – 50 % present
3: 50 – 75 % present
4: 75 – 95 % present
5: 100% present

4.5 Estimation of age at death

Dental calcification and eruption times for both deciduous and permanent teeth were used to estimate age at death of infants and juveniles. A standard deviation of three to

six months is added as variations in tooth eruption occur per tooth type and in different populations (Ubelaker 1978). Long-bone epiphyseal closure was also employed, in conjunction with teeth, to age sub-adult individuals when long bones were present (Buikstra & Ubelaker 1994; Suchey *et al*. 1984).

Age at death of adult skeletons was estimated by examining degenerative changes that take place at bone-cartilage joints and symphyses during an individual's lifetime. Sub-adults and younger adults were aged using epiphyseal fusion following the method of Schwartz (1995). The Suchey-Brooks (1990) technique, based on changes in the pubic symphysis, was used to age adult males and females. Cranial suture closure was also employed in differentiating younger from older adults. However, this method was mostly used in conjunction with other aging methods, because of the variability in the fusion of cranial sutures (Brooks 1955). In general, cranial sutures may show signs of obliteration in younger adults, but the process is not as extensive as in older adulthood. The fusion of cranial sutures usually commences with the sagittal suture starts closing between ages 21 and 35 years, followed by the coronal and lambdoid sutures between age 36 and 55 years. Essentially, individuals with completely obliterated coronal and lambdoid sutures are classified as older adults (Anderson & Geiger 1965).

D. Age categories

The sample was divided into six age categories in order to explore possible age-related differences in pathological conditions. Patterns of diseases between groups of individuals within the same age provide better comparative information than specific ages. The age categories are based on the relationship between skeletal changes and chronological age. Age categories (in years) as presented in Morris (1984) were utilised in this project:

Infant: Birth to 5 years

Juvenile: 6 to 15 years

Sub-adult: 16 to 20 years

Younger adult: 21 to 40 years

Older adult: 41 years and above

4.6 Estimation of sex

Adult, and sometimes sub-adult, individuals were assessed for sex, based on sexually dimorphic developmental features. Estimating sex for a juvenile skeleton is difficult because the bony features associated with anatomical sexual dimorphism are usually not fully developed until adulthood. Morphological adulthood is generally reached at about 20 years of age, with complete fusion of long bones; and happens slightly later in men than in women (Buikstra & Ubelaker 1994). However, the sex of sub-adult skeletons can sometimes be estimated. Techniques used to determine sex for the adult skeleton involve multiple criteria, mainly linked to shape, robusticity, and occasionally size.

Features of the pelvis, cranium and sometimes post-cranials were used to assess the sex of an individual (Buikstra & Ubelaker 1994). On the pelvis, features examined include, the pubis, greater sciatic notch, pre-auricular sulcus and general morphology. Figures 4.05 and 4.06 illustrate some of these differences between males and females (Buikstra & Ubelaker 1994). The pubis with observable differences in the pubic symphysis, sub-pubic concavity and the ischio-pubic ramus between males and females is the most reliable region to indicate sex of a skeleton. The greater sciatic notch appears broader in females and narrower in males. Scarring of the pre-auricular surface, which can be caused by parturition, has been recognised as a possible marker to indicate a female.

Often used as supporting elements to the pelvis or used alone if the pelvis is not available, the cranium and mandible offer another dimension in the diagnosis of sex. Robusticity is the key characteristic for the assessment of sex based on the skull and mandible. Landmarks on bone surfaces, such as the nuchal crest, mastoid process, supra-orbital margin, supra-orbital ridge and mental eminence are observed for signs of dimorphism. The emphasis is based on delicate, gracile features for the female, and more pronounced, robust features on the male skull. In figure 4.07, a score of 1 is typically female, whereas 5 would represent a typical male skull (Buikstra & Ubelaker 1994). Where the skeleton was complete, determination of sex was based on all these features for a more accurate estimate.

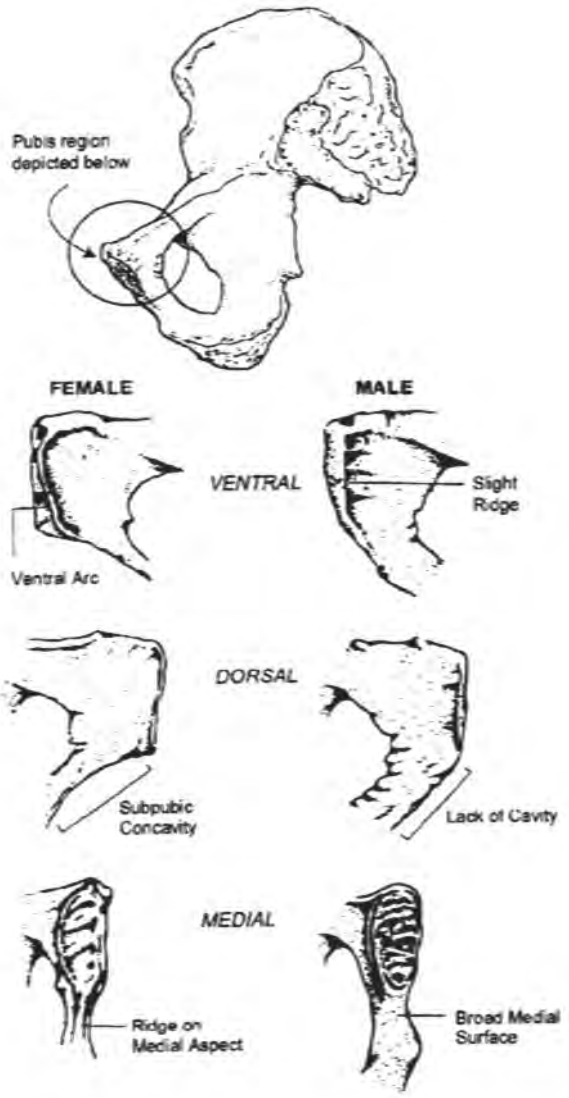


Figure 4.05: Estimation of sex from the pubic symphysis (Buikstra & Ubelaker 1994: 17)

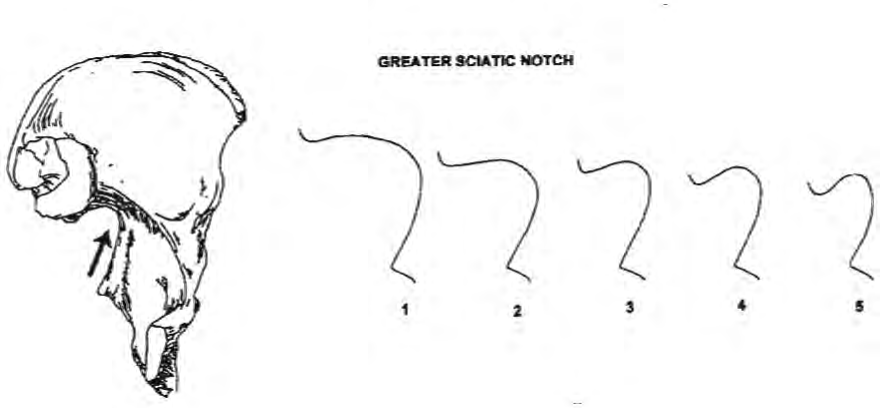


Figure 4.06: Estimation of sex from the sciatic notch (Buikstra & Ubelaker 1994: 18)

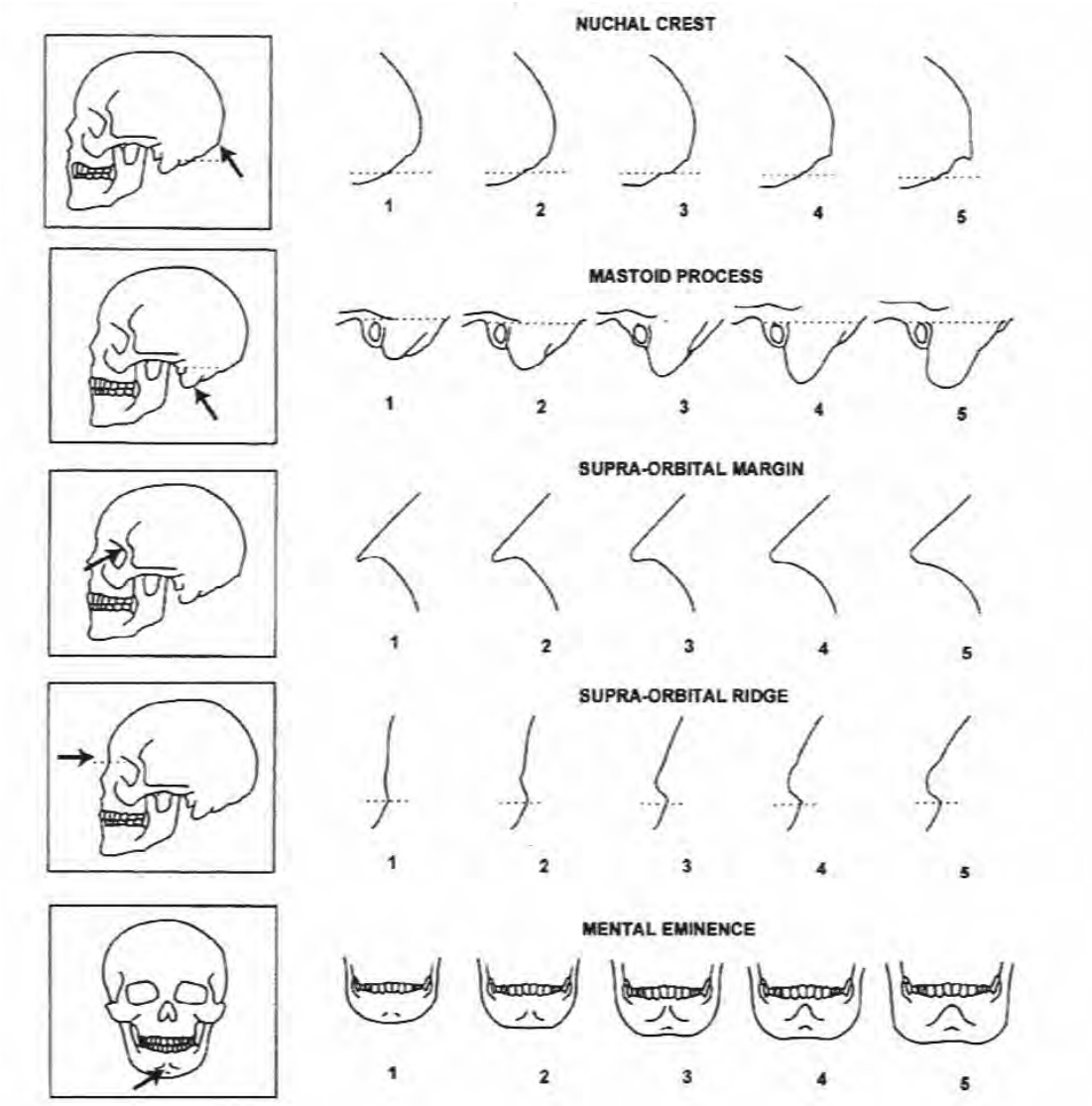


Figure 4.07: Estimation of sex from the skull (Buikstra & Ubelaker 1994: 20).

4.7 Dental morphological traits: metric and non-metric

For the current study, non-metric morphological features of the crowns and roots of permanent teeth were examined and scored. The traits were scored visually in terms of presence or absence, degree of development, and/or form, employing the Arizona State University Dental Anthropology (ASUDA) System (Turner *et al*. 1991; Scott & Turner 1997; Scott 2008). The ASUDA System comprises a set of plaques that serve as standards for the presence or absence, and degree of expression of various traits of the human permanent dentition (see Figures 4.08 and 4.09 for examples). This study examined 39 non-metric morphological traits; 38 from the ASUDA System and one trait (i.e. midline diastema) frequently in sub-Saharan Africans by Irish (1993) (Table 4.04).

These traits were selected in order to enable comparisons with other sub-Saharan African populations cited in Irish (1993), and described by Turner *et al*. (1991). This suite of traits has been shown to be highly group-specific even in populations that are closely related (Hanihara 2008), and was thus chosen to test for genetic similarities or differences within the early inhabitants of the Upemba Depression. Lastly, the large number of traits was chosen in order to best demonstrate population relatedness (Irish 2013; Hanihara 2008; Scott & Turner 1997).

Metric analyses of the permanent posterior dentition were also done. The posterior teeth (premolars and molars) were chosen in order to minimize environmental variation (Dahlberg 1945) and to maximize genotypic coverage (Garn *et al*. 1965, 1966; Moorees & Reed 1964). Maximum mesiodistal and buccolingual crown dimensions were measured using digital Vernier calipers, according to procedures by Moorees (1957) and Hillson (1996). In both metric and non-metric traits analyses, the observations and measurements were done on left and right teeth in order to consider asymmetry. Teeth that were heavily to extremely worn (i.e. grades 3 and 4, see Table 4.07 below for dental wear grades) and those clearly damaged by diseases or non-masticatory behaviours were excluded from analyses of non-metric and metric traits. Since these populations were known agriculturists, occlusal and interproximal wear was expected to be slight to moderate, thus not greatly affect these observations.

Table 4.04: The 39 dental and osseous traits used in the current study, based on the ASUDA system (Turner *et al*. 1991), together with the midline diastema (Irish 1993).

Traits on the maxilla	Traits on the mandible
1. Winging UI1	24. Lingual cusp number LP2
2. Labial curvature UI1	25. Anterior fovea LM1
3. Palatal torus	26. Mandibular torus
4. Shovel UI1	27. Groove pattern LM2
5. Double shovel UI1	28. Rocker jaw
6. Midline diastema UI1	29. Cusp number LM1
7. Interruption groove UI2	30. Cusp number LM2
8. Tuberculum dentale UI2	31. Deflecting wrinkle LM1
9. Canine mesial ridge UC	32. Distal trigonid crest LM1
10. Distal accessory ridge UC	33. Protostylid LM1
11. Hypocone UM2	34. Cusp 7 (metaconulid) LM1
12. Cusp 5 (metaconule) UM1	35. Tome's root LP1
13. Carabelli's trait UM1	36. Root number LC
14. Parastyle UM3	37. Root number LM1
15. Enamel extension UM1	38. Root number LM2
16. Root number UP1	39. Torsomolar angle LM3
17. Root number UM1	
18. Root number UM2	
19. Root number UM3	
20. Peg-shaped UI2	
21. Peg-reduced UM3	
22. Odontome P1-P2	
23. Congenital absence UM3	

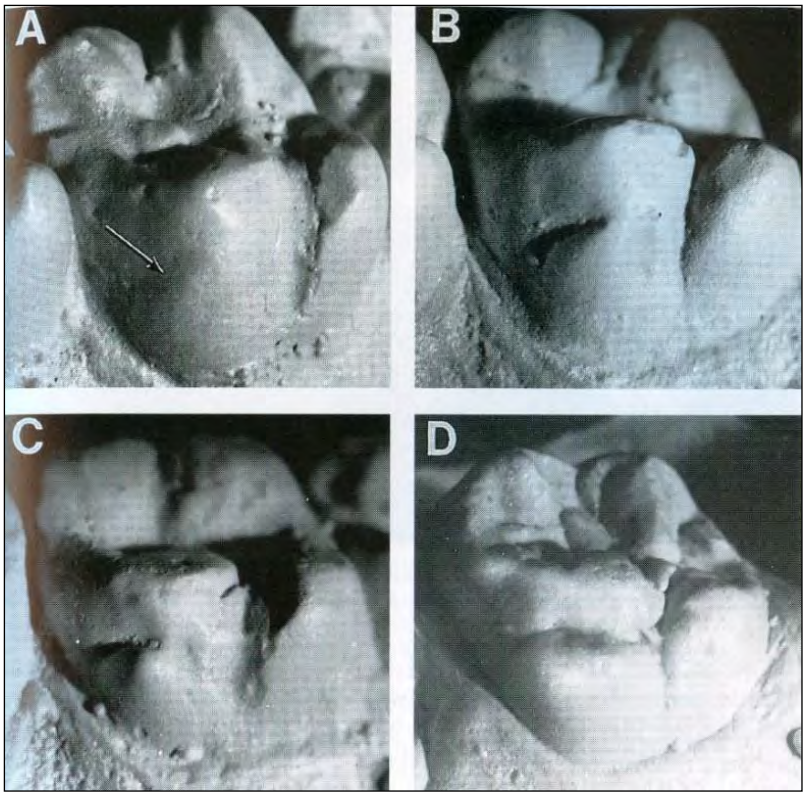


Figure 4.08: Carabelli's trait of the upper molars. (A) the arrow points to an extremely subtle manifestation of Carabelli's trait; (B) intermediate expression; (C) a small tubercle with a free apex; (D) a large cusp with a free apex (Scott & Turner 1997: 43).

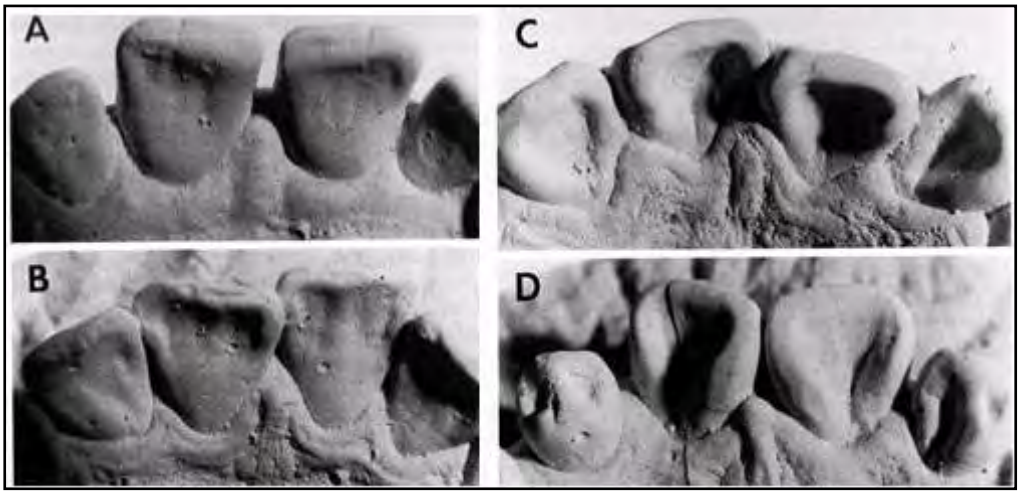


Figure 4.09: Range of variation in shoveling of the upper central incisors. A and B show either no or trace shoveling, while C and D exhibit pronounced shoveling (Scott & Turner 1997: 26).

4.8 Oral health and pathology

Studies of the dentition can contribute to dietary reconstructions since dental wear and pathologies are influenced by the nutritional quality and physical characteristics of food. Aspects of oral health and pathology recorded for this thesis include dental caries, antemortem tooth loss (AMTL), abscesses, calculus and periodontitis. Occlusal attrition or wear was also examined on the permanent dentition of each sub-adult and adult individual. Since dental changes and associated disease processes tend to increase with age, only sub-adult and adult dentitions were examined for signs of pathology and degree of occlusal wear.

Observations on the condition of all teeth and alveoli were done in order to crosscheck the data on all studied dental pathologies after recording and before analysis. An adaptation of the procedures described by Morris (1984) and Turner *et al*. (1991) was employed for scoring dental condition, as shown in Table 4.05.

Table 4.05: Standards for recording dental condition (after Morris (1984) and Turner *et al*. (1991)).

Score	Tooth condition
1	absent: tooth erupted but lost post-mortem; socket unresorbed
2	present: tooth erupted and in place
3	unerupted: socket unresorbed
4	erupting: socket unresorbed
5	socket resorbed: AMTL
6	socket broken: post-mortem damage; no assessment can be made

4.8.1 Dental caries

All permanent teeth present were examined macroscopically for dental caries. Caries or carious lesions appear as eroded areas on the enamel, usually dark-stained from the action of bacteria. Carious lesions were scored on the basis of their presence, size, and location using the categories described by Larsen *et al*. (1991) (Table 4.06). The size of the lesion could be suggestive of the severity of the disease and its impact on the

sufferer, whereas the location could carry information about the quality and nature of the diet (Hartnady & Rose 1991).

Table 4.06: Standards for scoring for dental caries (after Larsen *et al*. 1991).

Score	Severity	Location
1	None	None
2	Minimal (pin-head size; involving only the enamel)	Interproximal
3	Moderate (about one quarter of the crown destroyed; enamel and dentine involvement)	Buccal
4	Heavy (about half of the crown destroyed; enamel, dentine and pulp chamber involvement)	Lingual
5	Extreme (whole crown destroyed; only root stump remained; enamel, dentine and pulp chamber involvement)	Occlusal

Moderate to high rates of antemortem tooth loss may significantly distort the accuracy and interpretation of observations of dental caries. This is because a proportion of the teeth lost antemortem are likely to have been lost due to severe carious decay (Lukacs 1995; Kelley *et al*. 1991). The Decayed and Missing Index (DMI) suggested by Kelley *et al*. (1991) attempts to correct for this discrepancy in dental caries (Kelley *et al*. 1991). There is one issue, however, with the DMI as applied to non-living populations. The DMI assumes that the majority of antemortem tooth loss is a result of tooth decay, thus underestimating other factors that may lead to tooth loss such as periodontal disease, intentional tooth extraction, trauma, and so on (Kelley *et al*. 1991). For this reason, this study did not employ the DMI to correct for missing teeth in the assessment of dental caries. Tooth extraction for cultural reasons is known to have been practised by the Upembans, which will distort these analyses.

4.8.2 Antemortem tooth loss

Antemortem tooth loss (AMTL) can result from excessive tooth wear, caries, periodontitis, trauma and/or intentional extraction of teeth. Exposure of the pulp cavity through cariogenesis, excessive wear or trauma can lead to bacterial infection

and subsequent abscessing of the surrounding alveolar bone that could result in tooth loss (Burns 1999). When a tooth is lost antemortem, the alveolar bone begins to resorb, resulting in a decrease in the height of the bone at that part of the maxilla or mandible (Burns 1999).

All tooth sockets were examined macroscopically for antemortem tooth loss. If there was evidence of alveolar bone resorption, that tooth was scored as lost antemortem (see Table 4.05).

4.8.3 Abscesses

Abscesses are a result of inflammation of the pulp cavity following a spread of bacterial infection at the root, whereby build-up of pus occurs (Hillson 1996). Pus accumulation in the pulp cavity can create a pressure that can inflate the alveolar bone out of its normal contour and eventually cause destruction and resorption of the surrounding bone. Dental caries, trauma and periodontitis have been suggested as factors leading to abscess formation (Aufderheide & Rodriguez-Martin 1998; Burns 1999).

Presence of abscesses, as seen from alveolar bone destruction, was recorded for all maxillary and mandibular elements present. Criteria described by Lukacs (1989) were employed for the assessment of abscesses in order to avoid misdiagnosis. "If the location of the abscess was near the apex of the tooth root and the margin of the abscess cavity was rounded with evidence of reactive bone growth, then the individual was scored as having an abscess lesion" (Lukacs 1989: 271). When present, abscesses were scored by location in relation to the affected tooth and by size with three categories:

1: none
2: small to medium size (1-5mm in diameter)
3: large size (>5mm in diameter)

4.8.4 Occlusal wear

Dental wear, though not pathological, has been shown to affect the incidence of diseases found in the dentition, such as caries and abscesses (Aufderheide & Rodriguez-Martin 1998). For this reason, dental wear was assessed for each sub-adult and adult individuals with permanent teeth. Since tooth wear is directly proportional to age, it was appropriate to assess only the permanent teeth of sub-adult, and younger and older adult individuals separately.

Based on scores for dental wear developed by Brothwell (1981), the occurrence and severity of occlusal attrition on adult dentition was analysed (Table 4.07). The rate of occlusal wear for each tooth present was scored from 0 to 4. Since teeth wear at different rates posteriorly and anteriorly, posterior and anterior attrition scores were calculated separately. The anterior attrition score is the average rate of occlusion for the incisors and canines; while posterior attrition score is defined as the average rate of occlusion for the premolars and molars (Brothwell 1981). Mean attrition scores were also calculated as the average of anterior and posterior attrition scores.

Table 4.07: Numerical classification and description of tooth wear categories*

Stages	**Incisors and canines**	**Molars**
0 unworn	No wear	No wear
1 minimal	Enamel only	Enamel wear and slight dentine exposure on one cusp
2 slight to moderate	Slight to moderate dentine exposure	All cusps have slight to moderate dentine exposed, with coalescence of some cusps
3 heavy	Large dentine exposure, with rim still present	Dentine fully exposed on occlusal surface, with enamel rim
4 extreme	Tooth crown lost, enamel rim also worn, approaching CEJ	Tooth crown lost, enamel rim also worn, approaching CEJ

*Based on Morris 1984: 185; Table 4.2

4.8.5 Dental calculus

Dental calculus can inform us about the oral hygiene or lack thereof of an individual or population. The presence of calculus indicates long-standing plaque accumulation, suggesting infrequent mechanical cleaning of the teeth (Hillson 2008). To some extent, dietary composition can also be inferred from dental calculus, both by studying the phytoliths that get trapped in it, and also because a diet rich in refined carbohydrates tends to lead to plaque development (Hillson 1986). At a population level, there is a slight inverse relationship between calculus and caries, because calculus offers some protection against demineralisation by caries-forming bacteria (Manji *et al*. 1989).

Supragingival calculus was scored for each tooth using a four-degree severity scale adapted from Sledzik and Moore-Jansen (1991) and Brothwell (1981). The scoring system used is as follows:

1: none
2: minimal (restricted to CEJ)
3: slight to moderate (at least one third of crown covered by deposits)
4: heavy (large deposits that cover at least half of the crown)

4.8.6 Periodontal disease

Periodontitis is defined as a chronic, slowly progressive and destructive inflammatory disease process that affects the periodontium. The inflammation of the surrounding soft tissues is an immune response triggered by micro-organisms present in dental plaque (Marsh & Martin 1999). With constant plaque deposits, the inflammation can escalate to involve the periodontal ligaments that hold the teeth into their sockets, starting from the cemento-enamel junction down to the root. Once the teeth have lost their connection into the sockets, the alveolar bone becomes porous and subsequently resorbs due to the lack of active force exerted on the bone (Marsh & Martin 1999; Hillson 2008). Periodontitis commonly affects the posterior teeth.

Skeletally, periodontal disease appears as a reduction in the height of the alveolar bone or as pocket of decreased bone density. In severe cases, resorption of the socket

bone can lead to loss of adjacent teeth (Larsen 1997; Burns 1999). Thus, not only does periodontitis contribute to the frequency of antemortem tooth loss, but it is also a good indicator of general oral health. For this study, periodontitis was recorded as either present or absent, and when present, its severity was scored according to Kerr (1991), as follows:

1: none
2: mild (only the interdental walls resorbed)
3: moderate (about a third to half of roots exposed)
4: severe (two-thirds to three-quarters of roots exposed)

4.9 Phytolith analyses from dental calculus:

Calculus, from tooth surfaces, was also sampled in order to extract phytoliths (Table 4.04). In its uncalcified state, dental calculus can act as a trap for organic and inorganic particles, such as phytoliths (Lalueza Fox *et al*. 1996; Piperno 2006). The recovery and identification of phytoliths in dental calculus of archaeological populations has provided another tool for reconstructing diet of past populations. Phytolith analyses can provide us with a direct association of vegetal foods consumed by populations under study (Armitage 1975; Holt 1993; Middleton 1993; Reinhard & Danielson 2005). Such evidence has the potential to complement the stable isotope data.

The question of which plants were consumed by the inhabitants of the Upemba Depression was essential to the reconstruction of the diet of these people. Archaeological recovery of perishable consumables is controversial and incomplete. For the current study, the presence of dental calculus was recorded and then visible calculus deposits were mechanically sampled. Pieces of calculus of at least 0.1g were detached from the tooth surfaces using a scalpel. Initially, they were allowed to fall onto a piece of clean tin foil, and were then transferred into plastic snap-top Eppendorf microcentrifuge tubes (Lalueza Fox *et al*. 1996; Nelson 1997; Reinhard *et al*. 2001). The scalpel was dry-scrubbed after each sample taken to avoid cross-sample contamination.

Extraction and identification of phytoliths from dental calculus

All of the laboratory preparation, extraction and identification of phytoliths was done by Ms. Rahab Kinyanjui, at the National Museums of Kenya in Nairobi. The procedures described by Nelson (1997) and Reinhard *et al*. (2001) were used in the extraction of phytoliths. The calculus samples were cleaned with distilled water in order to eliminate soil residues and possible contamination. The samples were left for 30 minutes in distilled water to allow penetration. The samples were then centrifuged for one minute and the water decanted. The calculus samples were then treated with 10% HCl for six to twelve hours in order to remove carbonates. This was followed by 10% HNO_3 treatment to remove organic materials; each time removing acids from the residues by washing three times with distilled water and centrifuging at 3000rpm. The phytolith residue was then dried in a 70°C oven, and 10ml of sodium polytungstate ($Na_6[H_2W_{12}O_{40}]$) added to each sample to separate phytoliths from other heavier particles. The heavy liquid solution was prepared by mixing sodium polytungstate ($Na_6[H_2W_{12}O_{40}]$) with distilled water to a specific gravity of 2.4 g/cm^3. The floating component that contained phytoliths was transferred to a clean vial, where it was washed three times with distilled water. A drop of the phytolith residue was placed onto a slide, which was then heated to evaporate water from the residue. A drop of Entellan® New (a mounting medium with 500-600 mPas viscosity) was added to the dry residue and mixed thoroughly before placing the cover slip. Excess embedding agent was removed with a cloth moistened with xylene. All work with Entellan® New was carried out in a fume hood.

Microscopic examination was performed at 100x power and increased to 400x when the phytoliths were located, the higher magnification allowing for better description and identification of the phytoliths. A reference collection from published literature and a large collection of phytoliths from modern plants from central and East Africa was used to identify the phytoliths taxonomically (Twiss 1992; Runge 1999; Mercader *et al*. 2000; Madella *et al*. 2005; Piperno 2006; Barboni *et al*. 2007; Barboni & Bremond 2009; Barboni *et al*. 2010). Descriptive attributes recorded for the phytoliths followed those described in the modern reference collection. The siliceous nature of the phytoliths was confirmed by X-ray microanalysis. All identified particles

were described, identified and tallied for each slide, averaging approximately 100 morphotypes.

4.10 Stable isotope analyses of carbon, nitrogen and oxygen

4.10.1 Sampling of tissues

Bone and dental tissue samples were collected for carbon, nitrogen and oxygen isotope analyses (Table 4.08) for the purposes of dietary reconstruction, as well as to aid in the identification of possible immigrant individuals. Bone collagen was used to obtain organic carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) isotope ratios, while tooth enamel apatite provided the inorganic carbon ($^{13}C/^{12}C$) and oxygen ($^{18}O/^{16}O$) isotope ratios. Bone collagen reflects the average isotope values of diet over many years because of continuous bone remodelling (see Chapter 3 for a review). Enamel apatite, on the other hand, records the diet consumed during the time the tooth formed because, once developed, enamel does not remodel. Where possible, enamel from an early-forming permanent tooth (first molar or central incisor) and a late-forming permanent tooth (third or second molar) was sampled from each individual to obtain isotopic information about diet in both early and late childhood.

Bone pieces were mainly sampled from the femur or the tibia because these skeletal elements were often present and relatively well preserved. Sampling was restricted to areas where the bone is dense and with fewer landmarks to destroy. Their density offered a better chance of preserving collagen than thinner or less dense bones. However, when present, rib fragments were sometimes selected in place of long bones. A Dremel tool fitted with an emery cutting wheel was used to remove small pieces of at least five grams of bone from the skeletal remains housed at the National Museum of Lubumbashi, DRC.

Where possible, broken or fragmentary teeth were sampled in preference to undamaged ones in order to minimize destruction of the collection. Some remains were so fragile that enamel chips would break off during examination. In such cases, these chips were collected for isotope analyses and later manually ground to a fine powder in a pestle and mortar. Sampling of enamel from whole teeth was restricted to

the lingual or buccal surfaces of mandibular molars, where present. These surfaces were chosen because there are fewer morphological traits to destroy on these teeth than on the upper molars.

A rotary drill equipped with a 0.5mm diamond-tipped drill bit was used to sample enamel powder from whole teeth. The sample was taken by drilling the enamel along a line from the cervix to the occlusal surface, thus obtaining a sample that represents the entire time of the tooth's formation. The enamel powder was collected on a piece of tinfoil and each sample was then placed in a plastic snap-top Eppendorf microcentrifuge tube. A minimum of eight milligrams of powder was sampled from each tooth.

Other important samples collected include the following:

1. Bone and dental samples were taken from animal remains recovered from the graves, to establish an isotopic baseline from which to interpret the stable isotope ratios of the humans,

2. Contemporary foodstuffs bought at the market in Lubumbashi, DRC, were also analysed to add to the baseline stable isotope data for interpreting human isotope values. These foodstuffs included amaranth leaves, sweet potato leaves, pumpkin leaves, okra, pumpkin seeds, ground peanuts, and dried salted *Tilapia* fish (Table 4.08).

Table 4.08: Inventory of all samples collected for the current research.

Samples	Sanga	Katoto	Kamilamba	Katongo	Malemba-Nkulu	Kikulu	TOTAL
Human bone	37	19 (+17)*	3	1	4	7	**88 (+17)***
Human teeth (early-forming)	40	24	4	2	10	5	**85**
Human teeth (late-forming)	32	16	3	2	6	6	**65**
Faunal bone	17	12	0	0	1	0	**30**
Faunal teeth	7	2	0	0	0	0	**9**
Calculus	42	7	1	6	7	11	**74**
Foodstuffs (contemporary)	• wild amaranth leaves • sweet potato leaves • pumpkin leaves • okra • pumpkin seeds • ground peanuts • dried & salted *Tilapia* fish						

*Seventeen individuals from Katoto were sampled for isotope analyses only.

4.10.2 Bone collagen: preparation and mass spectrometry

Bone pieces of at least 1cm^2 or >0.5g (from both humans and animals sampled) were weighed on a micro-balance, then placed in 100ml of 0.1M hydrochloric acid (HCl) to remove the inorganic component (mostly hydroxyapatite) from the bone. The acid solution was changed every second day until all the hydroxyapatite had dissolved. Once decalcified, the pieces were flexible and slightly translucent. At times, some of the bone samples in acid were placed in the fridge to slow down the dissolution of the hydroxyapatite as some of them were disintegrating rapidly in the acid. In some cases, a more dilute acid solution (0.025M HCl) was used to try to maintain the structural integrity of the samples. This was done for a maximum of two months and the acid solution changed weekly (Schwarcz & Schoeninger 1991).

The acid-insoluble protein fraction of the bone, loosely referred to as 'collagen', was then rinsed in distilled water and then placed in 0.1M sodium hydroxide (NaOH) to get rid of organic contaminants, such as humates. This reaction was allowed to proceed for several hours. If there was a marked colour change (darkening) of the NaOH solution, it was replaced until discolouration ceased, indicating that (all) organic contaminants had been removed (Ambrose 1990; van Klinken 1999; Jørkov *et al*. 2007). Any visible rootlets were picked out of the soft collagen using fine tweezers. The samples were then soaked in distilled water until all traces of NaOH disappeared and freeze-dried. After freeze-drying, they were left so that their moisture contents could equilibrate with that of the atmosphere before the samples were weighed in order to calculate the collagen yield. Small quantities of the prepared collagen were then weighed into tin cups on a Sartorius micro balance, to an accuracy of 1μg. The cups were folded to enclose the sample and exclude air, before being analysed on the mass spectrometer.

The samples were combusted at in a Flash 2000 organic elemental analyzer at 1020°C. The gases produced were swept in a stream of helium into a Delta V Plus isotope ratio mass spectrometer (IRMS) via a Conflo IV gas control unit. All three items are made by Thermo Scientific, Bremen, Germany.
Measured isotope ratios are expressed relative to internationally accepted standards, using the delta notation. The standard for carbon is PeeDee Belemnite, while that for

nitrogen is atmospheric nitrogen gas. Repeated measurements of standard materials run at the same time as these samples yielded reproducibility (standard deviations) better than 0.2‰ for $\delta^{13}C$ (n = 20) and 0.1‰ for $\delta^{15}N$ (n = 15).

4.10.3 Enamel apatite: preparation and mass spectrometry

For each sample, 2 to 3mg of enamel powder were soaked in 1ml of 50% sodium hypochlorite (NaOCl) solution for 60 minutes to remove organic matter (Lee-Thorp *et al.* 2000). The samples were then centrifuged for one minute, the NaOCl solution was pipetted out, and the samples were rinsed three times with distilled water. Next, 0.1M acetic acid (CH_3CO_2H) was added to the samples and left to react for 15 minutes, to remove diagenetic carbonates (Krueger 1991; Koch *et al.* 1997). The samples were then centrifuged for one minute and the CH_3CO_2H solution suctioned out. Once more, they were rinsed three times with distilled water, and then freeze-dried overnight.

The samples were weighed into 12ml borosilicate glass tubes with screw top lids containing a septum. The tubes were placed in Thermo Finnigan (Germany) model II gas bench, in a temperature controlled sampler tray set to 72°C. Using the CTC Analytics A200S autosampler, the tubes were flushed with helium to remove the atmospheric air present in them. Five to seven drops (according to sample size) of 100% phosphoric acid were then manually added to each sample tube through the septum using a 1ml syringe. The samples were left to react for a minimum of three hours.

The gas evolved from each reaction was sampled by the autosampler and passed through a Nafion water removal unit, then a "Poraplot Q" GC column to separate the gases, through a second Nafion water trapand into a Finnigan MAT 252 isotope ratio mass spectrometer (IRMS) computer controlled by Isodat software.The measured isotope ratios are expressed as delta values, relative to the international standard PDB, as described above. The laboratory reference gas was calibrated by measuring international standard materials NBS 18, 19 and 20, and the day-to-day instrument consistency was monitored by running in-house standards Cavendish marble and Carrara marble. The reproducibility of repeated measurements of these standards was better than 0.1‰ for $\delta^{13}C$ (n = 12) and 0.2‰ for $\delta^{18}O$ (n = 12)

4.10.4 Quantifying 'real' dietary changes

One aspect of this study was concerned with distinguishing individuals who had lived all their lives in or near the locality where they died from immigrants from different areas. Therefore, comparisons of isotope ratios between bone collagen and enamel apatite or between early- and late-developing teeth were done. In order to identify meaningful changes in diet or habitat during a life of an individual, it was necessary to define a minimum shift in intra-individual delta values that would be greater than the random inter-individual variation (±1‰, [DeNiro & Schoeninger 1983]) seen in a population consuming a mono-isotopic diet. Based on the results of DeNiro and Schoeninger's (1983) study, differences in isotope values of 2‰ or more, are taken to signify significant dietary differences. This study uses this cut-off point to indicate a significant change in isotope values within a single individual.

4.11 Dental Modification

Dental modification in the form of intentional tooth extraction, filing and chipping has been documented among numerous prehistoric populations in southern Africa (Morris 1993, 1998; van Reenen 1986; Shaw 1931; Erlandsson & Bäckman 1999; Cox *et al.* 2001). There are many explanations for artificial alterations of tooth morphology. Some modifications were purely for aesthetic purposes (Fastlicht 1976; Romero 1970; de la Borbolla 1940), others were markers of ethnicity, tribal identification (Handler 1994; van Reenen 1977, 1978, 1986) and/or social status (Fastlicht 1976; Milner & Larsen 1991). In this study, the main motivation for examining intentional tooth modification was to investigate the identities and origins of the people who practiced tooth modification in the Upemba Depression between AD700 and 1800.

All anterior permanent teeth were examined for signs of dental modification, as well as possible tooth evulsion. Types of dental modification were categorised according to Gould *et al*. (1984), although some styles or patterns were observed that were not catalogued in Gould *et al*. (1984). These were described and illustrated in order to compile a comprehensive record of all patterns present within this population. Since antemortem tooth loss can be caused by severe periodontitis, abscesses and other

dental disease processes, individuals with heavily diseased mouths were excluded from the analysis of the tooth extraction practice. Examples of some of the patterns of dental modification, including intentional extraction and tooth chipping or filing had been observed previously in earlier research on this population (see Dlamini 2006).

Chapter 5: RESULTS

5.1 Demographic profile

5.1.1. Preservation and completeness of the skeletal remains

Preservation and condition of individual skeletons was determined in order to indicate the number of specimens available for study and how this affected numbers of individuals per analysis. As already discussed in Chapter 4, the preservation of the human remains from the Upemba varied greatly within and between sites. Some of the individuals were very well preserved, while others had almost completely disintegrated (see Chapter 4 for details). Damage to skeletal remains resulted from normal post-depositional processes, exacerbated by the tropical environment, as well as post-excavation handling and storage.

Post-mortem fragmentation of the remains was generally high, and was not confined to the more fragile bones of the torso, such as ribs and flat bones, but was widespread throughout the body. Long bones, crania, pelvises, and even phalanges were similarly affected by post-mortem fragmentation. There appears to be no difference in the completeness of the skeletal remains between sites (Table 5.01). The highest percentage of complete skeletons was found at Kikulu (18.1%), followed by Sanga (14.5%) and Katoto (13.3%). Skeletons from Kamilamba were less well preserved; less than 10% of individuals retained less than 50% of their skeletal elements. Since teeth were the principal focus of the current research, individuals without teeth were excluded from this study.

Females and males were similarly complete; with 36.9% of females and 33.4% of males having more than 75% of the skeleton preserved. In this sample set, there appears to be no relationship between sex and preservation; males and females were not differentially preserved. Preservation of skeletons derived from earlier time periods was not necessarily poorer; in fact, the opposite appears true for the Upemba Depression. Skeletons from the Kisalian were more complete than those from the Kabambian period: 34.5% of Kisalian skeletons were more than 50% complete versus

21.1% from the Kabambian. When comparing different parts of the skeleton, crania and mandibles were the most complete (57.3% more than 50% complete). They might have been preferentially preserved or more carefully curated than other skeletal elements (Table 5.01 and Figure 5.01).

In summary, less than half of the excavated skeletons were sufficiently well preserved to be included in the current research project (see Chapter 4, Table 4.04). Decay during burial, collecting bias and poor curation have all contributed to the current state of completeness of the skeletons from the Upemba Depression. Due to sample size limitations, inter-site comparisons were made only between Sanga and Katoto as they had the largest numbers of individuals and were therefore most suitable for statistical analyses. For temporal comparisons, the Kisalian and Kabambian periods yielded the two samples large enough for meaningful comparisons to be achieved. Finally, males and females were initially treated separately; where there were no differences, sexes were pooled.

Table 5.01: Completeness of skeletal remains by site, sex, time period and body part.

	0 – 5%	5 – 25%	25 – 50%	50 – 75%	75 – 95%	100%
Sanga (n = 64)	55.2%	7.1%	4.2%	6.4%	12.6%	14.5%
Katoto (n = 30)	46.1%	11.6%	9.2%	7.4%	12.4%	13.3%
Malemba-Nkulu (n = 25)	72.1%	5.2%	2.3%	2.3%	7.0%	11.1%
Kikulu (n = 14)	58.4%	6.7%	3.3%	6.0%	7.5%	18.1%
Kamilamba (n = 6)	90.0%	3.0%	1.9%	2.6%	2.2%	0.4%
Katongo (n = 6)	73.0%	0.7%	4.4%	2.6%	10.0%	9.3%
Female (n = 42)	45.1%	6.1%	6.7%	5.3%	13.3%	23.6%
Male (n = 32)	44.8%	7.8%	5.5%	8.5%	16.6%	16.8%
Kisalian (n = 85)	51.3%	8.4%	5.9%	6.6%	12.7%	15.2%
Kabambian (n = 41)	69.9%	6.1%	2.9%	3.7%	6.2%	11.2%
Cranium & mandible	29.6%	8.0%	5.1%	8.0%	18.9%	30.4%
Torso	62.7%	8.8%	7.4%	4.2%	7.5%	9.4%
L upper limb	59.1%	9.6%	5.1%	6.7%	9.3%	10.1%
R upper limb	60.5%	8.7%	4.7%	5.9%	10.6%	9.6%
L lower limb	63.2%	3.7%	4.6%	5.0%	10.6%	13.0%
R lower limb	63.8%	4.0%	4.2%	5.4%	10.2%	12.4%
Whole sample* (n = 145)	**52.7%**	**7.3%**	**5.4%**	**6.0%**	**12.1%**	**16.4%**

n* = number of skeletons studied
Whole sample*: includes skeletons from all six sites.

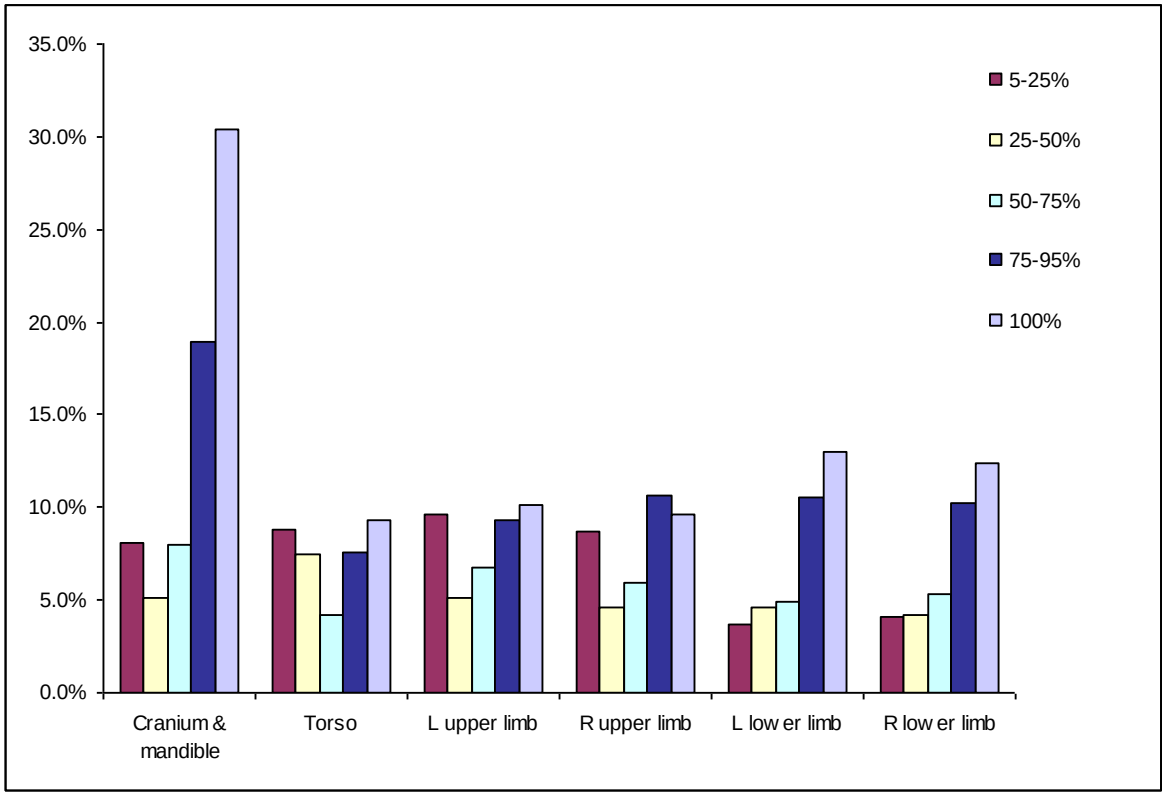


Figure 5.01: Completeness of skeletal remains by body part.

5.1.2. Age at death and sex

The skeletons analysed from the six sites in the Upemba Depression comprised 145 individuals of whom 93 (64.1%) were adults aged 21 years and over at death and the remaining 52 (35.9%) were sub-adults (Table 5.02 and Figure 5.02). Infants (0-5 years) made up 15.2% and juveniles (6-15 years) 17.2% of the total sample. There was a much lower proportion of sub-adults (16-20 years): 3.4% of the whole sample. Infant and juvenile mortality was highest at Malemba-Nkulu (56.0%) followed by Katoto (46.7%), while at Sanga it was 26.6%. The other three sites appeared to have lower infant/juvenile mortality rates, but this may be the result of smaller sample sizes. Fifty of the 73 adult individuals to whom ages could be assigned (68.5%) died between 21 and 40 years of age; while only 31.5% were older adults, i.e. over 40 years at death.

The pattern of more younger and fewer older adults recurred at all sites. Kolmogorov-Smirnov tests showed no significant differences between the age profiles at different sites. On the basis of this sample, there do not appear to be fluctuations in age and sex ratios through time, but that some slight regional variations did exist.

A total of 71 adults and three adolescents could be assigned a sex (n = 74). Of these, 56.8% were female and 43.2% were male. There were slightly more females than males at all six sites (Table 5.03 and Figure 5.03), but the differences were not statistically significant (χ^2 = 0.54 p = 0.4617 for Sanga compared with Katoto. At other sites, numbers are too small for statistical evaluation.) Age profiles of skeletons from the Kisalian compared with the Kabambian time period were not significantly different (Kolmogorov-Smirnov test), nor were the proportions of males and females (χ^2 = 0.05 p = 0.8296). The Atypical and Recent samples are too small for reliable assessment of any patterning (Tables 5.04 & 5.05 and Figures 5.04 & 5.05).

When looking at the pooled data for all six sites (Table 5.06), females appeared to be dying younger than their male counterparts. More than half (56.4%) of the individuals who died as younger adults were females, while 23.6% were males. This difference is statistically significant (χ^2 = 12.27; p = 0.0005) and while caution should be exercised when interpreting sex-related data, it is suggested here that female mortality was likely associated with childbirth (Angel 1969). The pattern of females dying younger

than males is repeated when looking at the older adult category. Males make up 56.5% of adults who died at ages above 40 years, whereas 39.1% of the females died as older adults. The difference is, however, not significant ($\chi^2 = 1.39$; $p = 0.2377$). Since not all sexed individuals could also be aged, only 66 individuals make up the sexed and aged total in Table 5.06. Two adult females and six adult males could not be placed into either younger or older age categories.

In summary, the samples per time period were demographically comparable and thus group comparisons could be done without correcting for differences in demographic data. When comparing sexes, however, caution should be exercised since there was a disparity between female and male ages at death.

Table 5.02: Age-at-death profile per site.

Age group	Sanga N/%	Katoto N/%	Malemba-Nkulu N/%	Kikulu N/%	Kamilamba N/%	Katongo N/%	TOTAL N/%
Infant	8/12.5	6/20.0	8/32.0	0/0.0	0/0.0	0/0.0	22/15.2
Juvenile	9/14.1	8/26.7	6/24.0	1/7.1	1/16.7	0/0.0	25/17.2
Sub-adult	2/3.1	2/6.7	0/0.0	0/0.0	1/16.7	0/0.0	5/3.4
Younger adult	23/35.9	9/30.0	5/20.0	7/50.0	3/50.0	3/50.0	50/34.5
Older adult	10/15.6	5/16.7	3/12.0	3/21.4	0/0.0	2/33.3	23/15.9
Adult*	12/18.8	0/0.0	3/12.0	3/21.4	1/16.7	1/16.7	20/13.8
TOTAL	**64**	**30**	**25**	**14**	**6**	**6**	**145**

Adult*: adult individuals of undeterminable age

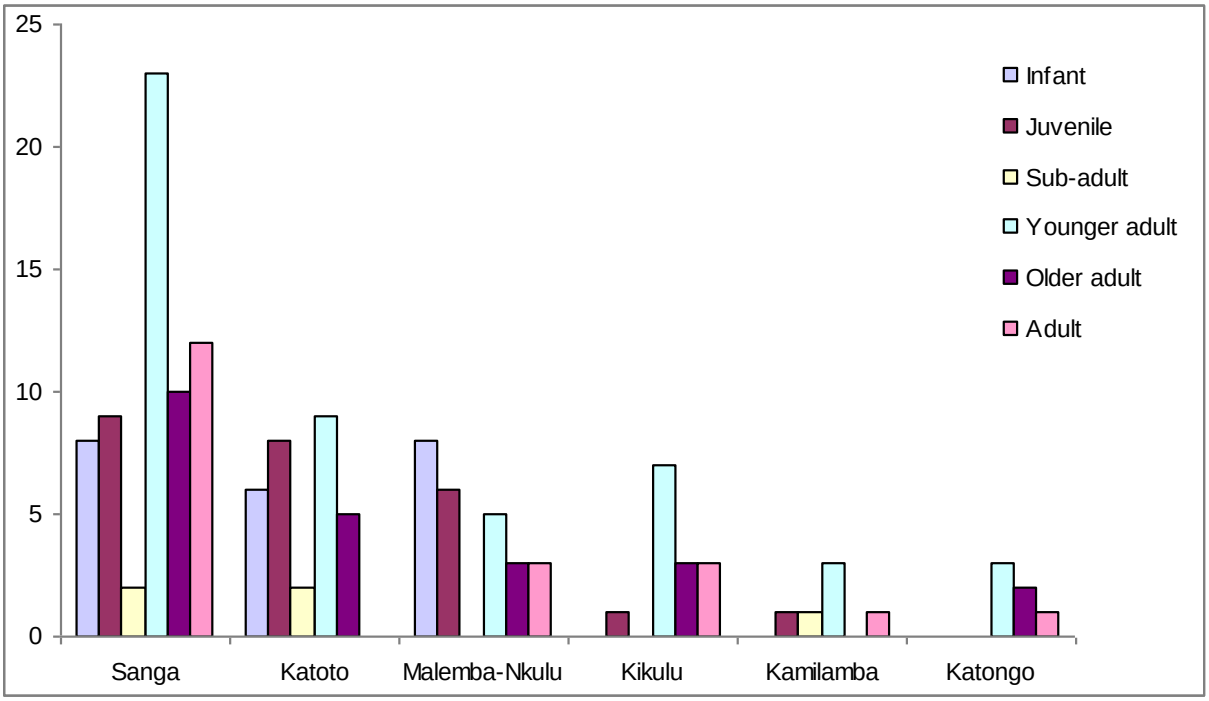


Figure 5.02: Age-at-death profile per site.

Table 5.03: Sex distribution per site.

Sex	Sanga N/%	Katoto N/%	Malemba-Nkulu N/%	Kikulu N/%	Kamilamba N/%	Katongo N/%	TOTAL N/%
Female	19/29.7	9/30.0	4/16.0	6/42.9	1/16.7	3/50.0	42/29.0
Male	17/26.6	5/16.7	3/12.0	5/35.7	0/0.0	2/33.3	32/22.1
Children*	17/26.6	14/46.7	14/56.0	1/7.1	1/16.7	0/0.0	47/32.4
Adult*	11/17.2	2/6.7	4/16.0	2/14.3	4/66.6	1/16.7	24/16.5
TOTAL	**64**	**30**	**25**	**14**	**6**	**6**	**145**

Children*: includes infants and juveniles
Adult*: adult individuals whose sex could not be determined

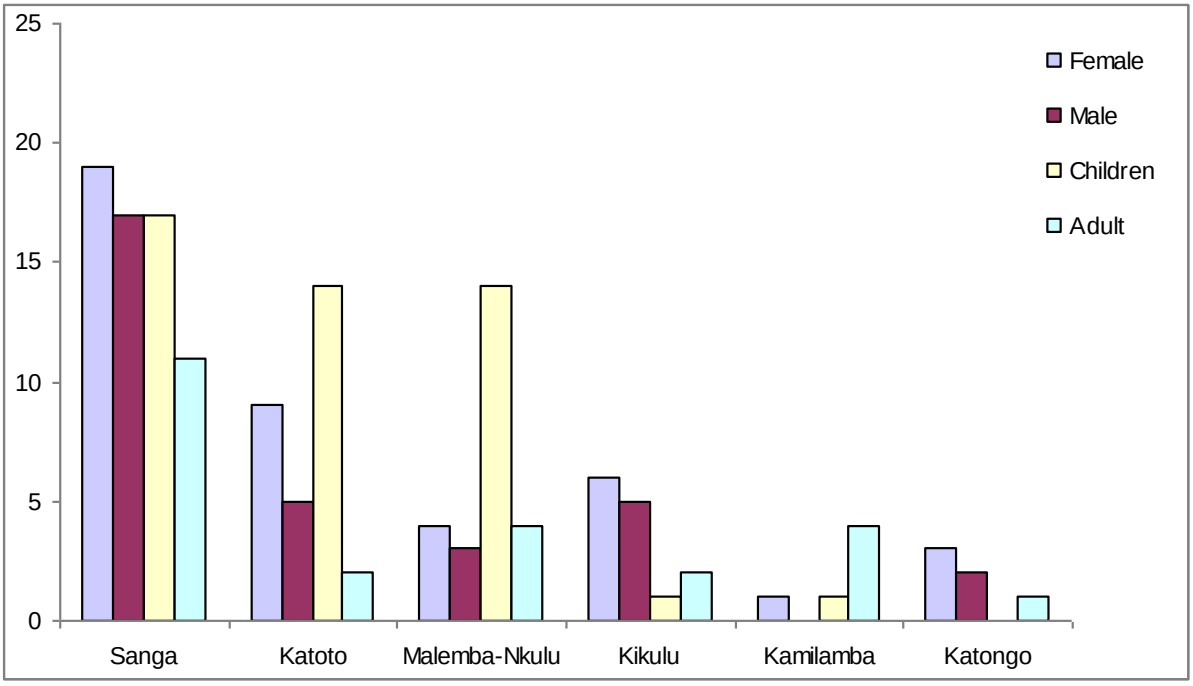


Figure 5.03: Sex distribution per site.

Table 5.04: Age-at-death distribution per time period.

	Kisalian	**Kabambian**	**Recent**	**Atypical**	**TOTAL**
Age group	N/%	N/%	N/%	N/%	N/%
Infant	13/15.3	7/17.1	1/20.0	1/7.1	22/15.2
Juvenile	18/21.2	6/14.6	0/0.0	1/7.1	25/17.2
Sub-adult	5/5.9	0/0.0	0/0.0	0/0.0	5/3.4
Younger adult	28/32.9	15/36.6	3/60.0	4/28.6	50/34.5
Older adult	16/18.8	4/9.8	0/0.0	3/21.4	23/15.9
Adult*	5/5.9	9/21.9	1/20.0	5/35.7	20/13.8
TOTAL	**85**	**41**	**5**	**14**	**145**

Adult*: adult individuals of undeterminable age

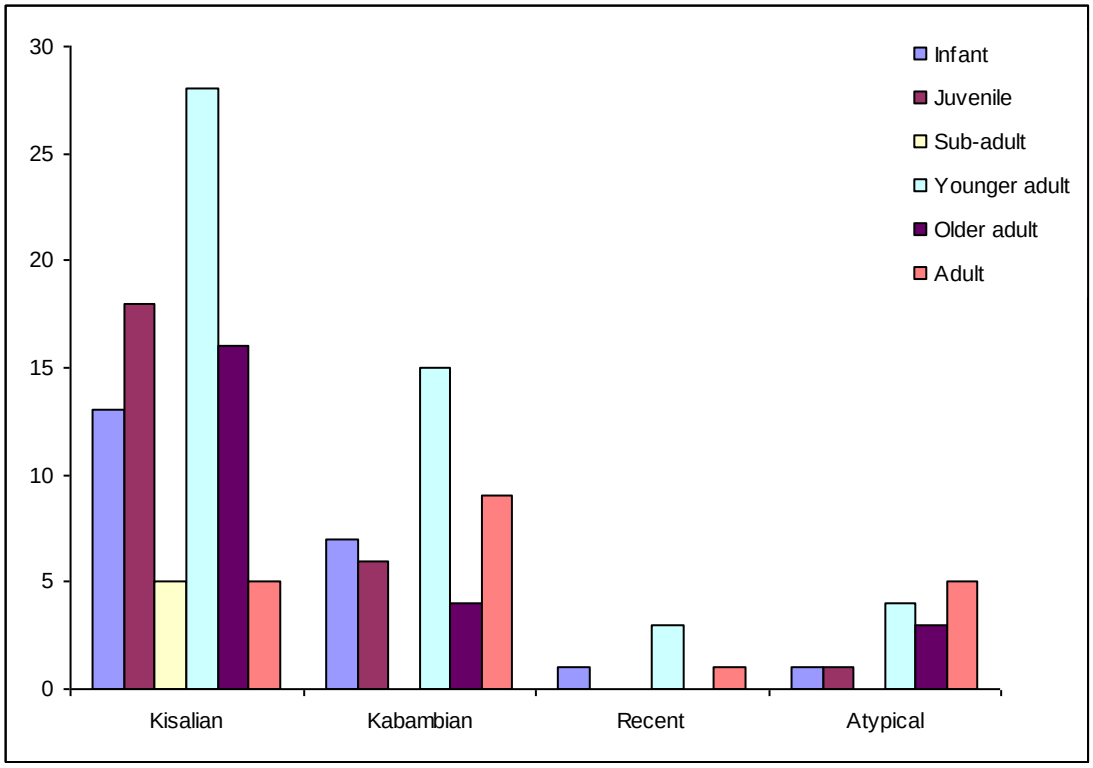


Figure 5.04: Age-at-death profile per time period.

Table 5.05: Sex distribution per time period.

Sex	Kisalian N/%	Kabambian N/%	Recent N/%	Atypical N/%	TOTAL N/%
Female	25/29.4	11/26.8	2/40.0	4/28.6	42/29.0
Male	18/21.2	7/17.1	1/20.0	6/42.8	32/22.1
Children*	31/36.5	13/31.7	1/20.0	2/14.3	47/32.4
Adult*	11/12.9	10/24.4	1/20.0	2/14.3	24/16.5
TOTAL	**85**	**41**	**5**	**14**	**145**

Children*: includes infants and juveniles
Adult*: adult individuals whose sex could not be determined

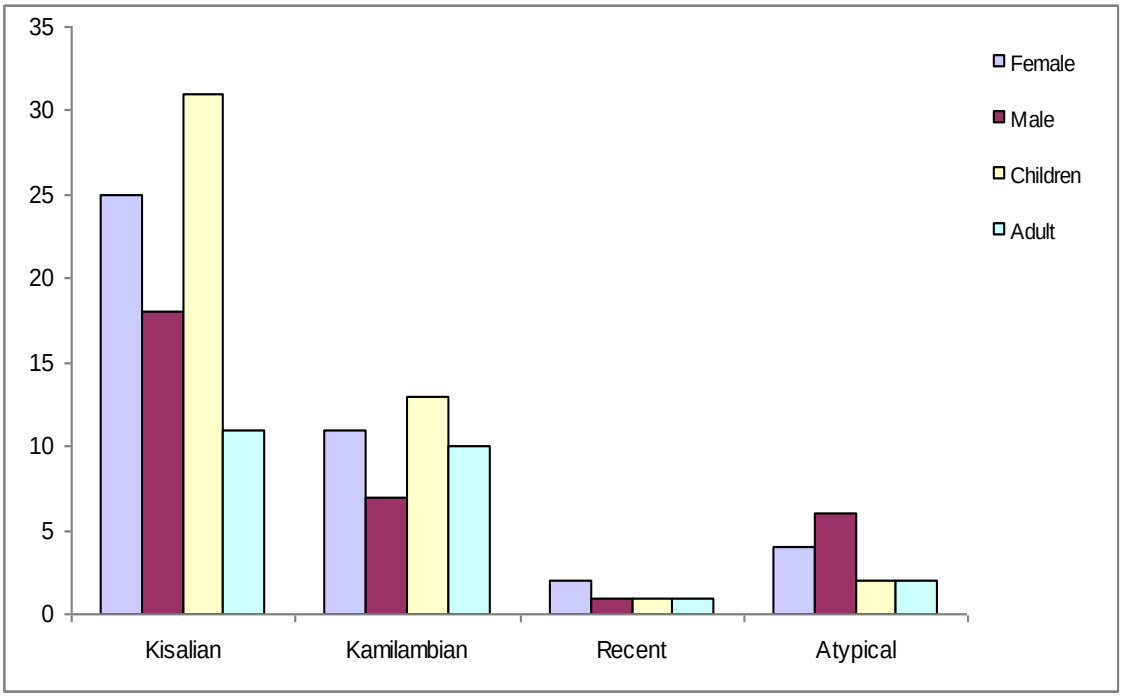


Figure 5.05: Sex distribution per time period.

Table 5.06: Summary of age-at-death and sex profiles pooled from all sites

Sex	Younger adult* N/%	Older adult N/%
Female	31/56.4	9/39.1
Male	13/23.6	13/56.5
Unknown	11/20.0	1/4.4
TOTAL	**55**	**23**

Younger adult*: includes sub-adults and younger adults

5.2 Dental traits

5.2.1 Non-metric morphological dental traits

Frequencies of the 39 dental traits recorded are presented in Tables 5.07 to 5.09 below, and in Appendix 2. The percentage of each trait's occurrence was assessed as present or absent according to a standardised procedure described by Turner (1985) and Haeussler *et al*. (1989). Frequencies on the left and right antimeres were examined for bilateral (a)symmetry, but chi-squared tests comparing the two showed no significant differences (Table 5.07). As a result, further comparisons are based on the left side only.

The samples from the Upemba as a whole have high frequencies of multiple-rooted molars (LM2: 95.5%; UM1: 94.2%; UM2: 79.2% and UM3: 64.3%), UM2 hypocone (81.3%), Y-grooved LM2 (75.0%) (Figure 5.06), upper canine mesial ridge (68.0%) (Figure 5.07), and UI1 shoveling (61.5%). Other traits occurring at moderate rates included UC distal accessory ridge (56.8%), five-cusped LM2 (53.0%), LM1 deflecting wrinkle (52.3%), mandibular torus (45.2%), UI1 labial curvature (43.9%), anterior fovea (42.9%), two-rooted UP1 (36.9%) and a midline diastema (35.7%). The rest of the traits were found at lower frequencies (mostly at less than 30%). Traits that were entirely absent included premolar odontome, UM3 congenital absence, peg-reduced UI2, UI1 winging, and two-rooted LC.

With the exception of one trait, male and female trait frequencies showed no significant differences (Table 5.08). Only a minority of females (8.7%) exhibited more than two lingual cusps on lower P2s in comparison to the males (46.2%) (χ^2 = 4.75, p = 0.0293). When considering temporal differences, only two traits differed between the Kisalian and the Kabambian (Table 5.09). Carabelli's trait in the UM1 was found at a much higher frequency in the Kisalian (40.0%) than the Kabambian (13.0%) (χ^2 = 4.18, p = 0.0410). In the Kabambian sample, the UC distal accessory ridge occurred on 100% of teeth examined, while it was found on only 40.0% in the Kisalian (χ^2 = 5.68, p = 0.0172). The Recent (Luba) period showed no significant differences with the Kisalian and Kabambian periods (Appendix 2).

The standardised procedure of scoring traits as present or absent (Turner 1985; Haeussler *et al*. 1989) does not consider the degree of trait expression. In this study, traits were first recorded as present or absent, then degree of expression assessed as moderate, marked or extreme. Table 5.10 demonstrates the disparity between the frequencies of traits when they are scored as present/absent, compared with the frequencies of traits expressed to a moderate, marked and extreme degree. Traits that were found at high frequencies using the dichotomised system (Turner 1985; Haeussler *et al*. 1989) occurred less frequently when only moderate, marked and extreme degrees of expression were considered. About two-thirds of the frequently-occurring traits were expressed moderately-markedly and only a third were markedly-extremely expressed. The most substantial change can be seen in UI1 shoveling, present in 61.5% of teeth but expressed moderately to markedly in only 5.1%. Other trait frequencies that changed significantly when only moderate to extremely marked expression was considered included the LM1 protostylid (27.0% vs. 1.6%), UM1 enamel extension (23.4% vs. 1.3%), LM1 deflecting wrinkle (52.3% vs. 31.8%), peg-shaped UM3 (23.0% vs. 0.0%), UI2 tuberculum dentale (31.1% vs. 11.1%) and so on. This implies that most of the frequently occurring traits noted above are weakly expressed in the overall sample (Tables 5.10 and 5.11). The implications of this in terms of heritability or genetic relatedness will be discussed in Chapter 6.

In summary, non-metric dental trait frequencies in the Upemba Depression suggest a high degree of dental morphological homogeneity between the sexes and time periods. Due to small sample sizes, inter-site comparisons for dental morphological traits were not done. In Chapter 6, trait frequencies observed in the Upemba samples will be compared with other geographic regions in sub-Saharan Africa in order to understand population affinities of the Upemba peoples on a continental scale.

Table 5.07: Frequencies of all 39 non-metric traits, comparing left and right antimeres (sexes, sites, and time periods combined). χ^2 tests comparing left and right frequencies showed no significant differences.

Trait	Frequency: Left	% Left	Frequency: Right	% Right	Calculated χ^2 value
Root number LM2	63/66	95.5	63/66	95.5	0.17
Root number UM1	81/86	94.2	79/83	95.2	0.00
Hypocone UM2	65/80	81.3	66/78	84.6	0.32
Root number UM2	57/72	79.2	51/64	79.7	0.01
Groove pattern LM2	45/60	75.0	37/57	64.9	1.42
Canine mesial ridge UC	34/50	68.0	28/49	57.1	1.25
Root number UM3	36/56	64.3	30/58	51.7	1.84
Shovel UI1	24/39	61.5	26/35	74.3	1.37
Distal accessory ridge UC	21/37	56.8	21/32	65.6	0.57
Cusp number LM2	35/66	53.0	29/62	46.8	0.50
Deflecting wrinkle LM1	23/44	52.3	22/46	47.8	0.18
Mandibular torus	38/84	45.2	37/82	45.1	0.00
Labial curvature UI1	25/57	43.9	29/55	52.7	0.88
Anterior fovea LM1	21/49	42.9	21/45	46.7	0.14
Root number UP1	24/65	36.9	26/71	36.6	0.00
Midline diastema UI1	10/28	35.7	10/28	35.7	0.00
Tuberculum dentale UI2	14/45	31.1	12/43	27.9	0.11
Parastyle UM3	18/59	30.5	16/60	26.7	0.22
Carabelli's trait UM1	22/78	28.2	25/82	30.5	0.10
Protostylid LM1	17/63	27.0	19/64	29.7	0.11
Interruption groove UI2	12/49	24.5	12/49	24.5	0.00
Lingual cusp number LP2	12/49	24.5	12/49	24.5	0.00
Enamel extension UM1	18/77	23.4	20/77	26.0	0.14
Peg-shaped UM3	14/61	23.0	16/60	26.7	0.22
Torsomolar angle LM3	8/36	22.2	7/36	19.4	0.08
Rocker jaw	11/65	16.9	11/65	16.9	0.00
Cusp 5 (metaconule) UM1	12/83	14.5	16/82	19.5	0.75
Palatal torus	5/36	13.9	5/36	13.9	0.12
Tome's root LP1	5/48	10.4	6/52	11.5	0.02
Cusp 7 (metaconulid) LM1	7/73	9.6	12/68	17.6	1.96
Cusp number LM1	6/69	8.7	4/67	6.0	0.08
Distal trigonid crest LM1	4/54	7.4	7/55	12.7	0.36
Double shovel UI1	2/45	4.4	3/45	6.7	0.00
Root number LM1	1/67	1.5	1/77	1.3	0.38
Odontome P1-P2	0/76	0.0	0/91	0.0	n/a
Congenital absence UM3	0/76	0.0	1/76	1.3	0.00
Peg-reduced UI2	0/55	0.0	0/54	0.0	n/a
Winging UI1	0/30	0.0	0/28	0.0	n/a
Root number LC	0/74	0.0	0/76	0.0	n/a

Table 5.08: Frequencies of all 39 non-metric traits for males and females (left antimeres only; sites and time periods combined). χ^2 values are for comparisons of frequencies in females and males; p-values are reported only if significant at the 0.05 level.

Trait	Frequency: Female	% Female	Frequency: Male	% Male	Calculated χ^2 value	p value
Root number LM2	27/29	93.1	18/19	94.7	0.15	
Root number UM1	32/35	91.4	24/25	96.0	0.03	
Hypocone UM2	24/32	75.0	18/20	90.0	0.95	
Groove pattern LM2	17/23	73.9	9/13	69.2	0.01	
Root number UM2	25/35	71.4	20/23	87.0	1.14	
Canine mesial ridge UC	12/17	70.6	6/11	54.5	0.21	
Shovel UI1	3/5	60.0	8/10	80.0	0.04	
Root number UM3	16/27	59.3	12/15	80.0	1.05	
Distal accessory ridge UC	6/11	54.5	3/6	50.0	0.11	
Mandibular torus	17/34	50.0	12/23	52.2	0.03	
Cusp number LM2	11/24	45.8	9/17	52.9	0.20	
Parastyle UM3	11/25	44.0	5/16	31.3	0.24	
Labial curvature UI1	6/15	40.0	4/15	26.7	0.15	
Root number UP1	12/33	36.4	7/18	38.9	0.02	
Midline diastema UI1	6/17	35.3	2/6	33.3	0.17	
Interruption groove UI2	6/18	33.3	3/12	25.0	0.01	
Enamel extension UM1	8/27	29.6	2/18	11.1	1.21	
Peg-shaped UM3	7/26	26.9	5/18	27.8	0.08	
Rocker jaw	8/31	25.8	2/16	12.5	0.46	
Protostylid LM1	5/20	25.0	1/11	9.1	0.36	
Deflecting wrinkle LM1	3/12	25.0	1/4	25.0	0.44	
Anterior fovea LM1	3/14	21.4	1/6	16.7	0.13	
Tuberculum dentale UI2	3/14	21.4	4/11	36.4	0.14	
Carabelli's trait UM1	4/26	15.4	1/19	5.3	0.34	
Torsomolar angle LM3	4/33	12.1	0/2	0.0	0.39	
Lingual cusp number LP2	2/23	8.7	6/13	46.2	4.75	**0.0293**
Palatal torus	1/21	4.8	2/8	25.0	0.84	
Tome's root LP1	1/23	4.3	2/15	13.3	0.15	
Cusp 7 (metaconulid) LM1	1/24	4.2	0/11	0.0	0.16	
Odontome P1-P2	0/30	0.0	0/23	0.0	n/a	
Congenital absence UM3	0/34	0.0	0/22	0.0	n/a	
Distal trigonid crest LM1	0/17	0.0	0/7	0.0	n/a	
Peg-reduced UI2	0/20	0.0	0/13	0.0	n/a	
Cusp 5 (metaconule) UM1	0/27	0.0	1/18	5.6	0.04	
Winging UI1	0/11	0.0	0/9	0.0	n/a	
Root number LC	0/34	0.0	0/22	0.0	n/a	
Root number LM1	0/28	0.0	0/15	0.0	n/a	
Double shovel UI1	0/9	0.0	1/11	9.1	0.01	
Cusp number LM1	0/22	0.0	0/10	0.0	n/a	

Table 5.09: Frequencies of all 39 non-metric traits for Kisalian and Kabambian periods (left antimeres only; sexes and sites combined). χ^2 values are for comparisons of frequencies in Kisalian and Kabambian periods; p-values are reported only if significant at the 0.05 level.

Trait	Frequency: Kisalian	% Kisalian	Frequency: Kabambian	% Kabambian	Calculated χ^2 value	p value
Root number LM2	35/35	100.0	20/23	87.0	2.52	
Root number UM1	42/45	93.3	28/30	93.3	0.22	
Hypocone UM2	38/45	84.4	17/23	73.9	1.09	
Root number UM2	29/38	76.3	19/24	79.2	0.00	
Groove pattern LM2	25/34	73.5	17/21	81.0	0.09	
Root number UM3	18/25	72.0	13/23	56.5	1.25	
Canine mesial ridge UC	23/33	69.7	9/11	81.8	0.15	
Shovel UI1	15/24	62.5	6/12	50.0	0.50	
Deflecting wrinkle LM1	17/29	58.6	6/14	42.9	0.94	
Labial curvature UI1	20/37	54.1	3/15	20.0	3.73	
Cusp number LM2	18/37	48.6	15/23	65.2	1.57	
Mandibular torus	21/51	41.2	12/24	50.0	0.52	
Carabelli's trait UM1	19/47	40.4	3/23	13.0	4.18	**0.0410**
Anterior fovea LM1	14/35	40.0	6/12	50.0	0.07	
Distal accessory ridge UC	10/25	40.0	7/7	100.0	5.68	**0.0172**
Root number UP1	13/33	39.4	7/24	29.2	0.64	
Parastyle UM3	10/28	35.7	4/21	19.0	0.92	
Torsomolar angle LM3	4/14	28.6	4/16	25.0	0.04	
Protostylid LM1	10/37	27.0	5/21	23.8	0.00	
Midline diastema UI1	4/15	26.7	3/8	37.5	0.00	
Interruption groove UI2	8/32	25.0	4/14	28.6	0.01	
Tuberculum dentale UI2	7/29	24.1	3/11	27.3	0.04	
Enamel extension UM1	10/44	22.7	5/25	20.0	0.00	
Lingual cusp number LP2	5/25	20.0	8/19	42.1	1.58	
Peg-shaped UM3	6/31	19.4	6/21	28.6	0.60	
Palatal torus	3/21	14.3	2/12	16.7	0.10	
Cusp 7 (metaconulid) LM1	6/44	13.6	1/24	4.2	0.66	
Cusp 5 (metaconule) UM1	6/47	12.8	6/26	23.1	1.30	
Rocker jaw	4/41	9.8	6/18	33.3	3.41	
Cusp number LM1	4/42	9.5	2/22	9.1	0.16	
Distal trigonid crest LM1	3/37	8.1	1/16	6.3	0.11	
Tome's root LP1	2/26	7.7	1/15	6.7	0.25	
Double shovel UI1	2/28	7.1	0/14	0.0	0.07	
Odontome P1-P2	0/42	0.0	0/23	0.0	n/a	
Congenital absence UM3	0/37	0.0	0/27	0.0	n/a	
Peg-reduced UI2	0/35	0.0	0/16	0.0	n/a	
Winging UI1	0/21	0.0	0/6	0.0	n/a	
Root number LC	0/44	0.0	0/21	0.0	n/a	
Root number LM1	0/36	0.0	1/25	4.0	0.03	

Figure 5.06: Y-groove pattern, determined by contact of cusps 2 and 3 (as arrowed), on LLM1 of Sanga T49.

Figure 5.07: Moderately developed (ASUDAS grade 3) mesial canine ridge (red oval) on RUC of Sanga T68.

Table 5.10: Description of the grades for the degree of trait expression (traits are listed in alphabetical order).

TRAIT	Frequency*	Moderate to marked*	Marked to extreme*
Anterior fovea LM1	ASU 2-4	ASU 2-3	ASU 4
Canine mesial ridge UC	ASU 1-3	ASU 2	ASU 3
Carabelli's trait UM1	ASU 2-7	ASU 3-4	ASU 5-7
Congenital absence UM3	ASU -	ASU -	n/a
Cusp 5 (metaconule) UM1	ASU 2-5	ASU 3-4	ASU 5
Cusp 7 (metaconulid) LM1	ASU 2-4	ASU 2-3	ASU 4
Cusp number LM1	ASU 6	ASU 6	n/a
Cusp number LM2	ASU 5+	ASU 5	ASU 6
Deflecting wrinkle LM1	ASU 2-3	ASU 2	ASU 3
Distal accessory ridge UC	ASU 2-5	ASU 2-3	ASU 4-5
Distal trigonid crest LM1	ASU +	ASU +	n/a
Double shovel UI1	ASU 2-6	ASU 3-4	ASU 5-6
Enamel extension UM1	ASU 1-3	ASU 2	ASU 3
Groove pattern LM2	ASU Y	ASU Y	n/a
Hypocone UM2	ASU 3-5	ASU 3-3.5	ASU 4-5
Interruption groove UI2	ASU +	ASU +	n/a
Labial curvature UI1	ASU 2-4	ASU 2-3	ASU 4
Lingual cusp number LP2	ASU 2-9	ASU 2-9	n/a
Mandibular torus	ASU 2-3	ASU 2	ASU 3
Midline diastema UI1	≥ 0.5mm	≥ 0.5mm	n/a
Odontome P1-P2	ASU +	ASU +	n/a
Palatal torus	ASU 2-3	ASU 2-3	ASU 4
Parastyle UM3	ASU 1-5	ASU 2	ASU 3-6
Peg-reduced UI2	ASU P or R	ASU P or R	n/a
Peg-shaped UM3	ASU P or R	ASU P or R	n/a
Protostylid LM1	ASU 1-6	ASU 1-6	n/a
Rocker jaw	ASU 1-2	ASU 1-2	n/a
Root number LC	ASU 2	ASU 2	n/a
Root number LM1	ASU 3	ASU 3	n/a
Root number LM2	ASU 2+	ASU 2	ASU 3
Root number UM1	ASU 3+	ASU 3	ASU 4
Root number UM2	ASU 3+	ASU 3	ASU 4
Root number UM3	ASU 3+	ASU 3	ASU 4
Root number UP1	ASU 2+	ASU 2	ASU 3
Shovel UI1	ASU 2-6	ASU 3-4	ASU 5-6
Tome's root LP1	ASU 3-5	ASU 2-4	ASU 5
Torsomolar angle LM3	ASU +	ASU +	n/a
Tuberculum dentale UI2	ASU 2-6	ASU 3-4	ASU 5-6
Winging UI1	ASU 1	ASU 1	n/a

Frequency*: after Turner (1985) and Haeussler *et al*. (1989)
Moderate to marked, and Marked to extreme categories: current study procedure

Table 5.11: Frequencies of traits scored as present/absent based on Turner (1985) and Haeussler *et al*. (1989) compared with frequencies of the same traits in strongly expressed categories only.

Trait	Frequency*	%	Moderate to marked*	%	Marked to extreme *	%
Root number LM2	63/66	**95.5**	63/66	**95.5**	0/66	**0.0**
Root number UM1	81/86	**94.2**	81/86	**94.2**	0/86	**0.0**
Hypocone UM2	65/80	**81.3**	42/80	**52.5**	23/80	**28.8**
Root number UM2	57/72	**79.2**	57/72	**79.2**	0/72	**0.0**
Groove pattern LM2	45/60	**75.0**	45/60	**75.0**	n/a	n/a
Canine mesial ridge UC	34/50	**68.0**	14/50	**28.0**	11/50	**22.0**
Root number UM3	36/56	**64.3**	36/56	**64.3**	0/56	**0.0**
Shovel UI1	24/39	**61.5**	2/39	**5.1**	0/39	**0.0**
Distal accessory ridge UC	21/37	**56.8**	16/37	**43.2**	5/37	**13.5**
Cusp number LM2	35/66	**53.0**	30/66	**45.5**	5/66	**7.6**
Deflecting wrinkle LM1	23/44	**52.3**	14/44	**31.8**	9/44	**20.5**
Mandibular torus	38/84	**45.2**	24/84	**28.6**	14/84	**16.7**
Labial curvature UI1	25/57	**43.9**	25/57	**43.9**	0/57	**0.0**
Anterior fovea LM1	21/49	**42.9**	21/49	**42.9**	0/49	**0.0**
Root number UP1	24/65	**36.9**	24/65	**36.9**	0/65	**0.0**
Midline diastema UI1	10/28	**35.7**	10/28	**35.7**	n/a	n/a
Tuberculum dentale UI2	14/45	**31.1**	5/45	**11.1**	1/45	**2.2**
Parastyle UM3	18/59	**30.5**	11/59	**18.6**	7/59	**11.9**
Carabelli's trait UM1	22/78	**28.2**	12/78	**15.4**	5/78	**6.4**
Protostylid LM1	17/63	**27.0**	1/63	**1.6**	n/a	n/a
Interruption groove UI2	12/49	**24.5**	13/51	**25.5**	n/a	n/a
Lingual cusp number LP2	12/49	**24.5**	15/51	**29.4**	n/a	n/a
Enamel extension UM1	18/77	**23.4**	1/77	**1.3**	0/77	**0.0**
Peg-shaped UM3	14/61	**23.0**	0/61	**0.0**	n/a	n/a
Torsomolar angle LM3	8/36	**22.2**	8/36	**22.2**	n/a	n/a
Rocker jaw	11/65	**16.9**	5/65	**7.7**	n/a	n/a
Cusp 5 (metaconule) UM1	12/83	**14.5**	7/83	**8.4**	0/83	**0.0**
Palatal torus	5/36	**13.9**	5/36	**13.9**	0/36	**0.0**
Tome's root LP1	5/48	**10.4**	6/48	**12.5**	1/48	**2.1**
Cusp 7 (metaconulid) LM1	7/73	**9.6**	6/73	**8.2**	1/73	**1.4**
Cusp number LM1	6/69	**8.7**	6/69	**8.7**	n/a	n/a
Distal trigonid crest LM1	4/54	**7.4**	4/54	**7.4**	n/a	n/a
Double shovel UI1	2/45	**4.4**	0/45	**0.0**	0/45	**0.0**
Root number LM1	1/67	**1.5**	1/67	**1.5**	n/a	n/a
Odontome P1-P2	0/76	**0.0**	0/76	**0.0**	n/a	n/a
Congenital absence UM3	0/76	**0.0**	0/76	**0.0**	n/a	n/a
Peg-reduced UI2	0/55	**0.0**	0/55	**0.0**	n/a	n/a
Winging UI1	0/30	**0.0**	0/30	**0.0**	n/a	n/a
Root number LC	0/74	**0.0**	0/74	**0.0**	n/a	n/a

Frequency*: includes trace to extreme expression. See Table 5.2.5.
Moderate to marked*, and Marked to extreme* categories: current study procedure

5.2.2 Metric dental traits

Mean mesio-distal and bucco-lingual diameters of all teeth measured (all sexes and time periods) can be found in Appendix 3. Values for mean diameters and the results of t-tests comparing males and females, Kisalian and Kabambian, and Sanga and Katoto are reported in Table 5.12. Unless otherwise stated, measurements are from the left antimere, since the two sides were bilaterally symmetrical (Table 5.13). The ratio of right to left mean diameters ranged from 0.98 to 1.03 for females and 0.96 to 1.05 for males, i.e. very close to one. Plotting the two against each other yields r^2 values of >0.99 for females and >0.98 for males (Figures 5.08 and 5.09). Scatterplots of all measured posterior teeth were drawn in order to demonstrate group clustering for each crown diameter (Figures 5.10 to 5.24). Ellipses show the 95% confidence interval.

Males generally had larger teeth than females (Table 5.12 and Figures 5.10 to 5.14). This difference was, however, not statistically significant except in three diameters, i.e. UM1 bucco-lingual ($t = -2.24$, $p = 0.0302$), LM2 mesio-distal ($t = -2.38$, $p = 0.0223$) and LM3 mesio-distal ($t = -2.03$, $p = 0.0490$) diameters. Tooth crown sizes among females were more varied than among the males. The greatest variation observed was in the UM2 bucco-lingual diameter, and the least in the UP1 mesio-distal diameter.

Slight differences were observed between time periods. Teeth in the Kisalian period appeared to be larger than in the Kabambian period (Table 5.12 and Figures 5.15 to 5.19). Only three diameters showed significant differences temporally; namely, UP2 mesio-distal ($t = 2.22$, $p = 0.0304$), LP2 mesio-distal ($t = 2.93$, $p = 0.0052$) and LM1 mesio-distal ($t = 3.21$, $p = 0.0022$) diameters. There was also greater variation in crown diameters during the Kisalian than in the Kabambian period (55.0% of the variance in mean diameters was found in the Kisalian period). The UM2 bucco-lingual diameter demonstrated the highest variation and the lowest was seen in LP1 mesio-distal diameter. This, however, seems very likely to be influenced by varying sample sizes per group.

When comparing tooth size between sites, no significant differences were found. Sample sizes at Sanga and Katoto limited detailed comparison of crown diameters. The teeth at both sites do, however, demonstrate very similar sized crown diameters (t-tests showed no significant differences). The six sites can therefore be pooled as no differences in tooth size existed between them (Table 5.12 and Figures 5.20 to 5.24).
In all analyses, no single tooth showed significant differences between groups in both mesio-distal and bucco-lingual crown diameters, i.e. significant differences were always observed in only one diameter of any particular tooth. It was interesting to note that five of the six significantly different diameters were mesio-distal and only one was bucco-lingual. It can, therefore, be said that mesio-distal diameters showed more variability than bucco-lingual diameters.

In summary, teeth were similar in size in men and women, in the Kisalian compared with the Kabambian period, and at the different sites.

Table 5.12: Results of T-tests comparing mean tooth diameters grouped by sex, time period, and site. Significant differences are bold and underlined.

Diameter	Male n* = 20	Std. Dev.	Female n* = 31	Std. Dev.	t-test M vs. F	Kisalian n* = 47	Std. Dev.	Kabambian n* = 25	Std. Dev.	t-test Kis vs. Kab	Sanga n* = 41	Std. Dev.	Katoto n* = 11	Std. Dev.	t-test Sanga vs. Katoto
UP1-MD	7.4	0.9	7.1	0.4	-1.40	7.1	0.5	7.0	0.4	0.64	7.3	0.7	7.2	0.6	0.37
UP1-BL	9.6	0.8	9.4	0.5	-0.52	9.5	0.7	9.3	0.6	0.94	9.5	0.8	9.4	0.7	0.19
UP2-MD	6.7	0.3	6.6	0.4	-0.60	6.8	0.4	6.5	0.4	**2.22**	7.3	0.6	7.3	0.3	0.18
UP2-BL	9.4	0.5	9.4	0.7	-0.52	9.4	0.6	9.2	0.6	1.08	8.3	0.6	8.6	0.6	-0.91
UM1-MD	10.4	0.6	10.2	0.6	-1.23	10.4	0.7	10.1	0.4	1.87	10.4	0.6	10.5	0.9	-0.76
UM1-BL	11.5	0.7	11.1	0.6	**-2.24**	11.1	0.7	11.1	0.7	-0.10	11.3	0.8	11.0	0.7	1.28
UM2-MD	10.0	0.6	9.8	0.8	-1.00	9.8	0.8	9.8	0.6	0.39	9.8	0.6	9.9	1.0	-0.14
UM2-BL	11.4	0.7	11.0	0.9	-1.80	11.0	0.9	11.0	0.8	0.10	11.2	0.9	10.9	1.2	0.79
UM3-MD	8.8	0.7	8.8	0.7	0.14	9.0	0.8	8.7	0.8	1.06	8.9	0.9	8.6	0.7	0.67
UM3-BL	10.6	0.9	10.4	0.9	-0.52	10.5	0.9	10.6	0.9	-0.19	10.7	0.9	10.8	1.2	-0.35
LP1-MD	7.3	0.4	7.0	0.5	-1.74	7.1	0.4	7.0	0.6	0.89	7.1	0.5	7.3	0.2	-0.42
LP1-BL	8.2	0.6	8.1	0.7	-0.68	8.0	0.5	8.1	0.8	-0.42	8.0	0.8	8.1	0.7	-0.15
LP2-MD	7.3	0.4	7.2	0.4	-0.36	7.4	0.5	7.0	0.4	**2.93**	6.8	0.4	6.5	0.3	1.82
LP2-BL	8.4	0.7	8.3	0.6	-0.27	8.4	0.5	8.3	0.7	0.19	9.4	0.6	9.0	0.4	1.64
LM1-MD	11.3	0.6	11.0	0.7	-1.32	11.4	0.6	10.9	0.6	**3.21**	11.3	0.7	11.2	0.4	0.34
LM1-BL	10.5	0.8	10.5	0.6	0.08	10.6	0.6	10.5	0.7	0.09	10.5	0.7	10.7	0.5	-0.85
LM2-MD	10.9	0.6	10.4	0.7	**-2.38**	10.8	0.8	10.7	0.5	0.60	10.8	0.7	10.6	1.0	0.76
LM2-BL	10.3	0.7	10.2	0.6	-0.76	10.2	0.7	10.3	0.7	-0.63	10.3	0.7	10.3	0.6	0.13
LM3-MD	11.0	0.6	10.5	0.9	**-2.03**	10.8	1.0	10.8	0.8	0.03	10.7	1.0	10.9	0.6	-0.51
LM3-BL	10.2	0.7	10.0	0.6	-1.01	10.1	0.6	10.0	0.7	0.22	10.0	0.7	10.2	0.4	-0.46

n*: valid number of cases for the t-test.

Table 5.13: Mean mesio-distal (MD) and bucco-lingual (BL) tooth diameters for males and females, comparing left (L) and right (R) antimeres (sites and time periods combined).

Diameter	R antimere: Male	L antimere: Male	right/left: Male	R antimere: Female	L antimere: Female	right/left: Female
UP1-MD	7.1	7.4	0.96	7.1	7.1	1.00
UP1-BL	9.5	9.6	0.99	9.4	9.4	1.00
UP2-MD	6.7	6.7	1.00	6.6	6.7	0.99
UP2-BL	9.4	9.4	1.00	9.4	9.3	1.01
UM1-MD	10.4	10.4	1.00	10.2	10.4	0.98
UM1-BL	11.4	11.5	0.99	11.1	11.1	1.00
UM2-MD	9.8	10.0	0.98	9.8	9.8	1.00
UM2-BL	11.3	11.4	0.99	11.0	11.0	1.00
UM3-MD	8.9	8.8	1.01	8.8	8.6	1.02
UM3-BL	11.1	10.6	1.05	10.4	10.3	1.01
LP1-MD	7.3	7.3	1.00	7.0	7.0	1.00
LP1-BL	8.1	8.2	0.99	8.1	7.9	1.03
LP2-MD	7.2	7.3	0.99	7.2	7.3	0.99
LP2-BL	8.5	8.4	1.01	8.3	8.4	0.99
LM1-MD	10.8	11.3	0.96	11.0	11.0	1.00
LM1-BL	10.7	10.5	1.02	10.5	10.5	1.00
LM2-MD	10.9	10.9	1.00	10.4	10.6	0.98
LM2-BL	10.4	10.3	1.01	10.2	10.2	1.00
LM3-MD	10.8	11.0	0.98	10.5	10.7	0.98
LM3-BL	9.9	10.2	0.97	10.0	10.0	1.00

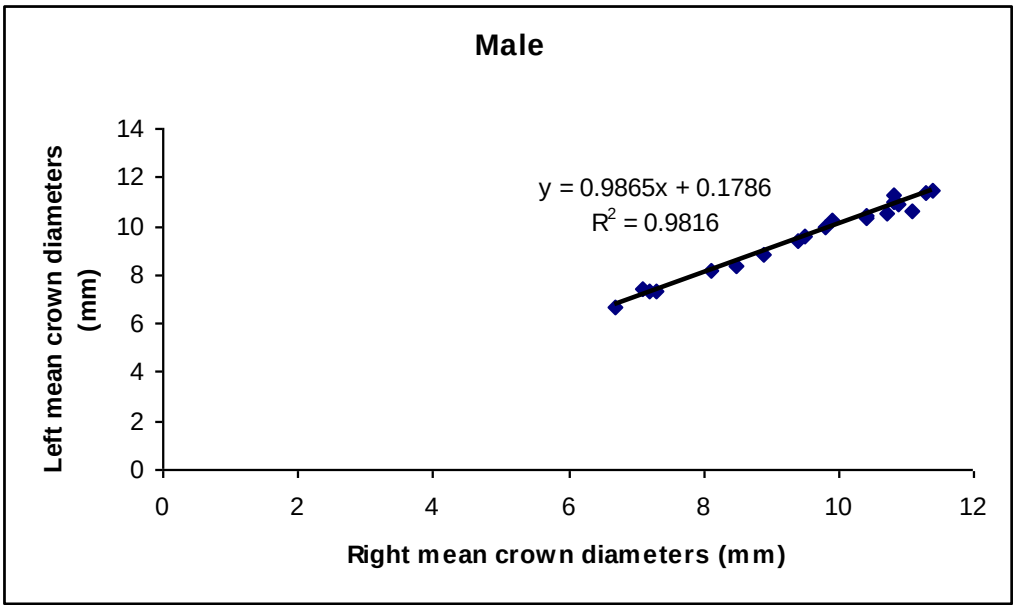


Figure 5.08: Left mean crown diameters (mesio-distal and bucco-lingual) plotted against right mean diameters for all males, to demonstrate bilateral symmetry.

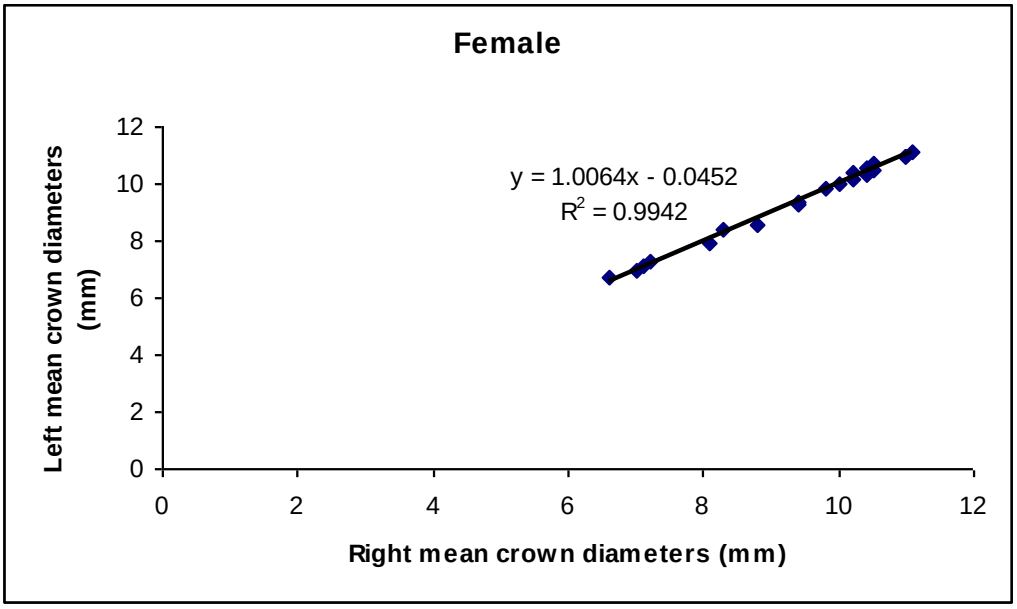
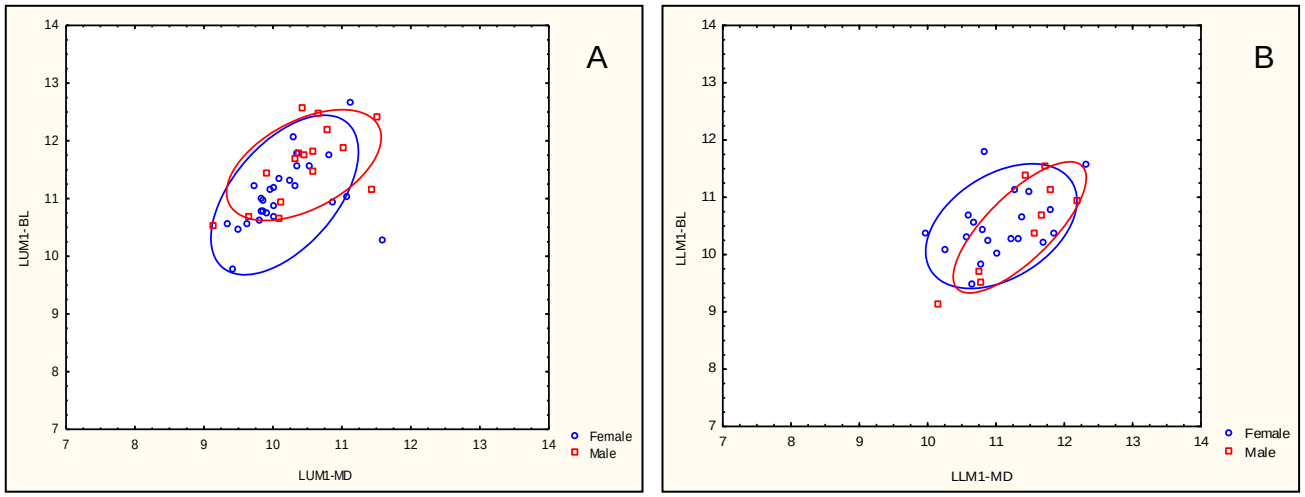
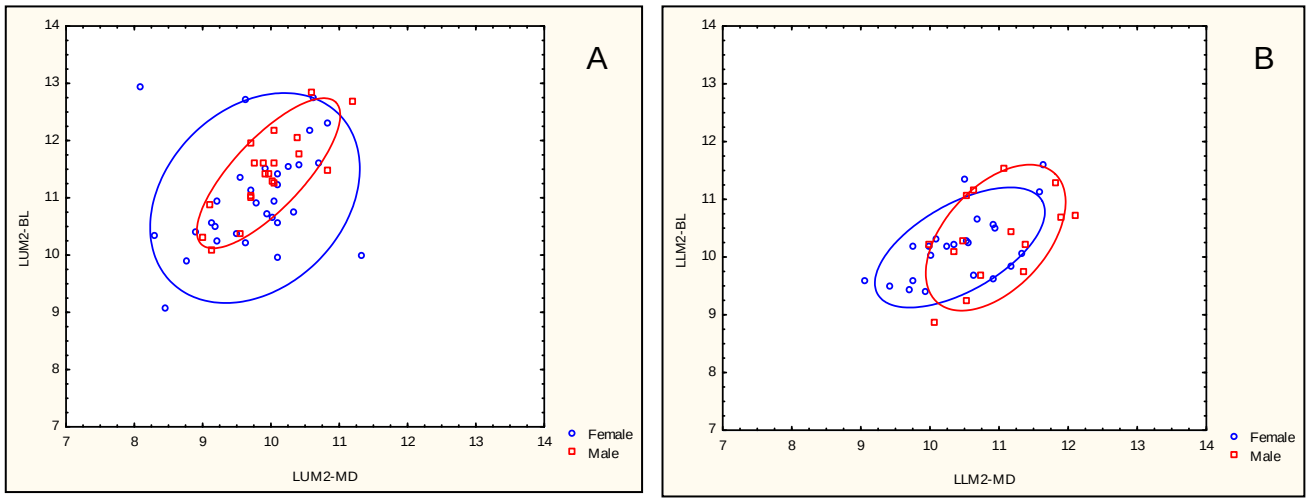


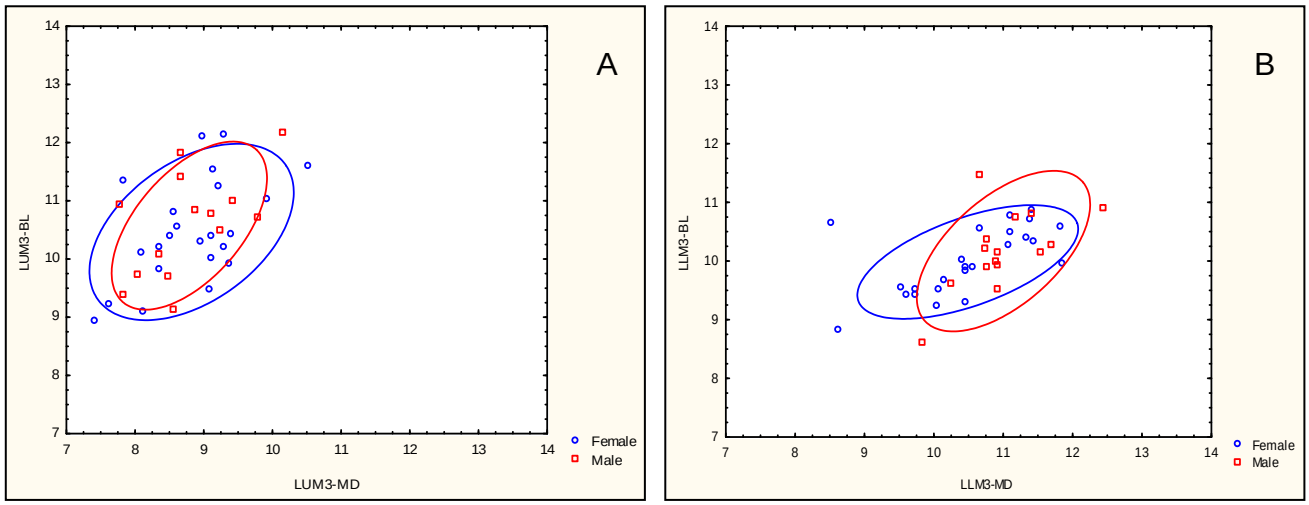
Figure 5.09: Left mean crown (mesio-distal and bucco-lingual) diameters plotted against right mean diameters for all females, to demonstrate bilateral symmetry.



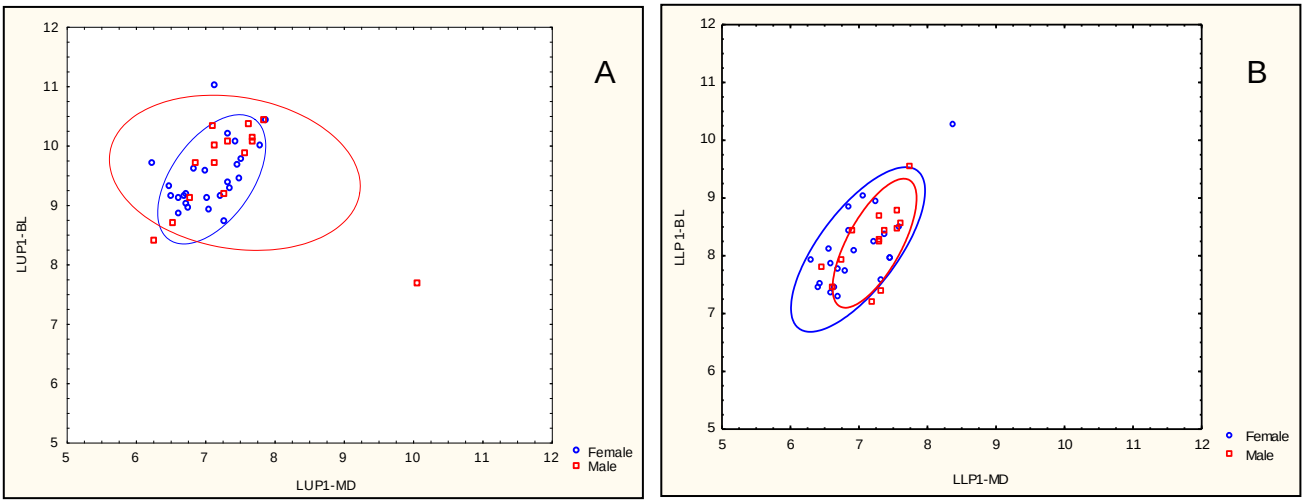
Figures 5.10A & B: Scatterplots of mesio-distal against bucco-lingual diameter showing LUM1 (A) and LLM1 (B), categorised by sex.



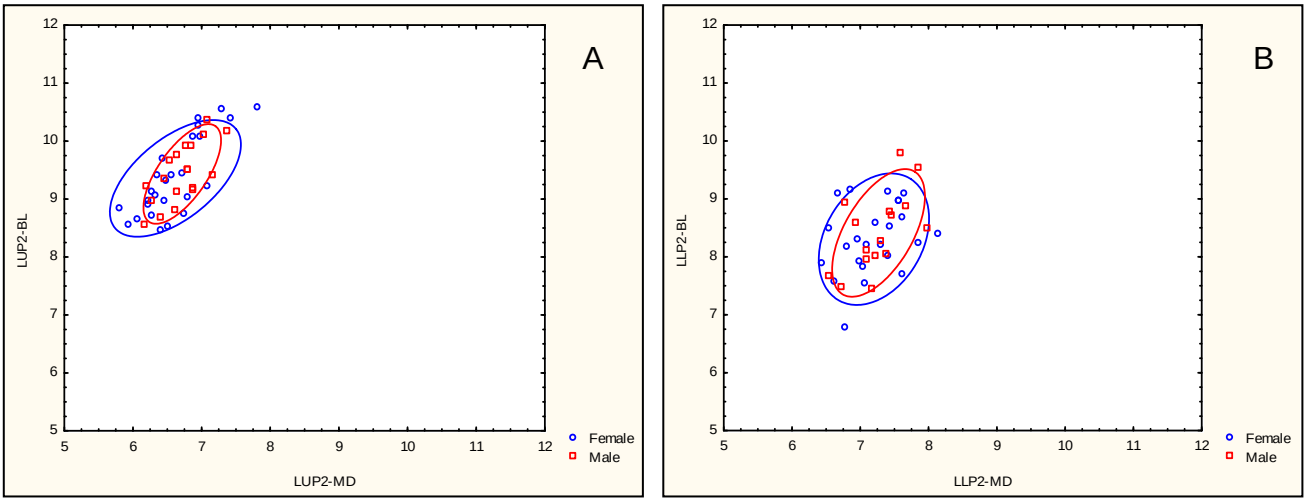
Figures 5.11A & B: Scatterplots of mesio-distal against bucco-lingual diameter showing LUM2 (A) and LLM2 (B), categorised by sex.



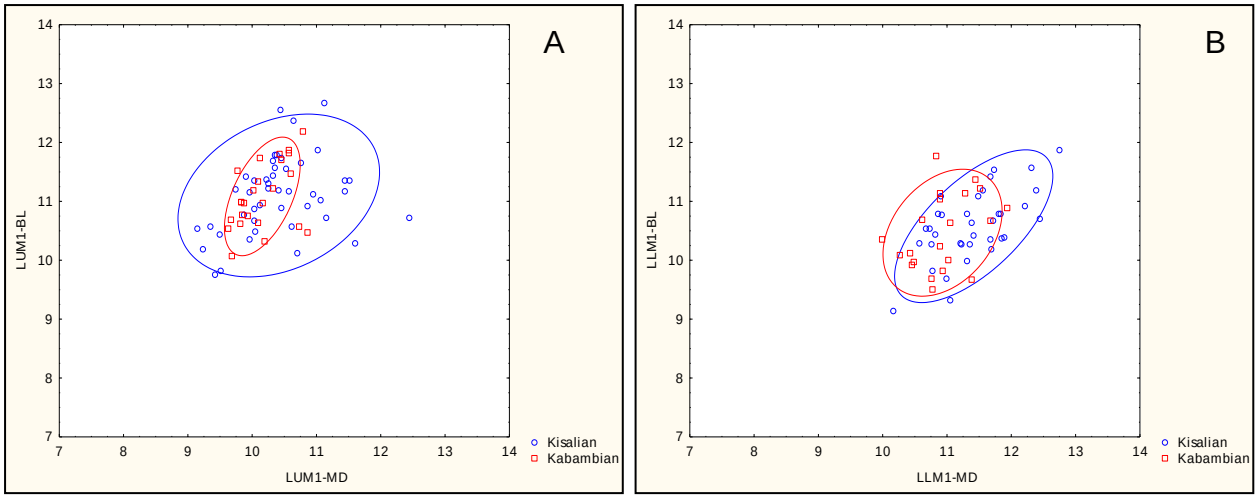
Figures 5.12A & B: Scatterplots of mesio-distal against bucco-lingual diameter showing LUM3 (A) and LLM3 (B), categorised by sex.



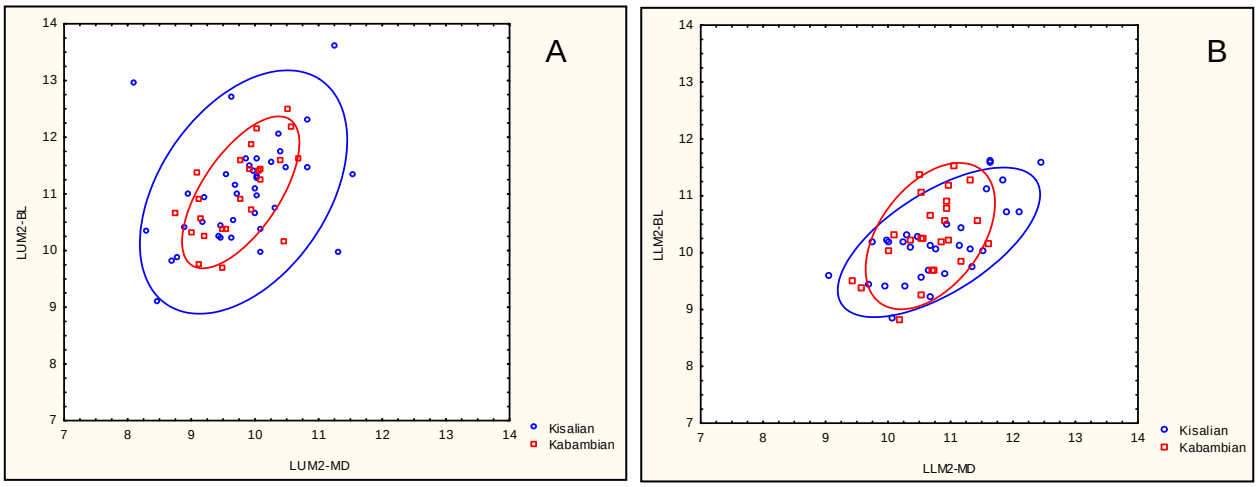
Figures 5.13A & B: Scatterplots of mesio-distal against bucco-lingual diameter showing LUP1 (A) and LLP1 (B), categorised by sex.



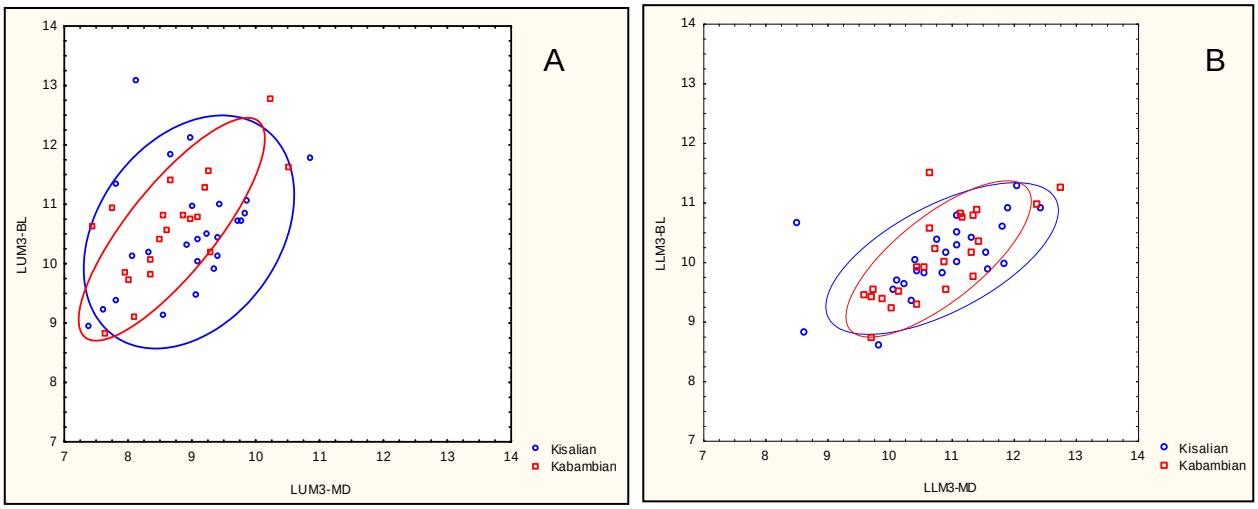
Figures 5.14A & B: Scatterplots of mesio-distal against bucco-lingual diameter showing LUP2 (A) and LLP2 (B), categorised by sex.



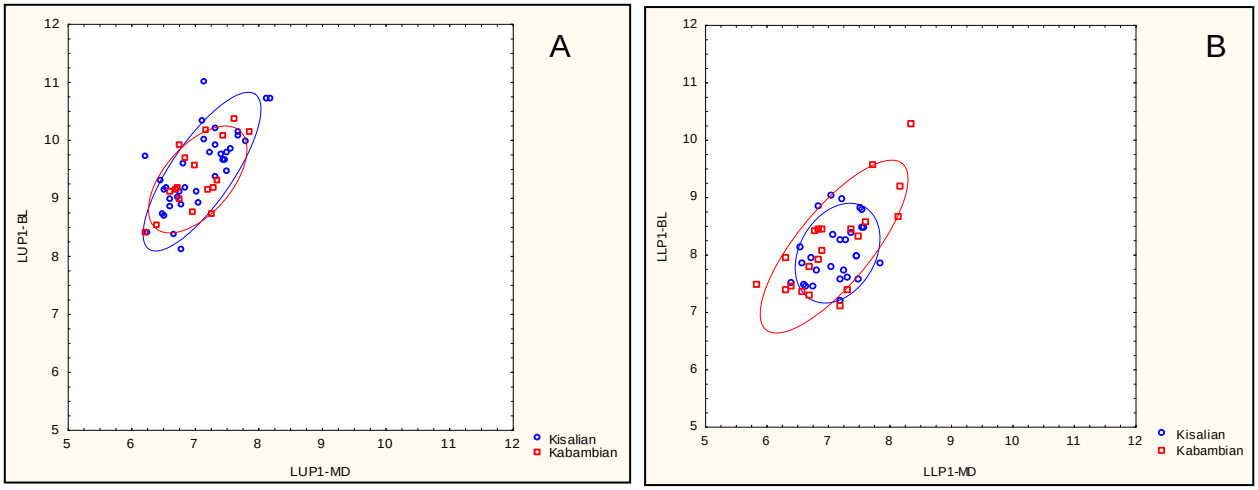
Figures 5.15A & B: Scatterplots of mesio-distal against bucco-lingual diameter showing LUM1 (A) and LLM1 (B), temporally categorised.



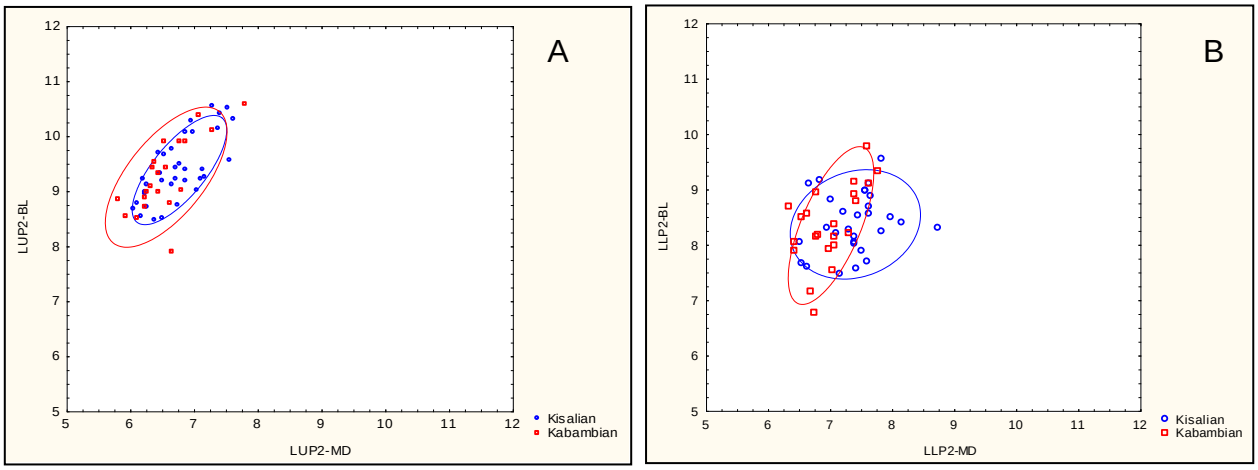
Figures 5.16A & B: Scatterplots of mesio-distal against bucco-lingual diameter showing LUM2 (A) and LLM2 (B), temporally categorised.



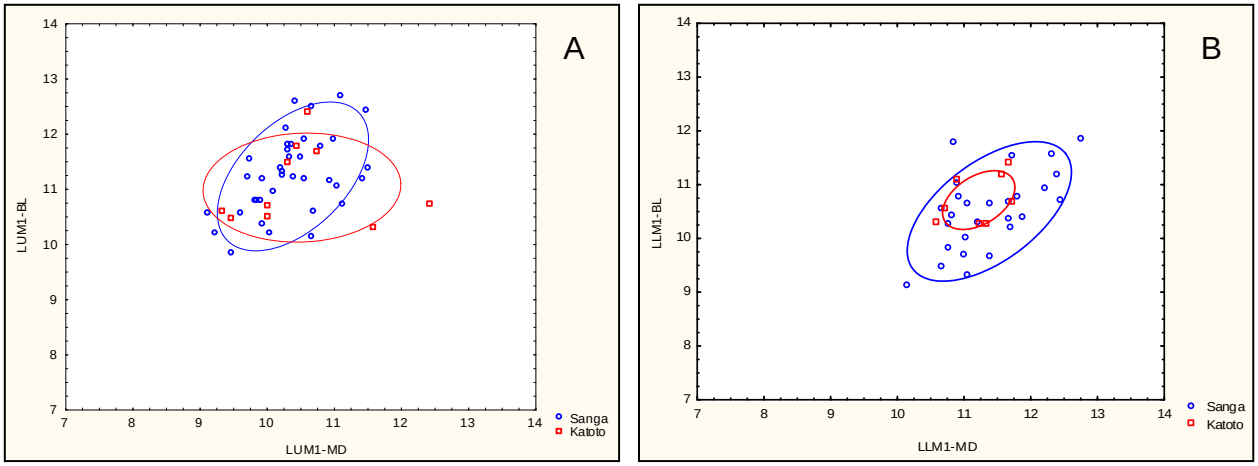
Figures 5.17A & B: Scatterplots of mesio-distal against bucco-lingual diameter showing LUM3 (A) and LLM3 (B), temporally categorised.



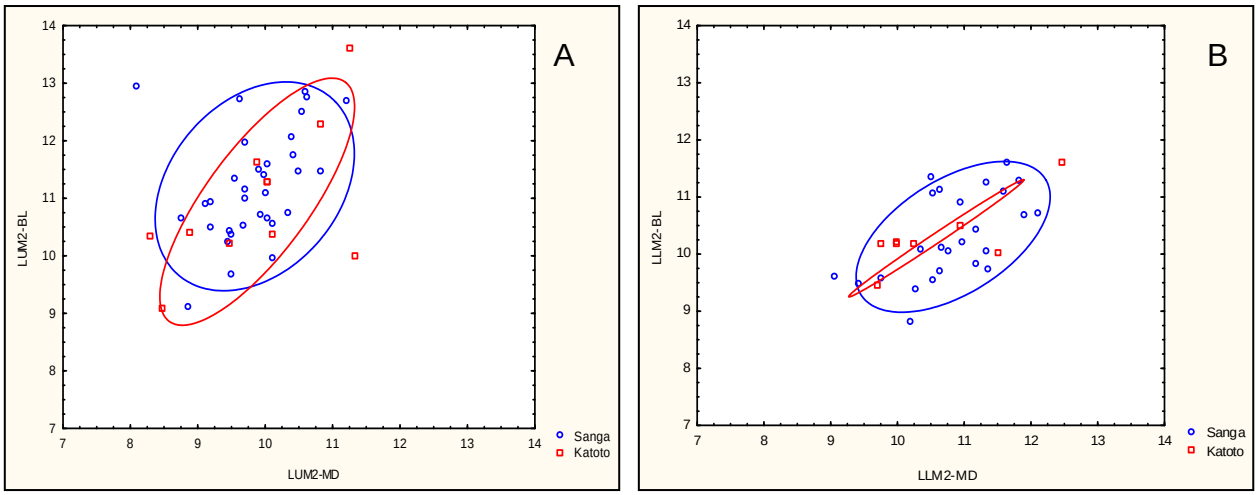
Figures 5.18A & B: Scatterplots of LUP1 and LLP1, BL against MD, temporally categorised.



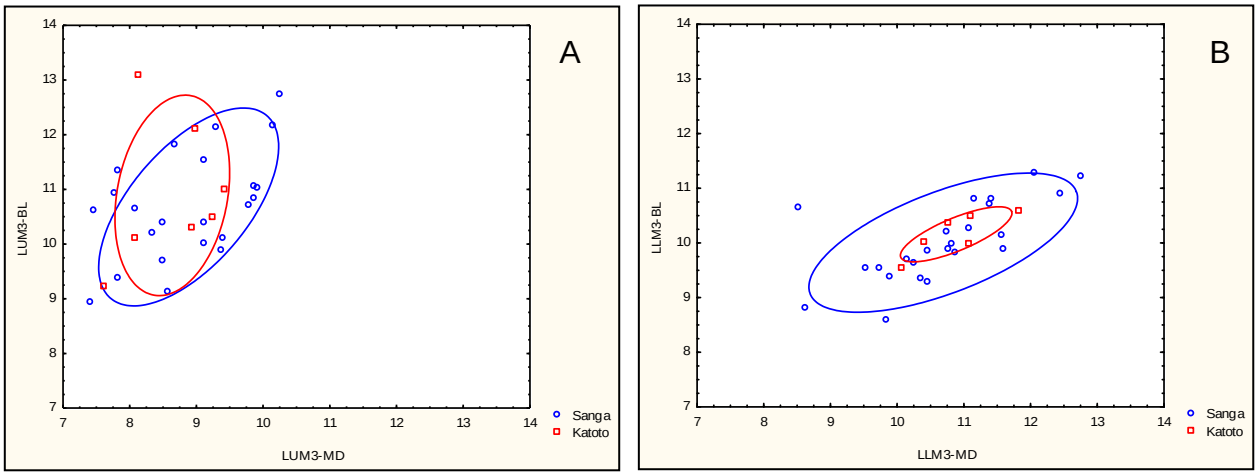
Figures 5.19A & B: Scatterplots of LUP2 and LLP2, BL against MD, temporally categorised.



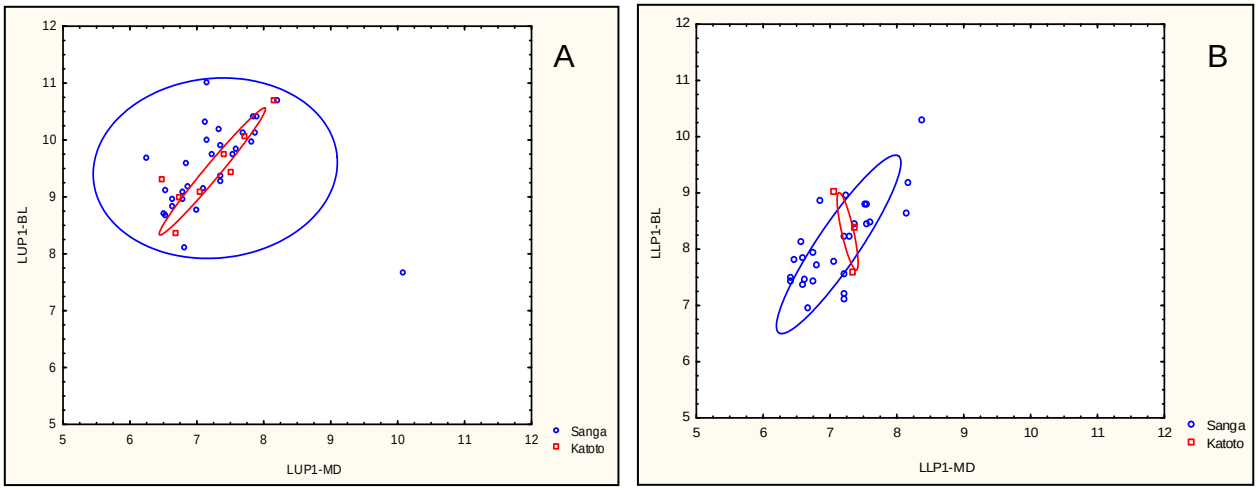
Figures 5.20A & B: Scatterplots of mesio-distal against bucco-lingual diameter showing LUM1 (A) and LLM1 (B), categorised by site.



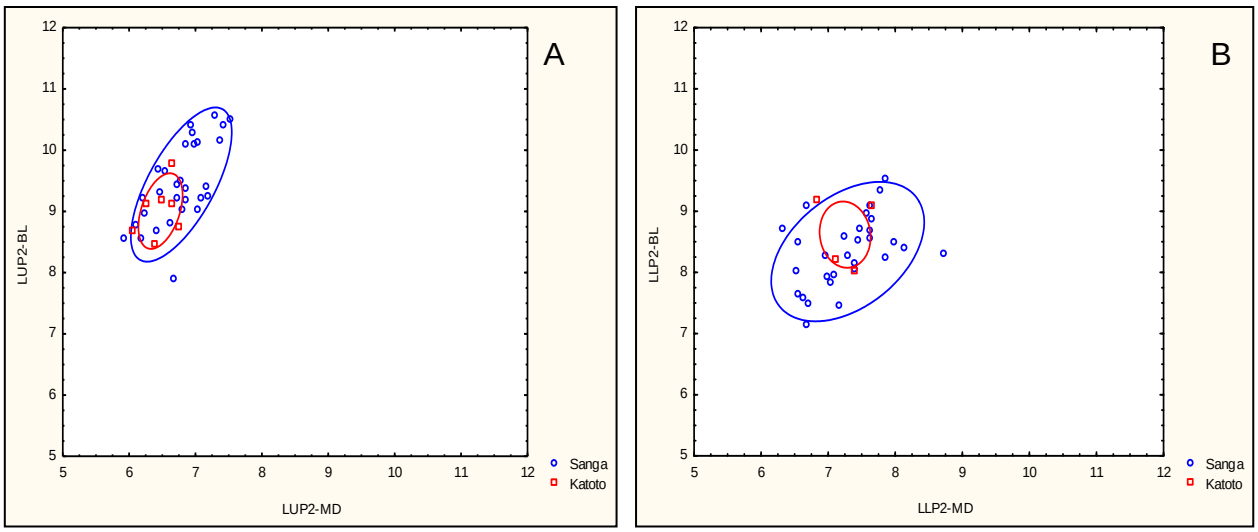
Figures 5.21A & B: Scatterplots of mesio-distal against bucco-lingual diameter showing LUM2 (A) and LLM2 (B), categorised by site.



Figures 5.22A & B: Scatterplots of mesio-distal against bucco-lingual diameter showing LUM3 (A) and LLM3 (B), categorised by site.



Figures 5.23A & B: Scatterplots of mesio-distal against bucco-lingual diameter showing LUP1 (A) and LLP1 (B), categorised by site.



Figures 5.24A & B: Scatterplots of mesio-distal against bucco-lingual diameter showing LUP1 (A) and LLP1 (B), categorised by site.

5.3 Oral health and pathology

Numbers of individuals for whom oral health and pathology could be studied were affected by the preservation and condition of teeth and sockets present. As a result, total numbers of individuals differed per analysis. Males and females were initially kept separate in all analyses of dental pathological conditions. However, since this meant that sample sizes were too small to make meaningful comparisons, the sexes were pooled and total numbers of individuals used to draw conclusions. Inter-site comparisons were made only between Sanga and Katoto due to their larger sample sizes. Unless otherwise stated, frequencies of all pathologies were calculated as the number of teeth or sockets with at least one observable pathological condition divided by the total number of teeth.

5.3.1 Dental caries

Tables 5.14 to 5.16 present the rates of caries in the Upemba adult population. Numbers of individuals were calculated based on the presence of at least one permanent tooth, although all individuals were represented by more than one tooth. In order to avoid double counting, only one lesion was counted per tooth affected regardless of the actual number of lesions. In essence, the severity of caries in this population is therefore underestimated.

Table 5.14 shows the distribution of caries by tooth class, on maxillary and mandibular teeth, caries severity and location on tooth surfaces. 187 carious lesions were recorded on 1713 teeth (10.9%) of 98 individuals. On average, the severity of caries in the Upemba adult population was moderate; with 1.9 carious lesions per individual (Table 5.15). Third molars (19.8%) were the most commonly affected teeth, followed by the M2 (19.2%) and the M1 (13.4%). Canines and incisors were least impacted by caries (Table 5.14 and Figure 5.25). 64.5% of caries were found on the mandible. The majority of the lesions recorded were minimal to moderate in severity. A sizeable proportion (18.7%) of carious lesions were, however, extremely severe, with the entire tooth crown destroyed.

The majority (62.0%) of caries were found on the interproximal (mesial and distal) surfaces of the teeth (Figure 5.25). Gross lesions (Figure 5.26), which have an unclear starting point and destruction of more than one tooth surface, made up 20.9% of all caries (Table 5.14). Occlusal caries, which initiate on the fissures and grooves of premolars and molars, accounted for 10.7% of all lesions. Root and flat-surface lesions were less common (3.7% and 2.7%, respectively). The location and severity of caries are important factors for the assessment of cariogenicity of diet and their implications will be explored in the following chapter.

The highest frequency of caries was found at Sanga (61.7% of individuals), followed by Malemba-Nkulu (61.5%), while at the other four sites, less than 30% of individuals were affected by caries (Table 5.15). The total number of teeth affected by caries was also very high at Sanga (17.1%), and showed a significant difference ($\chi^2 = 17.97$, $p = 0.0000$) when compared to 3.9% of carious teeth seen at Katoto. When sites are pooled, the overall percent of carious teeth was significantly higher in males (15.4%) than in females (9.8%) ($\chi^2 = 9.34$, $p = 0.0022$).

There were significantly more carious lesions in the Kisalian period (12.8% of teeth) compared to the Kabambian (6.6%) ($\chi^2 = 14.13$, $p = 0.0002$). At all sites combined, there was no significant difference in the proportion of older compared with younger adults affected by caries ($\chi^2 = 2.35$, $p = 0.1256$) (Table 5.16). Older adults were, however, more severely affected: 20.0% of the teeth of older adults showed carious lesions, while younger adults had 8.6% of teeth with caries ($\chi^2 = 31.47$, $p = 0.0000$). This indicates, therefore, that intensity of caries develops with age.

Table 5.14: Distribution of caries by tooth class, on upper versus lower jaw, severity and location of lesions; all groups pooled.

Tooth class	No. of carious teeth	Total no. of teeth	% Carious teeth
I1	14	150	7.5
I2	16	147	8.6
C	13	208	6.9
P1	24	236	12.8
P2	22	255	11.8
M1	25	239	13.4
M2	36	246	19.2
M3	37	232	19.8
TOTAL	**187**	**1713**	**10.9**
Maxillary	74	925	39.6
Mandibular	113	788	64.9
Severity of caries			
minimal	74	-	39.6
moderate	67	-	35.8
heavy	11	-	5.9
extreme	35	-	18.7
Location of caries			
interproximal	116	-	62.0
gross	39	-	20.9
occlusal	20	-	10.7
root	7	-	3.7
lingual	3	-	1.6
buccal	2	-	1.1

Table 5.15: Summary of caries rates in males and females, per site.

Sites	Sex	No. of individuals with caries	Total no. of individuals	% Individuals with caries	No. of carious teeth	Total no. of teeth	% Teeth with caries	Carious teeth/ individual
Sanga	F	14	19	73.7	55	369	14.9	2.9
	M	10	17	58.8	74	322	23.0	4.4
	Un	5	11	45.5	20	180	11.1	1.8
	Total	**29**	**47**	**61.7**	**149**	**871**	**17.1**	**3.2**
Katoto	F	4	8	50.0	6	103	5.8	0.8
	M	0	4	0.0	0	31	0.0	0.0
	Un	0	2	0.0	0	21	0.0	0.0
	Total	**4**	**14**	**28.6**	**6**	**155**	**3.9**	**0.4**
Malemba-Nkulu	F	3	5	40.0	8	119	6.7	1.6
	M	3	4	25.0	9	90	10.0	2.3
	Un	2	4	50.0	7	78	9.0	1.8
	Total	**8**	**13**	**61.5**	**24**	**287**	**8.4**	**1.8**
Kikulu	F	1	6	16.7	2	79	2.5	0.3
	M	2	5	60.0	4	94	4.3	0.8
	Un	0	2	0.0	0	21	0.0	0.0
	Total	**3**	**13**	**23.1**	**6**	**194**	**3.1**	**0.5**
Kamilamba	F	0	1	0.0	0	11	0.0	0.0
	M	0	0	n/a	0	0	n/a	n/a
	Un	1	4	25.0	1	96	1.0	0.3
	Total	**1**	**5**	**20.0**	**1**	**107**	**0.9**	**0.2**
Katongo	F	1	3	33.3	1	54	1.9	0.3
	M	0	2	0.0	0	28	0.0	0.0
	Un	0	1	0.0	0	17	0.0	0.0
	Total	**1**	**6**	**16.7**	**1**	**99**	**1.0**	**0.2**
Grand total	All	**98**	**98**	**46.9**	**187**	**1713**	**10.9**	**1.9**

F: Female; M: Male; Un: Unsexed

*Caries per individual = total no. of carious teeth/total no. of individuals

Table 5.16: Summary of caries rates; grouped by sex, time period, and age group.

	No. of individuals with caries	Total no. of individuals	% Individuals with caries	No. of carious teeth	Total no. of teeth	% Carious teeth	Carious teeth/ individual*
Sex							
Female	23	42	54.7	72	735	9.8	1.7
Male	15	32	46.9	87	565	15.4	2.7
Unknown	8	24	33.3	28	413	6.8	1.2
TOTAL	**46**	**98**	**46.9**	**187**	**1713**	**10.9**	**1.9**
Time period							
Kisalian	26	53	49.1	115	900	12.8	2.2
Kabambian	11	29	37.9	38	572	6.6	1.3
Recent	0	4	0.0	0	61	0.0	0.0
Atypical	9	12	75.0	34	180	18.9	2.8
TOTAL	**46**	**98**	**46.9**	**187**	**1713**	**10.9**	**1.9**
Age group							
Sub-adult	2	8	25.0	3	134	2.2	0.4
Young adult	22	48	45.8	76	881	8.6	1.6
Older adult	14	22	63.6	72	360	20.0	3.3
Adult	8	20	40.0	36	338	10.7	1.8
TOTAL	**46**	**98**	**46.9**	**187**	**1713**	**10.9**	**1.9**

*Caries per individual = total no. of carious teeth/total no. of individuals

Figure 5.25: Dental caries on the proximal and distal interproximal surfaces (red arrows) of LLM1 and LLP1 of Sanga T24/35.

Figure 5.26: A gross carious lesion (red circle) on RUM1 of Sanga T10.

5.3.2 Antemortem tooth loss

The incidence of antemortem tooth loss (AMTL) was recorded only in adult individuals with preserved alveolar spaces. Numbers of individuals were established based on the presence of at least one alveolar space available for study. All individuals were, however, represented by more than one socket. Table 5.17 shows the distribution of AMTL by tooth class and for maxillary versus mandibular teeth. Overall, 48.5% of 97 individuals had lost at least one tooth antemortem. The most frequently lost teeth were the central incisors (17.1%), followed by the first molars (12.0%). The canines were the least frequently lost (1.3%), followed by P1 (2.9%). In general, mandibular teeth (11.1%) were more frequently lost than maxillary teeth (5.1%) ($\chi^2 = 28.80$, $p = 0.0000$). In particular, the mandibular first molars (19.0%) and mandibular second molars (14.5%) had much higher AMTL frequencies than their maxillary equivalents (5.2% and 6.1%, respectively) ($\chi^2 = 13.86$, $p = 0.0002$ for first molars, and $\chi^2 = 5.61$, $p = 0.0179$ for second molars).

The unusually high frequency of loss of central incisors is due, at least in part, to a cultural practice within these societies of intentionally extracting incisors (Dlamini 2006; see also Chapter 2 and 5 for details). A correction was done to demonstrate the effect of this practice on the frequency of antemortem tooth loss, whereby obvious cases of intentional extraction were excluded from the analysis (see Methods Chapter for selection criteria). The corrected AMTL frequency is shown in Table 5.17. For all other AMTL comparisons, the uncorrected frequency was used. When intentional removal of incisors as a cultural modification was taken into account; the first molars became the most frequently lost teeth (12.0%), followed by the second molars at 10.4% (Table 5.17). Overall, only 6.4% (versus 8.2%) of all teeth were lost antemortem when intentional extraction was taken into account ($\chi^2 = 5.53$, $p = 0.0187$).

Looking at the severity of AMTL in the Upemba Depression, on average, two teeth were lost per individual. This rate, however, differs in different groups, with an average of 3.7 teeth lost per individual at Katongo (Table 5.18), compared with 0.7 at Kamilamba. At Katongo, all six individuals had lost at least one tooth antemortem (100.0%), while at Kamilamba, only one individual out of five (20%) had done so. All

other sites had similar frequencies of AMTL, with between 40-50% of individuals affected. A comparison between Sanga and Katoto showed no significant difference (χ^2 = 0.36, p = 0.5501) (Table 5.18). When looking at sex differences within sites, more males at both Sanga and Katoto were affected by AMTL than the females; but sample numbers are too small to be tested statistically. However, the number of teeth lost antemortem was significantly different between males (26.8%) and females (3.6%) at Katoto (χ^2 = 20.44, p = 0.0000).

When sites, time periods, and ages were pooled; males and females had comparable rates of AMTL, with males at 60.6% and females at 50.0% (χ^2 = 0.84, p = 0.3597) (Table 5.19). Temporally, there were more teeth lost in the Kisalian period (9.3%) than during the Kabambian (4.8%) (χ^2 = 13.63, p = 0.0002). Older adults had lost more teeth antemortem (15.7%) than younger age groups, with a high rate of 4.0 teeth lost per individual. The proportion of older adults affected by AMTL (82.6%) was nearly double that of younger adults (42.9%) (χ^2 = 8.47, p = 0.0036).

Table 5.17: Distribution of antemortem tooth loss (AMTL) by tooth class, on upper versus lower jaw and AMTL corrected for intentional tooth extraction; all groups pooled.

Tooth class	Teeth lost (upper)	Total sockets (upper)	% Teeth lost (upper)	Teeth lost (lower)	Total sockets (lower)	% Teeth lost (lower)	Teeth lost (overall)	Total sockets (overall)	% Teeth lost (overall)	Teeth lost (corrected)*	Total sockets (overall)	% Teeth lost (corrected)*
I1	20	136	14.7	28	135	20.7	48	271	17.7	23	271	8.5
I2	10	132	7.6	20	140	14.3	30	272	11.0	13	272	4.8
C	0	147	0.0	4	150	2.7	4	297	1.3	4	297	1.3
P1	4	153	2.6	5	154	3.2	9	307	2.9	9	307	2.9
P2	2	157	1.3	9	155	5.8	11	312	3.5	11	312	3.5
M1	8	155	5.2	29	153	19.0	37	308	12.0	37	308	12.0
M2	9	147	6.1	22	152	14.5	31	299	10.4	31	299	10.4
M3	7	147	4.8	16	154	10.4	23	301	7.6	23	301	7.6
Total	**60**	**1174**	**5.1**	**133**	**1193**	**11.1**	**193**	**2367**	**8.2**	**151**	**2367**	**6.4**

corrected*: corrected for intentional tooth extraction.

Table 5.18: Summary of AMTL in males and females, per site. AMTL frequencies were not corrected for intentional tooth extraction.

Sites	Sex	No. of individuals with AMTL	Total no. of individuals	% Individuals with AMTL	No. of resorbed sockets	Total no. of sockets	% Sockets with AMTL	AMTL/ individual
Sanga	F	8	19	42.1	53	515	10.3	2.8
	M	12	17	70.6	34	405	8.4	2.0
	Un	2	9	22.2	3	186	1.6	0.3
	Total	**22**	**45**	**48.9**	**90**	**1106**	**8.1**	**2.0**
Katoto	F	3	8	37.5	6	167	3.6	0.8
	M	3	5	60.0	19	71	26.8	3.8
	Un	0	2	0.0	0	33	0.0	0.0
	Total	**6**	**15**	**40.0**	**25**	**271**	**9.2**	**1.7**
Malemba-Nkulu	F	4	5	80.0	8	157	5.1	1.6
	M	1	4	25.0	8	124	6.5	2.0
	Un	1	4	25.0	2	86	2.3	0.5
	Total	**6**	**13**	**46.2**	**18**	**367**	**4.9**	**1.4**
Kikulu	F	3	6	50.0	18	176	10.2	3.0
	M	2	5	40.0	12	146	8.2	2.4
	Un	1	2	50.0	6	38	15.8	3.0
	Total	**6**	**13**	**46.2**	**36**	**360**	**10.0**	**2.8**
Kamilamba	F	0	1	0.0	0	11	0.0	0.0
	M	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Un	1	4	25.0	2	101	2.0	0.5
	Total	**1**	**5**	**20.0**	**2**	**112**	**1.8**	**0.4**
Katongo	F	3	3	100.0	11	77	14.3	3.7
	M	2	2	100.0	8	54	14.8	4.0
	Un	1	1	100.0	3	20	15.0	3.0
	Total	**6**	**6**	**100.0**	**22**	**151**	**14.6**	**3.7**
Grand total	All	**47**	**97**	**48.5**	**193**	**2367**	**8.2**	**2.0**

F: Female; M: Male; Un: Unsexed

*AMTL per individual = total no. of resorbed sockets/total no. of individuals

Table 5.19: Summary of AMTL rates; grouped by site, sex, time period, and age group. AMTL frequencies were not corrected for intentional tooth extraction.

	No. of individuals with AMTL	Total no. of individuals	% Individuals with AMTL	No. of resorbed sockets	Total no. of sockets	% Sockets with AMTL	AMTL/ individual*
Sex							
Female	21	42	50.0	96	1103	8.7	2.3
Male	20	33	60.6	81	800	10.1	2.5
Unknown	6	22	27.3	16	464	3.4	0.7
TOTAL	**47**	**97**	**48.5**	**193**	**2367**	**8.2**	**2.0**
Time period							
Kisalian	27	54	50.0	118	1270	9.3	2.2
Kabambian	12	29	41.4	37	768	4.8	1.3
Recent	3	4	75.0	9	84	10.7	2.3
Atypical	5	10	50.0	29	245	11.8	2.9
TOTAL	**47**	**97**	**48.5**	**193**	**2367**	**8.2**	**2.0**
Age group							
Sub-adult	1	7	14.3	2	197	1.0	0.3
Young adult	21	49	42.9	85	1214	7.0	1.7
Older adult	19	23	82.6	92	562	16.4	4.0
Adult	6	18	33.3	14	394	3.6	0.8
TOTAL	**47**	**97**	**48.5**	**193**	**2367**	**8.2**	**2.0**

*AMTL per individual = total no. of resorbed sockets/total no. of individuals

When all age groups are pooled, a strong negative correlation between caries and antemortem tooth loss (r^2 = 0.8635) was found. With the exception of the M2, all tooth types showing high frequencies of caries were also less frequently affected by AMTL. Therefore, an inverse relationship between caries and ATML exists. Interestingly, however, this relationship changes when we consider only the older adult age group. Frequently in the literature, AMTL rises with age, while caries rates drop (Morris 1992); this is based on the premise that as the teeth are lost (usually due to caries), less teeth are available for caries to develop. In this study, this trend did not hold true as caries rates continued to rise with age, i.e. older adults had more caries than younger adults, in addition to a higher incidence of AMTL. This suggests that caries are not the only cause for AMTL in older adults.

5.3.3 Dental abscesses

The incidence of dental abscesses was recorded only in adult individuals with preserved alveolar spaces. Numbers of individuals were calculated based on the presence of at least one alveolar space available for study. All individuals were, however, represented by more than one socket. Only 3.8% of sockets had been affected by abscesses (Table 5.20). Abscesses occurred mostly on the alveolar bone of first molars (9.3%); while first premolar sockets (1.5%) were least affected (Table 5.20 and Figure 5.27). In general, molars were more affected by abscesses than any other tooth class. The majority of abscesses were small to medium in size. Large abscesses made up a third (32.1%) of all recorded abscesses with fairly large parts of the alveolar bone destroyed (Figure 5.28).

In general, the number of individuals affected by abscesses was high (Table 5.21). Thirty-five of a total of 92 individuals (38.0%) had at least one abscess in their mouths. The average number of abscesses per individual was low at 0.8. When comparing sites, more individuals were affected by abscesses at Katongo (66.7%) than at any other site. This rate was closely followed by that seen at Katoto (57.1%); but at other sites, only about a third of individuals were affected by abscesses (Table 5.21). When looking at sex differences within sites, more males at Sanga and at Katongo were affected by abscesses than the females. The opposite pattern was seen at Katoto and at Kikulu; while at Malemba-Nkulu this rate was comparable between

the sexes. Once again, the very small sample numbers limit any statistical testing for the observed differences.

Overall, more females (43.9%) had abscesses compared to males (39.4%), but the number of sockets with abscesses was lower in females (3.5%) than among the males (4.4%). None of these sex differences were statistically significant (Table 5.22). When comparing time periods, the Kisalian period had 4.0% of all observed sockets with abscesses, while only 2.9% of sockets from the Kabambian period were affected ($\chi^2 = 1.44$, $p = 0.2304$). A marked difference in the occurrence of abscesses was seen only in older compared with younger adults: 7.1% of all alveolar spaces observed in older adults had abscesses, in comparison to 2.8% in younger adults ($\chi^2 = 5.24$, $p = 0.0221$). As seen with caries and AMTL, the frequency of abscesses in these populations increases with age.

Table 5.20: Location and severity of dental abscesses; all groups pooled.

Tooth type	No. of alveoli with abscess	Total no. of alveoli	% Abscessed alveoli
I1	6	235	2.6
I2	6	249	2.4
C	11	271	4.1
P1	4	275	1.5
P2	6	273	2.2
M1	25	270	9.3
M2	10	250	4.0
M3	10	241	4.1
TOTAL	**78**	**2064**	**3.8**
Maxillary	40	938	4.1
Mandibular	37	1079	3.4
Severity of abscess			
small-medium	53	-	67.9
large	25	-	32.1

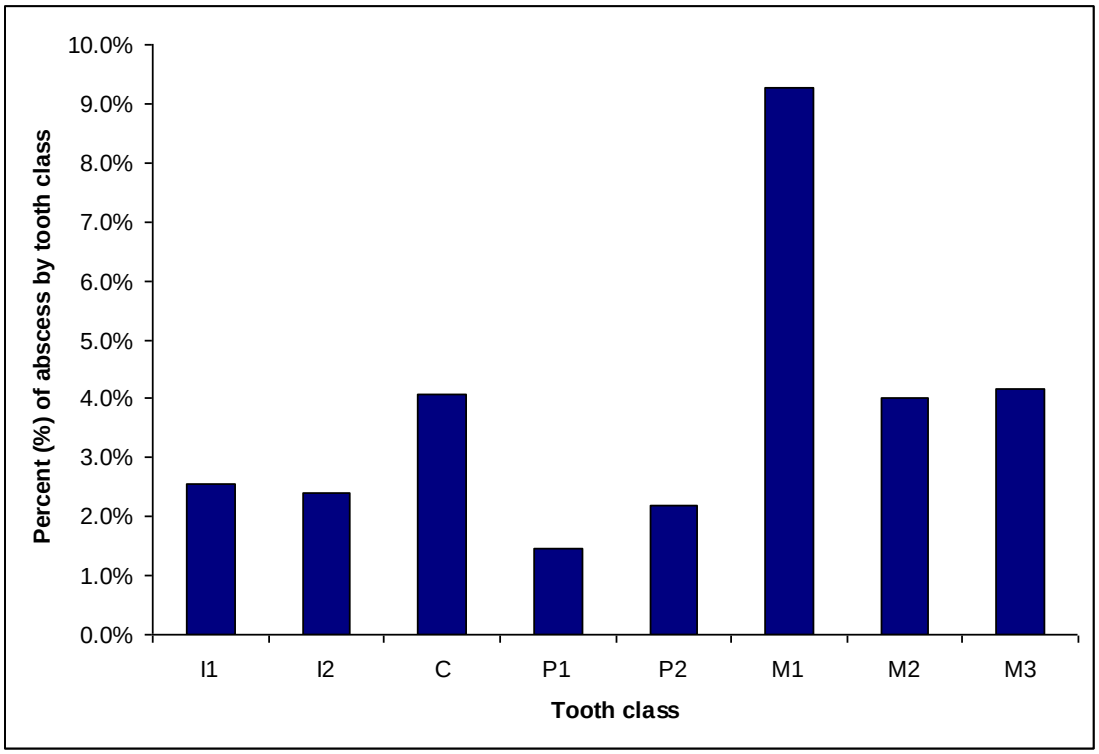
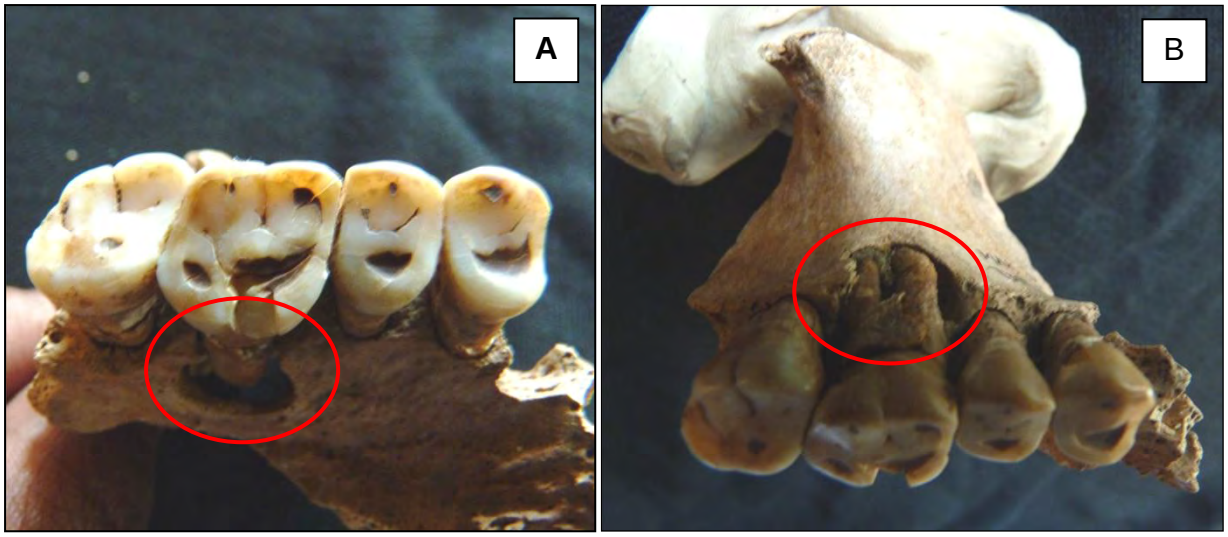


Figure 5.27: Location of abscesses in the dental arcade (sexes, sites, ages and time periods pooled).



Figures 5.28a & b: A large abscess on the alveolar space of RUM1 (red oval) from Malemba-Nkulu T35(B1), showing the extent of the abscess on the lingual (A) and buccal (B) side.

Table 5.21: Dental abscesses in males and females, per site.

Sites	Sex	No. of individuals with abscess	Total no. of individuals	% Individuals with abscess	No. of abscessed alveoli	Total no. of sockets	% Alveoli with abscess	Abscess/ individual
Sanga	F	5	19	26.3	14	493	2.8	0.7
	M	7	17	41.2	19	358	5.3	1.1
	Un	3	8	37.5	8	97	8.2	1.0
	Total	**15**	**44**	**34.1**	**41**	**948**	**4.3**	**0.9**
Katoto	F	6	8	75.0	11	166	6.6	1.4
	M	2	5	40.0	3	69	4.3	0.6
	Un	0	1	0.0	0	16	0.0	0.0
	Total	**8**	**14**	**57.1**	**14**	**251**	**5.6**	**1.0**
Malemba-Nkulu	F	3	5	60.0	5	155	3.2	1.0
	M	1	4	25.0	4	124	3.2	1.0
	Un	0	3	0.0	0	70	0.0	0.0
	Total	**4**	**12**	**33.3**	**9**	**349**	**2.6**	**0.8**
Kikulu	F	2	6	33.3	3	176	1.7	0.5
	M	1	5	20.0	1	133	0.8	0.2
	Un	1	2	50.0	1	30	3.3	0.5
	Total	**4**	**13**	**30.8**	**5**	**339**	**1.5**	**0.4**
Kamilamba	F	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	M	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Un	0	3	0.0	0	42	0.0	0.0
	Total	**0**	**3**	**0.0**	**0**	**42**	**0.0**	**0.0**
Katongo	F	2	3	66.7	4	76	5.3	1.3
	M	2	2	100.0	5	48	10.4	2.5
	Un	0	1	0.0	0	11	0.0	0.0
	Total	**4**	**6**	**66.7**	**9**	**135**	**6.7**	**1.5**
Grand total	All	**35**	**92**	**38.0**	**78**	**2064**	**3.8**	**0.8**

*Abscesses per individual = total no. of abscessed alveoli/total no. of individuals

Table 5.22: Prevalence of dental abscesses grouped by site, sex, time period, and age group.

	No. of individuals with abscess	Total no. of individuals	% Individuals with abscess	No. of alveoli with abscess	Total no. of alveoli	% Alveoli with abscess	Abscess/ individual*
Sex							
Females	18	41	43.9	37	1066	3.5	0.9
Males	13	33	39.4	32	732	4.4	1.0
Unknown	4	18	22.2	9	266	3.4	0.5
TOTAL	**35**	**92**	**38.0**	**78**	**2064**	**3.8**	**0.8**
Time period							
Kisalian	20	51	39.2	45	1117	4.0	0.9
Kabambian	10	27	37.0	19	650	2.9	0.7
Recent	2	4	50.0	3	71	4.2	0.8
Atypical	3	10	30.0	11	226	4.9	1.1
TOTAL	**35**	**92**	**38.0**	**78**	**2064**	**3.8**	**0.8**
Age group							
Sub-adults	1	8	12.5	1	198	0.5	0.1
Young adults	14	44	31.8	30	1067	2.8	0.7
Older adults	14	23	60.9	37	521	7.1	1.6
Adults	6	17	35.3	10	278	3.6	0.6
TOTAL	**35**	**92**	**38.0**	**78**	**2064**	**3.8**	**0.8**

*Abscesses per individual = total no. of abscessed alveoli/total no. of individuals

5.3.4 Dental wear

Occlusal dental wear was examined only on permanent teeth of adult individuals. Individuals represented by a minimum of one tooth were included in the analysis. All individuals studied were, however, represented by more than one tooth. Overall, teeth in the Upemba Depression were moderately worn, with an average wear score of 2.7 (Table 5.23). The most heavily worn teeth were the first molars (3.0), followed by the central incisors (2.9). Comparison of attrition on anterior and posterior teeth showed that the former were more worn than the latter, with average scores of 2.8 and 2.5 respectively ($t = 2.99$, $p = 0.0056$). Average wear scores for maxillary (2.7) and mandibular teeth (2.6) were not significantly different ($t = 0.38$, $p = 0.7078$; t-test for two independent samples).

Individuals from the sites of Katoto, Malemba-Nkulu, Kikulu and Katongo have more heavily worn teeth than those from Sanga and Kamilamba (Table 5.24). Inter-site differences were tested only between Sanga and Katoto due to their larger sample sizes. The difference in mean wear scores between these two sites was significant ($t = -2.54$, $p = 0.0137$). At all sites, the males had slightly more worn teeth than the females; only at Katoto was the wear score between sexes the same.

Males generally had teeth that appeared to be rather more worn than females (2.7 compared with 2.5) although the difference is not statistically significant (Table 5.24). Teeth in the earlier Kisalian period were less worn (2.6) than those in the later Kabambian (2.8) period ($t = -3.81$, $p = 0.0003$). Unlike in the pattern seen for the stable isotope results (see section 5.5.2 below), Katoto did not have any influence over the difference between the Kisalian and Kabambian periods. When Katoto was excluded from the dental wear calculations, the Kisalian period still had less worn teeth (2.5) than the Kabambian (2.8) ($t = -4.42$, $p = 0.0000$). Mean wear scores for younger (2.6) versus older (2.9) adult individuals were also significantly different ($t = -3.52$, $p = 0.0008$).

Table 5.23: Mean dental wear by tooth type (all groups pooled).

Tooth type	Mean maxillary wear	Mean mandibular wear	Overall mean wear
I1	3.1	2.8	2.9
I2	2.8	2.8	2.8
C	2.7	2.7	2.7
P1	2.6	2.5	2.6
P2	2.7	2.6	2.6
M1	3.0	3.0	3.0
M2	2.3	2.4	2.4
M3	2.1	2.2	2.2
Mean	**2.6**	**2.7**	**2.7**
Mean anterior wear		2.8	
Mean posterior wear		2.5	

Table 5.24: Mean dental wear for sites, sexes, time periods, and age groups

	Number of individuals	Mean wear
Sites		
Sanga female	19	2.4
Sanga male	17	2.6
Sanga unknown sex	11	2.9
Sanga total	**47**	**2.6**
Katoto female	8	2.8
Katoto male	4	2.8
Katoto unknown sex	2	2.5
Katoto total	**14**	**2.7**
Malemba-Nkulu female	5	2.6
Malemba-Nkulu male	4	3.0
Malemba-Nkulu unknown sex	4	2.9
Malemba-Nkulu total	**13**	**2.8**
Kikulu female	6	2.4
Kikulu male	5	2.6
Kikulu unknown sex	2	3.0
Kikulu total	**13**	**2.7**
Kamilamba female	1	2.4
Kamilamba male	0	n/a
Kamilamba unknown sex	4	2.6
Kamilamba total	**5**	**2.5**
Katongo female	3	2.7
Katongo male	2	2.8
Katongo unknown sex	1	3.1
Katongo total	**6**	**2.9**
Sex		
Females	42	2.5
Males	32	2.7
Unknown	24	2.8
Time period		
Kisalian	53	2.6
Kabambian	29	2.8
Recent	4	2.3
Atypical	12	2.6
Age group		
Sub-adults	8	2.0
Young adults	48	2.6
Older adults	22	2.9
Adults	20	2.9

5.3.5 Dental calculus

Once again, only adult individuals were examined for dental calculus. Individuals were represented by the presence of at least one tooth. Calculus affected 83.7% of all individuals and 70.5% of all teeth examined. The teeth most commonly found to have calculus were lower lateral incisors (93.8%), followed by lower central incisors (89.7%). The lower M2s (55.0%) were the least affected teeth (Table 5.25). There were no significant differences between the frequency of calculus on mandibular compared with maxillary teeth. Just over half (50.5%) of calculus deposits were moderately formed, and only 9.2% were heavy (Figure 5.29).

With the exception of Katoto, calculus affected more than 60% of all teeth examined at all sites (Table 5.26). Sanga had the highest percentage of teeth with calculus (79.0%). At Katoto, only 34.4% of all teeth were observed to have calculus. The frequency of calculus at Sanga and Katoto was significantly different ($\chi^2 = 10.58$, $p = 0.0011$).

Overall, 84.8% of males and 85.4% females were affected by calculus. Nearly all (96.6%) individuals in the Kabambian had calculus, while only 79.2% of individuals in the Kisalian period did so (Table 5.27); this difference is, however, not statistically significant ($\chi^2 = 3.22$, $p = 0.0730$). There was an increase in calculus with age, as indicated by frequencies of 34.8% in sub-adult, 66.6% in younger adult, and 78.3% in older adult teeth ($\chi^2 = 16.51$, $p = 0.0000$; between younger and older adults).

Table 5.25: Location and severity of calculus; all groups pooled.

Tooth type	No. of teeth with calculus	Total no. of teeth	% Teeth with calculus	Upper teeth (%)	Lower teeth (%)
I1	117	147	79.6	73.0	89.7
I2	124	145	85.5	79.0	93.8
C	152	205	74.1	73.1	75.3
P1	168	234	71.8	67.5	76.9
P2	171	250	68.4	65.7	71.7
M1	151	226	66.8	72.9	58.8
M2	153	243	63.0	69.7	55.0
M3	146	227	64.3	61.7	67.0
TOTAL	**1182**	**1677**	**100.0**	**69.8**	**71.3**
Severity of calculus					
minimal	476	-	40.3	-	-
moderate	597	-	50.5	-	-
heavy	109	-	9.2	-	-

Figure 5.29: Heavy calculus deposits on upper teeth of Sanga T126.

Table 5.26: Calculus prevalence in males and females per site.

Sites	Sex	No. of individuals with calculus	Total no. of individuals	% Individuals with calculus	No. of teeth with calculus	Total no. of teeth	% Teeth with calculus
Sanga	F	17	18	94.4	262	325	80.6
	M	16	18	88.9	248	336	73.8
	Un	9	11	81.8	150	174	86.2
	Total	**42**	**47**	**89.4**	**660**	**835**	**79.0**
Katoto	F	5	8	62.5	35	101	34.7
	M	2	4	50.0	18	31	58.1
	Un	0	2	0.0	0	22	0.0
	Total	**7**	**14**	**50.0**	**53**	**154**	**34.4**
Malemba-Nkulu	F	4	5	80.0	73	120	60.8
	M	3	4	75.0	40	87	46.0
	Un	4	4	100.0	61	78	78.2
	Total	**11**	**13**	**84.6**	**174**	**285**	**61.1**
Kikulu	F	5	6	83.3	51	79	64.6
	M	5	5	100.0	83	94	88.3
	Un	2	2	100.0	14	21	66.7
	Total	**12**	**13**	**92.3**	**148**	**194**	**76.3**
Kamilamba	F	1	1	100.0	7	11	63.6
	M	n/a	0	n/a	n/a	0	n/a
	Un	3	4	75.0	65	100	65.0
	Total	**4**	**5**	**80.0**	**72**	**111**	**64.9**
Katongo	F	3	3	100.0	36	53	67.9
	M	2	2	100.0	26	28	92.9
	Un	1	1	100.0	13	17	76.5
	Total	**6**	**6**	**100.0**	**75**	**98**	**76.5**
Grand total	All	**82**	**98**	**83.7**	**1182**	**1677**	**70.5**

Table 5.27: Calculus prevalence grouped by site, sex, time period, and age group.

	No. of individuals with calculus	Total no. of individuals	% Individuals with calculus	No. of teeth with calculus	Total no. of teeth	% Teeth with calculus
Sex						
Female	41	35	85.4	464	689	67.3
Male	33	28	84.8	415	576	72.0
Unknown	24	19	79.2	303	412	73.5
TOTAL	**98**	**82**	**83.7**	**1182**	**1677**	**70.5**
Time period						
Kisalian	53	42	79.2	546	870	62.8
Kabambian	29	28	96.6	473	575	82.3
Recent	4	3	75.0	22	61	36.1
Atypical	12	9	75.0	141	171	82.5
TOTAL	**98**	**82**	**83.7**	**1182**	**1677**	**70.5**
Age group						
Sub-adult	8	4	50.0	48	138	34.8
Young adult	48	39	81.3	559	839	66.6
Older adult	22	21	95.5	285	364	78.3
Adult	20	18	90.0	290	336	86.3
TOTAL	**98**	**82**	**83.7**	**1182**	**1677**	**70.5**

5.3.6 Periodontitis

The occurrence of periodontitis was assessed only on adult individuals represented by at least one alveolar space. Of 91 individuals examined for the presence of periodontitis, 57 showed signs of the disease (62.6%). Generally, periodontitis was mild to moderate in severity when all samples were pooled. An attempt was made to statistically compare the degree of severity of periodontitis between males and females, and in different time periods; however, the sample sizes are too small to be able to draw any reliable conclusions (Table 5.28).

Periodontitis was present at all sites other than at Kamilamba (Table 5.28). Individuals at Katoto were least affected by the disease (53.8%); while at Katongo, as many as 83.3% of individuals had periodontitis; but this difference was not statistically significant ($\chi^2 = 0.53$, $p = 0.4672$). Moreover, there were no significant differences in the frequency of periodontitis in males and females, nor between the Kisalian and Kabambian periods. Periodontitis clearly progressed with age; nearly double the proportion of older compared with younger adults suffered from the disease (90.9% vs. 52.3%) ($\chi^2 = 8.02$, $p = 0.0046$).

Table 5.28: Summary of periodontitis occurrence and severity; grouped by site, sex, time period, and age group.

	mild	moderate	severe	Individuals with periodontitis	Total no. of individuals	% Individuals with periodontitis
Sites						
Sanga female	5	4	2	11	18	61.1
Sanga male	6	4	4	14	18	77.8
Sanga unknown sex	4	1	0	5	8	62.5
Sanga total	**15**	**9**	**6**	**30**	**44**	**68.2**
Katoto female	2	3	0	5	8	62.5
Katoto male	0	2	0	2	4	50.0
Katoto unknown sex	0	0	0	0	1	0.0
Katoto total	**2**	**5**	**0**	**7**	**13**	**53.8**
Malemba-Nkulu female	1	2	0	3	5	60.0
Malemba-Nkulu male	1	0	1	2	4	50.0
Malemba-Nkulu unknown sex	1	2	0	3	4	75.0
Malemba-Nkulu total	**3**	**4**	**1**	**8**	**13**	**61.5**
Kikulu female	1	2	0	3	6	50.0
Kikulu male	3	0	0	3	5	60.0
Kikulu unknown sex	1	0	0	1	1	100.0
Kikulu total	**5**	**2**	**0**	**7**	**12**	**58.3**
Kamilamba female	n/a	n/a	n/a	n/a	0	n/a
Kamilamba male	n/a	n/a	n/a	n/a	0	n/a
Kamilamba unknown sex	0	0	0	0	3	0.0
Kamilamba total	**0**	**0**	**0**	**0**	**3**	**0.0**
Katongo female	1	1	0	2	3	66.7
Katongo male	1	1	0	2	2	100.0
Katongo unknown sex	0	1	0	1	1	100.0
Katongo total	**2**	**3**	**0**	**5**	**6**	**83.3**

Table 5.28 (continued): Summary of periodontitis occurrence and severity; grouped by site, sex, time period, and age group.

	mild	moderate	severe	Individuals with periodontitis	Total no. of individuals	% Individuals with periodontitis
Sex						
Females	10	12	2	24	40	60.0
Males	11	7	5	23	33	69.7
Unknown	6	4	0	10	18	55.6
TOTAL	**27**	**23**	**7**	**57**	**91**	**62.6**
Time period						
Kisalian	10	15	5	30	50	60.0
Kabambian	10	6	1	17	27	63.0
Recent	2	0	0	2	4	50.0
Atypical	5	2	1	8	10	80.0
TOTAL	**27**	**23**	**7**	**57**	**91**	**62.6**
Age group						
Sub-adults	0	0	0	0	8	00.0
Young adults	14	5	4	23	44	52.3
Older adults	4	13	3	20	22	90.9
Adults	9	5	0	14	17	82.4
TOTAL	**27**	**23**	**7**	**57**	**91**	**62.6**

5.4 Phytolith analyses

A total of 74 calculus samples from 74 individuals were analysed for the presence of phytoliths. All samples yielded phytoliths in varying quantities. The largest number of phytoliths found in a single sample was 257, while the smallest was four. The sample with the most counted and recorded phytoliths came from the site of Katoto (KAT T49). In total, 71 different morphotypes were identified from the samples (Table 5.29). The most commonly found morphotypes were spheroid verrucate (15.5%), followed by spheroid psilate at 14.7% (Table 5.29). These are unfortunately some of the most adiagnostic morphotypes of phytoliths, indicating only the presence of woody and/or herbaceous plants (Piperno 2006). They do, however, indicate vegetation with some tree cover because they are produced in low numbers by Poaceae species. They also indicate the consumption of wild dicotyledonous fruits and vegetables (Albert & Bamford 2012). Some of the ones that could be identified to family level include custard apples (Annonaceae), palms (Arecaceae), and squashes (Cucurbitaceae). Some of these plants are native to the African (sub-) tropics and are still wildly collected and/or cultivated today.

Scalloped phytoliths, typically from squashes (Cucurbitaceae) species, were recovered from the dental calculus of 17 individuals, from all sites and time periods. All parts of Cucurbitaceae contain large numbers of phytoliths, but the most diagnostic (scalloped surface morphology) and useful ones originate in the fruit rind (Bozarth 1987; Piperno 2006). The spheroid echinate phytolith (Figure 5.30a), which could come from palms, was frequently found in the samples. Palms are known to produce the same kind of phytoliths throughout the plant body (leaves, petioles, stems and fruits) (Piperno 2006). Eight types that were very rarely found throughout the whole assemblage include achenes, saddles (Figure 5.30b), and trichomes (Figure 5.30c). These morphotypes come from, but are not exclusive to, plants such as papyrus (achene phytoliths), bamboo (saddle collapsed phytoliths), sorghum (trichome phytoliths), and finger millet (saddle squat phytoliths). These morphotypes were only represented by a single count in some samples. Overall, woody and herbaceous plants dominated the phytolith assemblage from the Upemba, while grasses were less commonly present.

Twenty-one of the 71 (29.6%) morphotypes were found only in the samples from the Kisalian period and not in any other time period (Table 5.30 and Appendix 4). Nine of the 71 (12.7%) morphotypes were found exclusively in the Kabambian samples. The greatest range of phytoliths recorded was during the Kisalian; with 60 of the 71 (84.5%) morphotypes found there, while the Kabambian period had 63.4% of all morphotypes recorded. This, of course, should be considered in light of the larger Kisalian calculus sample (n = 43) compared to the Kabambian (n = 22).

A chi-squared test comparing the uniqueness of morphotypes during the Kisalian and Kabambian periods showed no significant difference (χ^2 = 2.83, p = 0.0922). This suggests that either the plants consumed during each time period were similar or that the vegetation remained unchanged pre- and post-AD 1400. Of the 71 morphotypes identified, only eleven were commonly found throughout all time periods. Interestingly, some of the unique Kisalian phytoliths included those commonly found in edible grasses (Poaceae), such as sorghum, millet, and bamboo (Appendix 4). Poaceae phytoliths found in the dental calculus of the Upemba Depression inhabitants are not exclusive to edible grasses, but could also come from wild grasses.

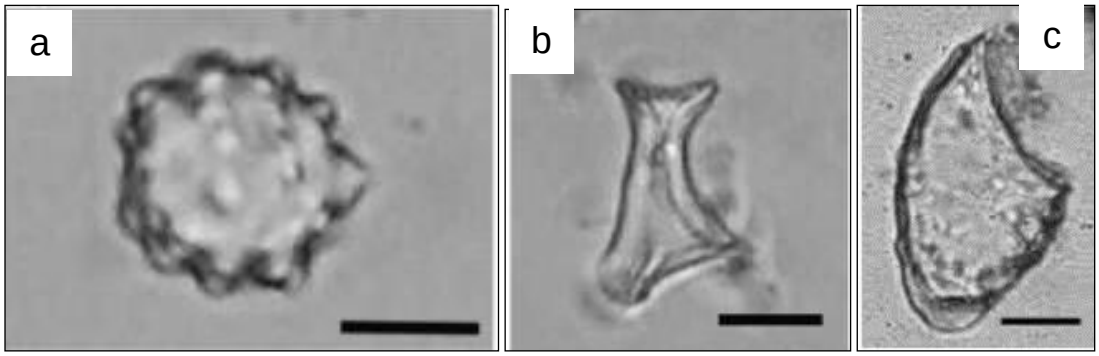
When considering sites separately, the largest number of calculus samples came from Sanga (n = 41), and these also yielded the greatest range of phytoliths, with 58 of the 71 (81.7%) morphotypes found there (Appendix 4). This was followed by Kikulu (n = 11), with 40.8% of the total morphotypes recorded found at this site. A single sample from Kamilamba included 14.1% of the morphotypes. Sanga also had phytoliths that were exclusively found at this site and nowhere else. Seventeen of the 71 (23.9%) morphotypes were found solely at Sanga; while Katoto, with a total of eight calculus samples, had 5 morphotypes (7.0%) that were unique to this site. One of the unique morphotypes from Katoto, the bilobate long convex (Poaceae - Aristidoideae), is indicative of open habitats and swamps (Piperno 2006). When the number of unique and shared morphotypes from Sanga and Katoto were compared, no significant difference was found (χ^2 = 1.30, p = 0.2540). The unique morphotypes from Sanga are probably a reflection of the larger size of calculus samples from this site in comparison to the other five.

Table 5.29: Morphotypes, possible sources and counts of phytoliths in dental calculus samples from the Upemba Depression.

Present morphotypes	Possible vegetation structure	Possible edible plants in study area: common name (Piperno 2006)	Total counts
Spheroid verrucate	Woody plants		785
Spheroid psilate	Mixed woody & herbaceous		745
Spheroid scabrate	Woody plants		573
Tracheid	Woody plants		452
Spheroid echinate	Woody plants	Palms (Arecaceae)	411
Irregular verrucate	Mixed woody & herbaceous		353
Irregular scabrate	Mixed woody & herbaceous		192
Sclereid	Woody plants	Custard apple (Annonaceae)	188
Spheroid scalloped	Woody & herbaceous plants	Squash (Cucurbitaceae)	136
Spheroid globular	Woody plants		103
Starlets (leaves)	Mixed woody & herbaceous		98
Spheroid rugose	Woody plants		93
Spheroid psilate (leaves)	Mixed woody & herbaceous		87
Irregular echinate	Mixed woody & herbaceous	Dicotyledonous fruits	76
Irregular psilate	Mixed woody & herbaceous		71
Ellipsoid psilate	Mixed woody & herbaceous		57
Indeterminable	Mixed woody & herbaceous		57
Ellipsoid scabrate	Mixed woody & herbaceous		45
Irregular facetate	Mixed woody & herbaceous	Custard apple (Annonaceae)	43
Starlet	Mixed woody & herbaceous		43
Ellipsoid echinate	Mixed woody & herbaceous	Palms (Arecaceae)	38
Bilobate short convex	Poaceae	Sorghum, millet (Panicoideae)	28
Irregular psilate (seed)	Mixed woody & herbaceous		25
Scalloped phytolith	Woody & herbaceous plants	Squash (Cucurbitaceae)	25
Spheroid granulate	Woody plants		24
Cross	Poaceae	Sorghum, millet (Panicoideae)	23
Blocky scabrate	Mixed woody & herbaceous		22
Platelet	Mixed woody & herbaceous		22
Seed phytolith	Woody plants		20
Blocky facetate	Mixed woody & herbaceous		14
Polyhedral (seed)	Mixed woody & herbaceous	Adiagnostic	13
Sclereid (seed)	Woody plants	Custard apple (Annonaceae)	13
Honeycomb spheroid	Mixed woody & herbaceous		12
Cylindroid ciliated	Mixed woody & herbaceous		11
Saddle	Poaceae	Finger millet (Chloridoideae)	11
Bilobate short concave	Poaceae	Sorghum, millet (Panicoideae)	10

Table 5.29 (continued): Morphotypes, possible sources and counts of phytoliths in dental calculus samples from the Upemba Depression.

Present morphotypes	Possible vegetation structure	Possible edible plants in study area: common name (Piperno 2006)	Total counts
Blocky echinate	Mixed woody & herbaceous		10
Polyhedral psilate	Mixed woody & herbaceous	Adiagnostic	10
Rondel	Poaceae	Grasses	10
Saddle plateau	Poaceae	Bamboo (Bambusoideae)	10
Polyhedral scabrate	Mixed woody & herbaceous		8
Rugose	Mixed woody & herbaceous		8
Tower wide	Poaceae	Sorghum, millet (Panicoideae)	8
Blocky psilate	Mixed woody & herbaceous		7
Facetate	Mixed woody & herbaceous	(Annonaceae)	7
Parallelipiped echinate	Mixed woody & herbaceous		7
Bulliform	Mixed woody & herbaceous		6
Commelina bulliform	Herbaceous plants		6
Cylindroid psilate	Mixed woody & herbaceous		6
Tracheids scabrate	Woody plants		6
Epidermal cell	Mixed woody & herbaceous	Adiagnostic	4
Scutiform	Mixed woody & herbaceous		4
Cylindroid scabrate	Mixed woody & herbaceous		3
Irregular scalloped	Mixed woody & herbaceous		3
Polyhedral	Mixed woody & herbaceous		3
Prickle	Mixed woody & herbaceous		3
Tower horned	Poaceae	Sorghum, millet (Panicoideae)	3
Bilobate short flattened	Poaceae	Finger millet (Chloridoideae)	2
Ellipsoid scalloped	Mixed woody & herbaceous		2
Parallelipiped psilate	Mixed woody & herbaceous		2
Polylobate	Poaceae	Sorghum, millet (Panicoideae)	2
Saddle ovate	Poaceae	Reeds (Pooideae)	2
Trapezoid	Poaceae	Reeds (Pooideae)	2
Achene	Poaceae	Papyrus (Cyperaceae)	1
Bilobate long convex	Poaceae	Grasses (Aristidoideae)	1
Blocky verrucate	Mixed woody & herbaceous		1
Parallelipiped sinuate	Mixed woody & herbaceous		1
Saddle collapsed	Poaceae	Bamboo (Bambusoideae)	1
Saddle squat	Poaceae	Finger millet (Chloridoideae)	1
Spheroid starlet	Mixed woody & herbaceous		1
Trichome	Poaceae	Sorghum (Panicoideae)	1
71			**5071**



Figures 5.30 a, b & c: Phytolith photographs of the spheroid echinate (a) (Iriarte & Paz 2009) collapsed saddle (b) (Iriarte & Paz 2009) and trichome (c) (Iriarte & Paz 2009) morphotypes, possibly from palms (Arecaceae), bamboo (Bambusoideae) and sorghum (Panicoideae), respectively.

Table 5.30: Unique and shared morphotypes found between the Kisalian and Kabambian periods, as well as between Sanga and Katoto. χ^2 tests compare unique and shared morphotypes between the Kisalian and Kabambian periods, and between Sanga and Katoto.

Time period & Site	Unique morphotypes	Shared morphotypes	Total	χ^2 test	p value
Kisalian	21	39	60		
Kabambian	9	36	45	2.83	0.0922
Sanga	17	41	58		
Katoto	5	23	28	1.30	0.2540

5.5 Stable isotope analyses

5.5.1 Bone collagen and other tissues

$\delta^{13}C$ and $\delta^{15}N$ of archaeological faunal bone collagen and contemporary foodstuffs

A few archaeological faunal specimens from Sanga, Katoto and Malemba-Nkulu were available for analysis for comparison with the humans (Table 5.31 and Figure 5.31). These archaeological faunal remains, along with some contemporary foodstuffs, were sampled in order to provide a baseline from which to interpret the isotope results from the humans (see Chapter 5 for details).

Eight bovid bones could unfortunately not be identified to species, but three have rather positive $\delta^{13}C$ values (-8.9‰, -7.2‰ and -6.1‰) as expected for animals grazing on C_4 grasses. Five others have much more negative $\delta^{13}C$ values (-19.8‰, -18.2‰, -16.9‰, -15.3‰, and -15.3‰), reflecting substantial intake of C_3 browse. Interestingly, a single crocodile has $\delta^{13}C$ of -17.6‰ grouping with the browsers and fairly close to the value of -16.1‰ for a single catfish bone. Fish and terrestrial browsers were more important foods for this crocodile than grazers. A similar pattern has been reported for crocodiles from the Kruger Park in South Africa (Harding & Hart 2010). A single tortoise (likely a turtle) and a mustelid have $\delta^{13}C$ of -15.8‰ and -15.5‰, respectively.

The $\delta^{15}N$ values of the archaeological faunal collagen range from 2.7‰ for one of the bovids to 8.2‰ for the catfish, with a mean of 6.3 ± 1.6‰. The crocodile, with $\delta^{15}N$ of 7‰, is less enriched in ^{15}N than the catfish, indicating that terrestrial foods and/or lower trophic level riverine foods were more important in its diet than catfish of the size of this specimen.

There are very few preserved archaeological plant food remains from these sites. Those that have been recovered include *Eleusine* sp. (finger millet) and *Elaeis* sp. (palm). Grain crops such as sorghum and millet were cultivated in this region, and endemic starchy roots probably played an important role in the diet (see Chapter 2 for details). In order to gain some idea of the carbon and nitrogen isotope values of plant foods from this region, samples of a number of locally-grown contemporary crops were obtained: okra, amaranth (leaf), peanuts, pumpkin (seed and leaf), sweet potato

(leaf), as well as dried tilapia fish. The $\delta^{13}C$ and $\delta^{15}N$ values are shown in Table 5.31 and Figure 5.32. Since the $\delta^{13}C$ value of the atmosphere has decreased by approximately 1.5‰ since the start of the Industrial Revolution due to the burning of fossil fuels (Francey *et al*. 1999), 1.5‰ has been added to the $\delta^{13}C$ values in Table 5.31 and Figure 5.32 to make them directly comparable to the values in Figure 5.31 and 5.33. This is, however, a relatively minor adjustment and it is clear that all the plants in Figure 5.32 are C_3, with the exception of amaranth.

$\delta^{15}N$ values of plants in Table 5.31 and Figure 5.32 range from 1.5 to 7.9‰. Leafy plant foods contribute little protein (i.e. little nitrogen) to the diet, but seeds such as pumpkin seeds ($\delta^{15}N$ = 6.7‰) may be significant sources of protein. The range of $\delta^{15}N$ values in the contemporary plant foods is essentially the same as the range of values for archaeological animals in Figure 5.31. Given the limitations associated with this dataset, it is not possible to work out exactly what the trophic level spacing in $\delta^{15}N$ is for the Upemba populations, but it is likely closer to 3-4‰, as reported in older literature (see Hedges & Reynard 2007 for a review) rather than 6‰ or more, as suggested by some authors (Drucker & Bocherens 2004).

Table: 5.31: Bone collagen quality indicators, bone collagen $\delta^{13}C$ and $\delta^{15}N$ values, enamel apatite $\delta^{13}C$ and $\delta^{18}O$ values of archaeological faunal remains and contemporary foodstuffs. 1.5‰ has been added to the $\delta^{13}C$ values of contemporary foodstuffs to correct for the fossil fuel effect.

Grave no.	Archaeological fauna	C:N ratio	%C	%N	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	Tooth sampled	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)
Bone collagen									
Katoto B (unmarked)	Bovid	3.3	37.5	13.1	-6.1	4.0	-	-	-
Sanga T23A	Bovid	3.3	40.7	14.3	-7.2	6.3	-	-	-
Malemba-Nkulu T32(A5)	Bovid	3.3	42.3	15.0	-8.9	6.8	-	-	-
Sanga T68B	Bovid	3.3	37.6	13.5	-15.3	6.5	-	-	-
Sanga T68A	Bovid	3.3	24.9	6.6	-15.3	6.6	-	-	-
Sanga T143	Bovid	3.3	41.9	14.9	-16.9	5.4	-	-	-
Sanga T85B	Bovid	3.4	15.5	5.2	-18.2	6.4	-	-	-
Sanga T62	Bovid	3.4	20.1	6.8	-19.8	2.7	-	-	-
Sanga T23E	Crocodile	3.4	38.5	13.3	-17.6	7.0	-	-	-
Sanga T23I	Catfish (freshwater)	3.6	12.3	4.0	-16.1	8.2	-	-	-
Sanga T76A	Tortoise	3.4	40.1	13.9	-15.8	6.0	-	-	-
Sanga T76B	Mustelid	3.3	38.7	13.6	-15.5	7.9	unidentified tooth	-8.1	-4.8
Sanga T23H	Reptile	3.3	33.9	11.8	-13.7	7.9	-	-	-

Table: 5.31 (continued)**:** Bone collagen quality indicators, bone collagen $\delta^{13}C$ and $\delta^{15}N$ values, enamel apatite $\delta^{13}C$ and $\delta^{18}O$ values of all archaeological faunal remains and contemporary foodstuffs. 1.5‰ has been added to the $\delta^{13}C$ values of contemporary foodstuffs to correct for the fossil fuel effect.

Grave no.	Archaeological fauna	C:N ratio	%C	%N	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	Tooth sampled	$\delta^{13}C$ (‰)	$\delta^{18}O$ (‰)
Enamel apatite									
Sanga T23B	Bovid	-	-	-	-	-	premolar	2.4	0.6
Sanga T23C	Bovid	-	-	-	-	-	molar	1.4	-0.5
Katoto T21	Bovid	-	-	-	-	-	incisor	-0.5	-1.5
Katoto T40	Bovid	-	-	-	-	-	premolar	-4.6	-3.3
Sanga T23D	Bovid	-	-	-	-	-	unidentified tooth	-11.7	-5.9
Sanga T22	Hippo	-	-	-	-	-	molar	-11.7	-6.6
Katoto T6A	Canid	-	-	-	-	-	unidentified tooth	-6.8	-6.4
Sanga T86	Rhino	-	-	-	-	-	unidentified tooth	-5.9	-8.2
Sanga T156	Mustelid	-	-	-	-	-	carnassial	-9.5	-5.3
Contemporary foodstuffs									
n/a	*Cucurbita* sp. (pumpkin seed)	11.9	65.9	5.5	-27.7	6.7	-	-	-
n/a	*Ipomoea batatas* (sweet potato leaf)	13.6	40.6	3.0	-26.3	7.9	-	-	-
n/a	*Arachis hypogaea* (peanut)	14.8	62.9	4.2	-25.3	1.5	-	-	-
n/a	*Cucurbita* sp. (pumpkin leaf)	6.5	42.9	6.6	-24.2	7.1	-	-	-
n/a	*Abelmoschus* sp. (okra)	10.0	39.8	4.0	-22.4	2.9	-	-	-
n/a	*Amaranthus* sp. (amaranth leaf)	9.3	40.3	4.4	-11.0	6.7	-	-	-
n/a	*Tilapia* sp. (fish)	4.4	14.8	3.4	-20.6	5.9	-	-	-

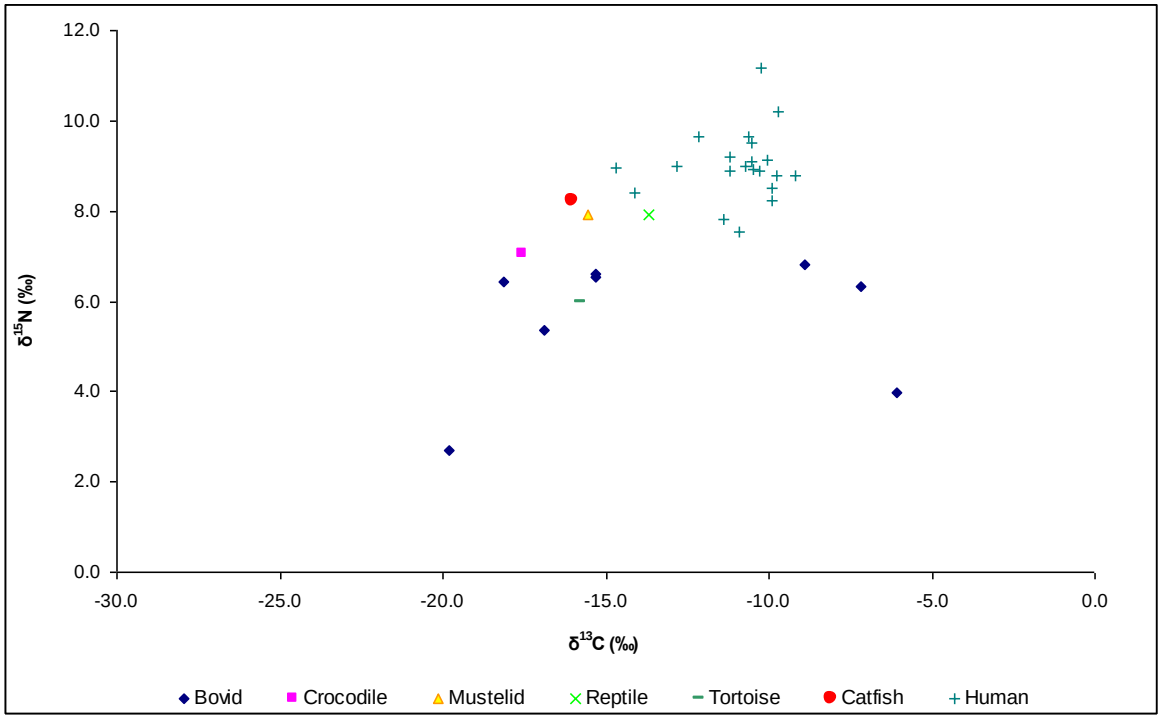


Figure 5.31: Bone collagen $\delta^{13}C$ and $\delta^{15}N$ values of archaeological fauna and human remains.

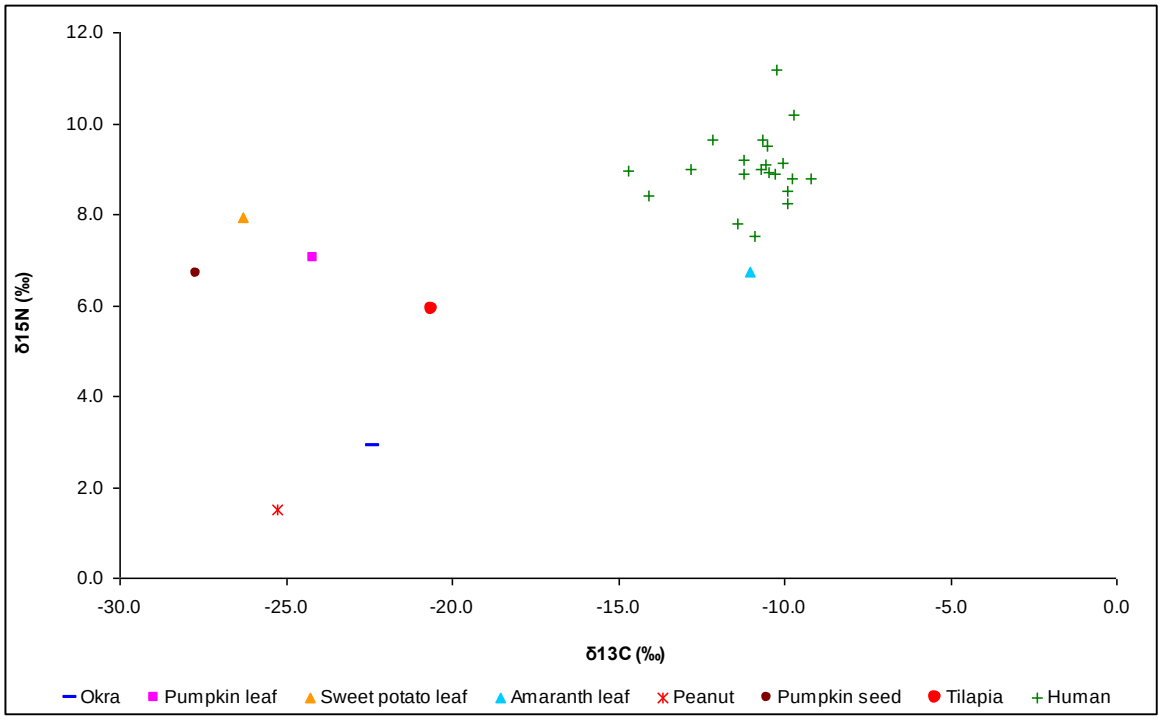


Figure 5.32: $\delta^{13}C$ and $\delta^{15}N$ values of contemporary foods compared with archaeological human bone collagen. 1.5‰ has been added to the contemporary $\delta^{13}C$ values to correct for the fossil-fuel effect. Note that the tilapia sample consisted of muscle tissue (flesh) and was not de-fatted.

$\delta^{13}C$ and $\delta^{15}N$ of human bone collagen

Collagen preservation at the six sites in the Upemba was very poor. This was not surprising considering the hot and humid environmental conditions at the sites. Of the 87 human bone samples prepared, only 21 produced sufficiently good quality collagen that the isotope results are likely to be reliable. All collagen isotope values reported in Tables 5.31 and 5.32, and Figures 5.31 to 5.34 were measured on material that meets the quality criteria recommended in the literature, i.e. C:N ratios in the range 2.9 to 3.6, %C in the range 10.3 to 39.3 and %N in the range 3.4 to 14.0 (Ambrose 1990; van Klinken 1999). A total of 19 samples from Sanga and only two from Katoto met these criteria (Table 5.32). Bone samples from Malemba-Nkulu, Kikulu, Katongo and Kamilamba had poor collagen preservation and thus no reliable isotope values.

Figure 5.33 shows the distribution of $\delta^{13}C$ and $\delta^{15}N$ values for Sanga and Katoto. The two samples from Katoto had significantly depleted $\delta^{13}C$ values ($\delta^{13}C$ = -14.1 and -14.7‰) compared with those from Sanga (range -12.8 to -9.7‰, $\delta^{13}C_{mean}$ = -10.6 ± 0.9‰). The Katoto values lie outside the range of variation seen at Sanga; a t-test confirms the significant difference between the two sites (t = 5.95, p = 0.0000). The $\delta^{15}N_{mean}$ values were, however, very similar at 9.0 ± 0.8‰ for Sanga and 8.4 and 9.0‰ for Katoto (t = 0.63, p = 0.5373). The two highest $\delta^{15}N$ values at Sanga (10.2 and 11.2‰) are from children under the age of five years at death. Their bone collagen may include a substantial proportion of tissue laid down when they were still breastfeeding. At this time, they would have been a trophic level higher than their mothers, with corresponding enrichment in $\delta^{15}N$. The remaining humans at Sanga have $\delta^{15}N$ ranging between 7.5 and 9.7‰, with a mean of 8.9 ± 0.6‰.

Table: 5.32: Bone collagen quality indicators, $\delta^{13}C$ and $\delta^{15}N$ values of all human remains, with associated enamel apatite $\delta^{13}C$ and $\delta^{18}O$ results.

Grave number	Sex	Bone sampled	C:N ratio	%C	%N	$\delta^{13}C_{collagen}$	$\delta^{15}N_{collagen}$	Tooth sampled	$\delta^{13}C_{apatite}$	$\delta^{18}O_{apatite}$	$\Delta_{apatite-collagen}$
KAT 17B	male	femur	3.3	13.4	4.7	-14.1	8.4	-	-	-	-
KAT 58	male	fibula	3.3	35.5	12.5	-14.7	9.0	-	-	-	-
SGA T50	male	femur	3.2	32.5	11.7	-11.4	7.8	M1	-2.0	-1.8	9.4
SGA T80	male	phalanx	3.4	26.4	9.1	-12.8	9.0	-	-	-	-
SGA T85	male	femur	3.3	24.1	8.6	-10.5	9.1	M3	-3.0	-3.7	7.5
SGA T88	male	rib	3.6	10.6	3.5	-11.2	9.2	M3	-3.0	-0.8	8.2
SGA T112	male	rib	3.2	36.9	13.3	-9.8	8.8	-	-	-	-
SGA T140	male	tibia	3.5	11.1	3.7	-10.5	8.9	M3	-10.6	-3.4	-0.1
SGA T154	male	fibula	3.5	11.8	4.0	-9.2	8.8	M1	-1.5	-1.3	7.7
SGA T14	female	femur	3.5	14.5	4.9	-10.9	7.5	M3	-3.5	-1.4	9.5
SGA T22	female	femur	3.3	29.0	10.4	-11.2	8.9	M3	-2.7	-1.9	9.3
SGA T24/35	female	humerus	3.4	14.6	5.1	-10.0	9.1	P2	-4.1	-3.1	6.0
SGA T68	female	rib	3.5	14.3	4.8	-9.9	8.5	M3	-2.2	-2.5	6.0
SGA T76	female	rib	3.4	19.5	6.8	-10.5	9.5	M1	-4.5	-3.4	6.1
SGA T86	female	femur	3.3	39.3	14.0	-12.2	9.7	M3	-5.2	-2.2	7.5
SGA T116	female	rib	3.4	17.6	6.1	-10.3	8.9	M1	-2.7	-1.3	7.6
SGA T71B	juvenile	femur	3.5	10.3	3.4	-9.9	8.2	M1	-1.5	-1.3	6.9
SGA T102	juvenile	rib	3.2	37.9	13.7	-10.7	9.0	M1	-4.2	-1.8	7.2
SGA T105	juvenile	femur	3.5	12.6	4.2	-10.6	9.6	I1	-2.8	-2.6	7.0
SGA T124	juvenile	rib	3.5	13.2	4.4	-9.7	10.2	-	-	-	-
SGA T151	juvenile	humerus	3.4	33.8	11.5	-10.2	11.2	-	-	-	-

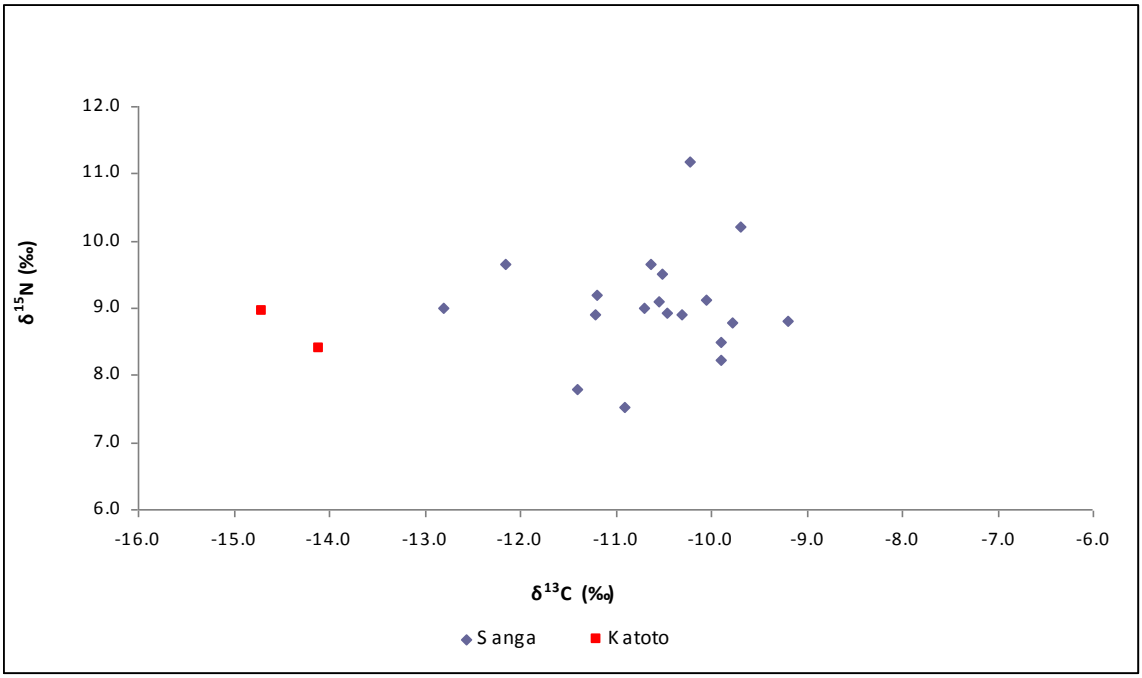


Figure 5.33: Distribution of $\delta^{13}C$ and $\delta^{15}N$ values of human bone collagen samples.

$\delta^{13}C$ values for the fauna bracket those of the humans, demonstrating that the humans ate diets that incorporated both C_3 and C_4-based foods. The $\delta^{13}C$ values of Sanga human collagen are, however, suggestive of diets rich in C_4 plants and/or C_4-based animal protein, with a much smaller contribution from C_3 foods. C_3 foods were more important in the diets of the two individuals from Katoto.

In light of the contemporary food isotope values, it can be inferred that the diets of the Upembans (especially at Sanga) relied heavily on C_4 plant-based foods, with some contribution from C_3-based foods (Figures 5.32 and 5.33). Amaranth or similar C_4 photosynthetic plants, as well as tilapia and other fresh-water fish, and/or animal products from grazing animals appear to have made a major contribution to the diets of the Upembans.

5.5.2 Enamel apatite

$\delta^{13}C$ and $\delta^{18}O$ of archaeological faunal enamel

Table 5.31 (above) and Figure 5.34 show enamel apatite $\delta^{13}C$ and $\delta^{18}O$ values of all archaeological fauna compared with means ± one standard deviation for human remains from each of the six sites. The $\delta^{13}C$ values of the hippo and one bovid lie at the C_3 end of the spectrum (~ -12‰), with relatively low $\delta^{18}O$ (-6.6 and -5.9‰ respectively). Three bovids with $\delta^{13}C$ of 2.4, 1.4 and -0.5‰ lie at the C_4 end of the spectrum; these were grazers. They have the most positive $\delta^{18}O$ values (0.6, -0.5 and -1.5‰) of all the animals analysed (Table 5.31).

Based on this very small sample size, there appears to be a direct relationship between $\delta^{13}C$ and $\delta^{18}O$ values. Animals with the most positive $\delta^{13}C$ values also show the most positive $\delta^{18}O$ values. Since the sample is very small, and the teeth are not identified to species, one cannot make too much of this, but it is worth noting that this pattern is the opposite of that reported for animals in East African savanna environments, where browsers (C_3 feeders) typically have more enriched $\delta^{18}O$ than grazers. Browsers tend to be less dependent on drinking water, acquiring a greater proportion of their moisture from [evaporated] leaf water (Levin *et al.* 2006). The picture is, however, likely to be different in more forested environments, and this topic is certainly worthy of further research in the future. For the present, these analyses of faunal teeth serve to indicate the range of $\delta^{13}C$ and $\delta^{18}O$ in the Upemba Depression during the time period of interest.

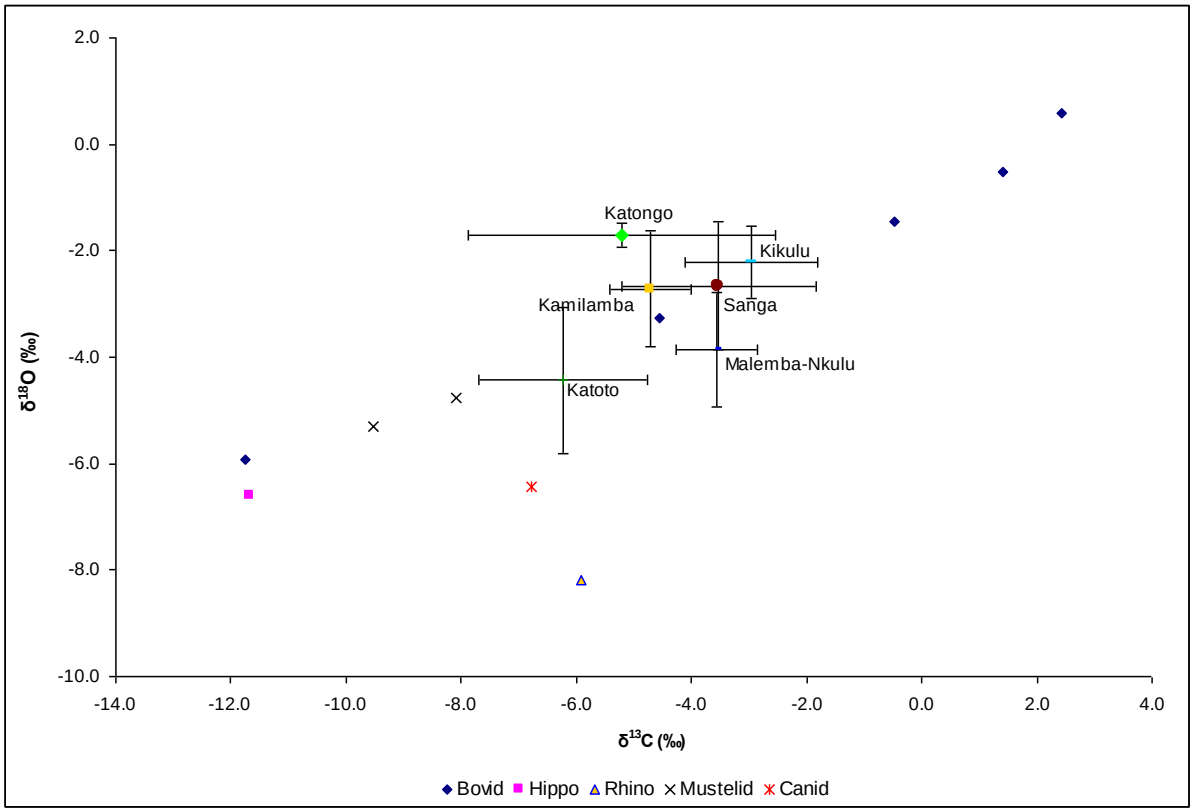


Figure 5.34: Enamel apatite $\delta^{13}C$ and $\delta^{18}O$ values of all archaeological fauna and human remains from the six sites.

Table 5.33: Enamel apatite $\delta^{13}C$ and $\delta^{18}O$ for all skeletons grouped by time period, site and sex: summary data.

Period	Sample (n = 127)	$\delta^{13}C_{mean}$	Std. Dev.	Min	Max	$\delta^{18}O_{mean}$	Std. Dev.	Min	Max
Kisalian	77	-5.1	2.1	-10.6	-1.1	-3.7	1.5	-7.8	-0.6
Kisalian (excluding Katoto)	35	-3.8	2.1	-10.6	-1.1	-2.7	1.1	-4.8	-0.6
Kisalian (excluding Katoto & 3 outliers)	33	-3.3	1.1	-5.4	-1.1	-2.7	1.1	-4.8	-0.6
Kabambian	40	-3.3	1.2	-8.0	-1.4	-2.9	1.2	-5.5	-1.0
Kabambian (excluding 1 outlier)	39	-3.2	1.0	-5.4	-1.4	-2.9	1.2	-5.5	-1.0
Atypical	9	-3.8	1.4	-5.6	-1.4	-2.3	1.4	-5.3	-0.6
Recent	1	-7.9	-	-	-	-1.8	-	-	-
Site									
Sanga	41	-3.5	1.7	-10.6	-1.1	-2.7	1.2	-5.3	-0.6
Sanga (excl. 1 outlier)	40	-3.3	1.3	-6.4	-1.1	-2.7	1.2	-5.3	-0.6
Katoto	42	-6.2	1.5	-9.0	-3.0	-4.5	1.4	-7.8	-2.4
Malemba-Nkulu	17	-3.6	0.7	-5.1	-2.2	-3.9	1.1	-5.5	-2.2
Kikulu	15	-3.0	1.2	-5.4	-1.4	-2.2	0.7	-3.1	-0.6
Kamilamba	7	-4.7	2.7	-9.5	-1.9	-2.7	0.8	-3.7	-1.5
Katongo	5	-5.2	2.7	-8.0	-2.0	-1.7	0.2	-2.0	-1.4
Sex									
Females	47	-4.2	2.0	-9.0	-1.1	-3.2	1.3	-6.3	-0.8
Males	32	-4.7	2.2	-10.6	-1.4	-3.1	1.4	-6.4	-0.6
Males (excl. 1 outlier)	31	-4.5	2.0	-8.2	-1.4	-3.1	1.4	-6.4	-0.6
Juveniles	27	-5.0	2.0	-8.6	-1.5	-4.0	1.6	-7.8	-1.2
Unknown	21	-4.2	2.0	-9.5	-1.9	-3.1	1.6	-6.2	-0.6

$\delta^{13}C$ and $\delta^{18}O$ of human enamel apatite

Tooth enamel is much more resistant to post-depositional alteration than bone. As a result, all of the 127 tooth enamel samples that were taken from 90 individuals could be analyzed successfully. For some individuals, both early-forming and late-forming teeth were sampled; hence, there are more samples than individuals. $\delta^{13}C$ and $\delta^{18}O$ values for all samples are presented in Appendix 5. Table 5.34 presents the mean $\delta^{13}C$ and $\delta^{18}O$ values, standard deviations, and ranges for each time period, site and sex. As seen above for collagen $\delta^{13}C$, the enamel apatite $\delta^{13}C$ values demonstrate that the humans ate diets that incorporated both C_3 and C_4-based foods (Figure 5.34).

When sites and sexes were pooled, the Kisalian period (pre-AD 1400) showed the widest range of $\delta^{13}C$ and $\delta^{18}O$ values, with $\delta^{13}C$ ranging from -1.1‰ to -10.6‰, mean -5.1 ± 2.1‰ (n = 77). With the exception of one outlier ($\delta^{13}C$ = -8.0‰), all $\delta^{13}C$ values from the later Kabambian period (post-AD 1400) were more positive than -6‰, with a mean of -3.2 ± 1.0‰ (n = 39). In other words, they were more enriched in ^{13}C (consumed more C_4-based foods) than the Kisalian period (Mann-Whitney: Z value = 4.43, p = 0.0000). The $\delta^{18}O$ values, too, are more variable during the Kisalian period, ranging from -0.6 to -7.8‰, while in the Kabambian, the range narrowed to between -0.6 and -5.5‰ (Mann-Whitney: Z value = 2.72, p = 0.0065).

It was interesting, however, to note that when all values from the site of Katoto were removed from the Kisalian sample, the Kisalian period became much more similar to the Kabambian; i.e. the differences in the $\delta^{13}C$ and $\delta^{18}O$ values became insignificant (Mann-Whitney: Z value = 0.58, p = 0.5627, for both $\delta^{13}C$ and $\delta^{18}O$) (Figures 5.36 and 5.37). It is therefore apparent that the values from Katoto were driving the apparent differences between the two time periods; and that the main difference is between Katoto and the other sites, rather than between the Kisalian and the Kabambian. Furthermore, when outliers were taken into consideration, the differences between the two time periods became even smaller. There are three outliers with very negative $\delta^{13}C$ values in the Kisalian sample (SGA-T140 M3, KMI-T7 M3 and KMI-T7 M1), and one in the Kabambian (KTG-T8 M3) (Figure 5.38). These outliers deviate from the mean $\delta^{13}C$ values of the respective time periods by at least 2‰. When these outliers are removed from the samples, the two time periods have almost

identical $\delta^{13}C$ values (Table 5.33). It is, therefore, evident that there is no real difference in $\delta^{13}C$ of the diets of the Kisalian and Kabambian peoples.

The two sites with the largest sample sizes, and therefore likely to yield the most reliable inter-site comparison were Katoto (n = 42) and Sanga (n = 41). Humans from Katoto have enamel apatite $\delta^{13}C$ ranging between -3.0 and -9.0‰, with a mean of -6.2 ± 1.5‰. Those from Sanga have enamel apatite $\delta^{13}C$ ranging between -1.1 and -6.4‰, with a mean of -3.3 ± 1.3‰, when an outlier (Sanga T140) is excluded. The values from Katoto are significantly more depleted than those from Sanga (Mann-Whitney: Z value = 6.63, p = 0.0000). This pattern mirrors that reported above for $\delta^{13}C$ in bone collagen, where the two individuals from Katoto had more negative values than those from Sanga. This is clearly a robust pattern, resulting from a significant dietary difference between the two sites (Figure 5.38).

Malemba-Nkulu and Kikulu have mean enamel apatite $\delta^{13}C$ values of -3.6 ± 0.7‰ (n = 17) and -3.0 ± 1.2‰ (n = 15) respectively. They therefore cluster with Sanga (Mann-Whitney: Z value = 0.99, p = 0.3243, for Sanga versus Malemba-Nkulu and Mann-Whitney: Z value = -0.80, p = 0.4219, for Sanga versus Kikulu). The numbers of individuals from Kamilamba and Katongo are very small (7 and 5 respectively), and the enamel $\delta^{13}C$ values vary widely. The $\delta^{13}C$ values of the humans from Sanga, Malemba-Nkulu and Kikulu are suggestive of diets rich in C_4 plants or C_4-based animal protein, with a much smaller contribution from C_3 foods. C_3 foods were more important in the diets of the individuals from Katoto.

$\delta^{18}O$ values of the human teeth from the six sites all fall within the range of the archaeological fauna. A pattern that stands out from the human $\delta^{18}O$ values is that Katoto had the most depleted $\delta^{18}O$ values in comparison to the other five sites in the Upemba Depression (Figures 5.34, 5.37 and 5.38) but still within the range of the faunal $\delta^{18}O$ values. Katoto has $\delta^{18}O$ values ranging between -2.4 and -7.8‰, with a mean of -4.5 ± 1.4‰. $\delta^{18}O$ values from Sanga are slightly less varied and range between -0.6 and -5.3‰ ($\delta^{18}O_{mean}$ = -2.7 ±1.2‰) (Mann-Whitney: Z value = 5.18, p = 0.0000). The range of $\delta^{18}O$ values is particularly significant in assessing whether any of the humans may have been immigrants. As far as the oxygen data can inform, no outliers or foreigners can be identified in this sample set.

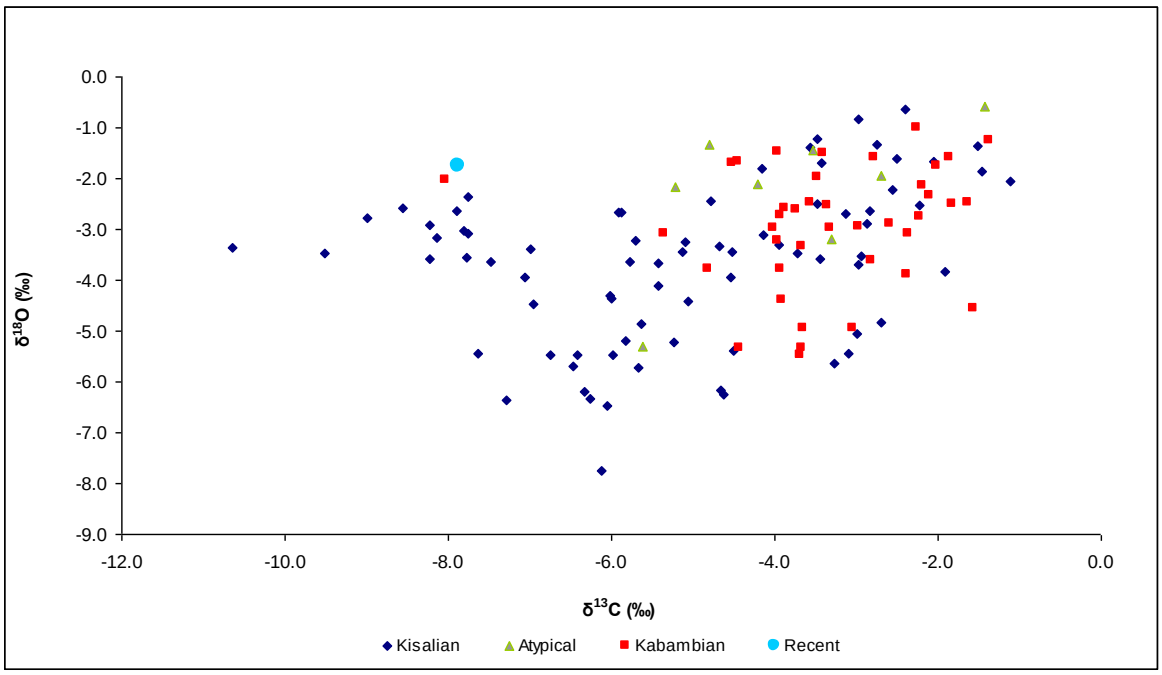


Figure 5.36: Distribution of $\delta^{13}C$ and $\delta^{18}O$ values of all human enamel apatite by time period (sexes and sites pooled).

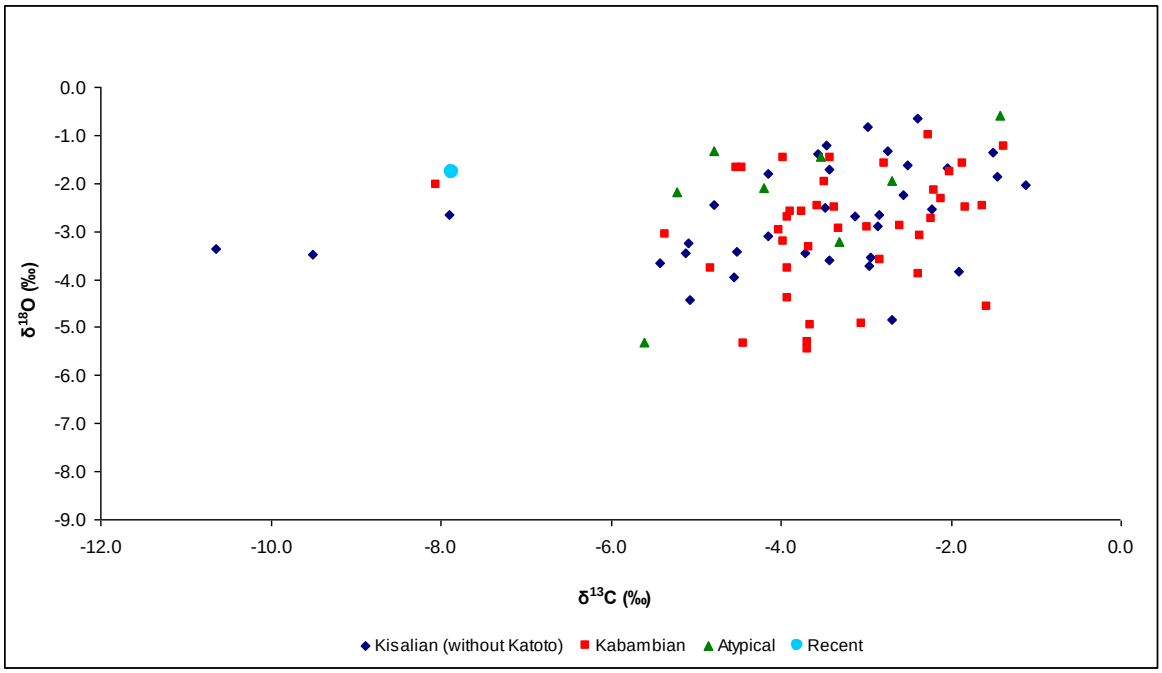


Figure 5.37: Distribution of $\delta^{13}C$ and $\delta^{18}O$ values of all human enamel apatite by time period, excluding samples from Katoto (sexes and sites pooled).

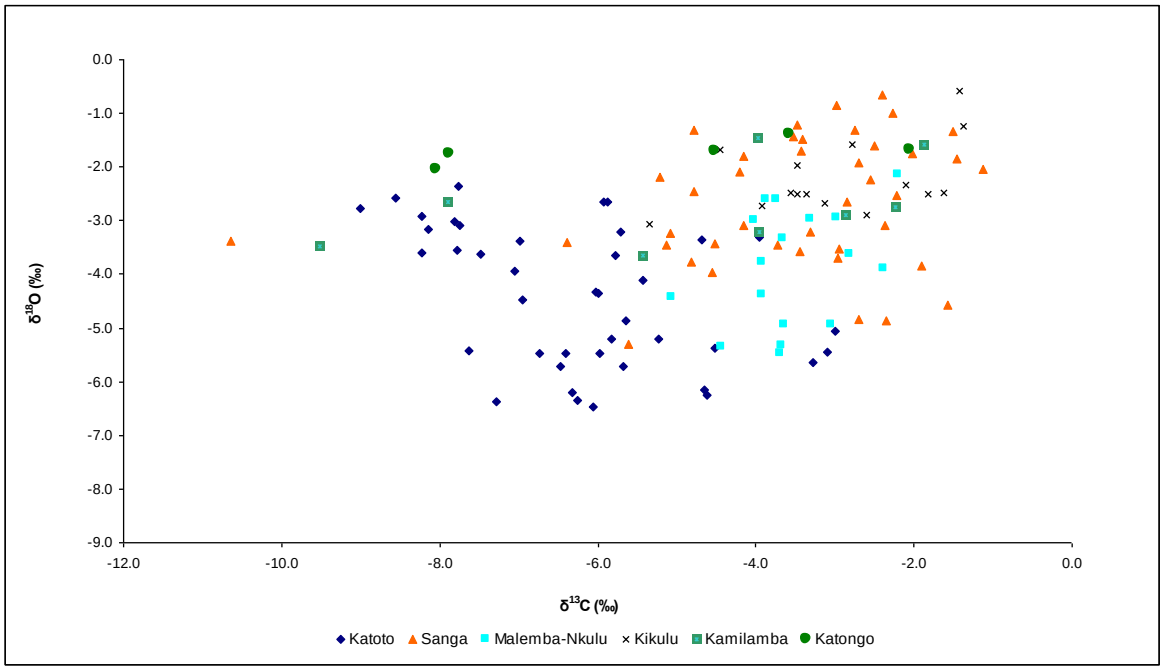


Figure 5.38: Distribution of $\delta^{13}C$ and $\delta^{18}O$ values of all human enamel apatite by site (sexes and time periods pooled).

When sexes were compared, the mean $\delta^{13}C$ and $\delta^{18}O$ values for all sites and time periods pooled showed no significant differences (Table 5.33). When Sanga T140 is excluded because he is an outlier, the mean $\delta^{13}C$ value for all males was -4.5 ± 2.0‰, while that for females was -4.2 ± 2.0‰. Mean $\delta^{18}O$ values were also similar, at -3.1 ± 1.4‰ for males and -3.2 ± 1.3‰ for females.

Next, $\delta^{13}C$ values of males and females were compared within each site. At Sanga, there was a significant difference between males (-4.1 ± 1.2‰, n = 11) and females (-2.8 ± 1.1‰, n = 15) (Mann-Whitney Z value = 2.23, p = 0.0256). At Malemba-Nkulu, there was also a significant difference, with males at -2.7 ± 0.4‰ (n = 3) and females at -3.8 ± 0.6‰ (n = 7) (Mann-Whitney Z value = -2.05, p = 0.0402). These sample sizes are, however, very small so the conclusion for Malemba-Nkulu should be treated with caution. The direction of the difference is also in the opposite direction from Sanga (where males had more negative $\delta^{13}C$ values than females; at Malemba-Nkulu, the opposite is the case). There was no significant difference between $\delta^{13}C$ values of males and females at Katoto and at Kikulu (Table 5.34). Comparisons between sexes could not be made at Katongo since there was only one female and four males, nor at

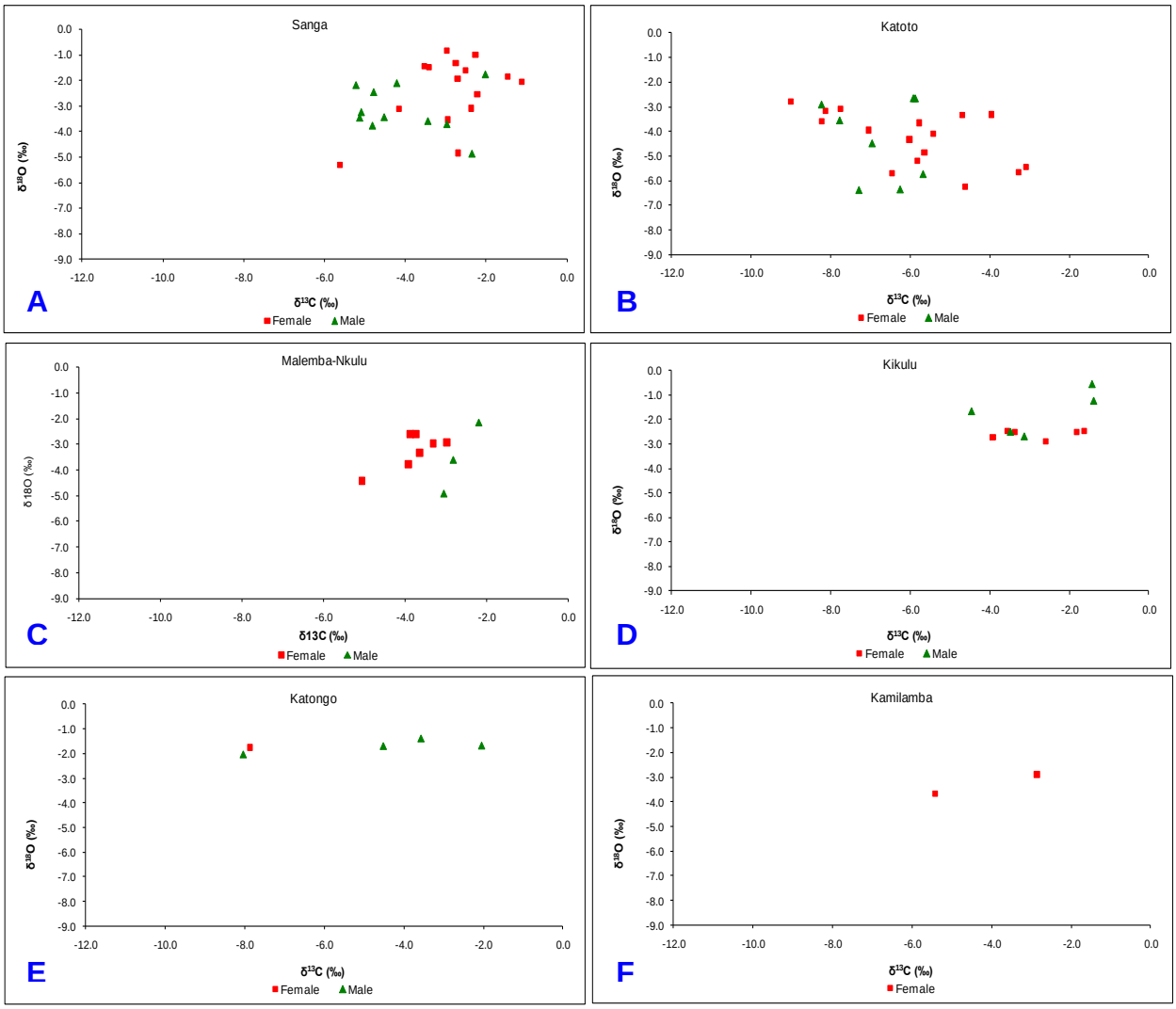
Kamilamba where both samples were from females (Table 5.34 and Figures 5.39a to f).

A significant difference was also observed at Sanga between $\delta^{18}O$ values of males (-3.1 ± 0.9‰) and females (-2.4 ± 1.3‰) (Mann-Whitney: Z value = 2.02, p = 0.0430). On the contrary, males (-1.7 ± 0.9‰) at Kikulu appeared to have more positive $\delta^{18}O$ values than females (-2.6 ± 0.2‰), although this was not statistically significant (Mann-Whitney: Z value = -1.55, p = 0.1207). At other sites, there were no significant differences between $\delta^{18}O$ values from males and females (Table 5.34).

Table 5.34: Mean $\delta^{13}C$ and $\delta^{18}O$ of enamel apatite in males and females per site (time periods pooled).

Sex	N	$\delta^{13}C_{mean}$	Std. Dev.	MWU*	t-test	$\delta^{18}O_{mean}$	Std. Dev.	MWU*	t-test
Sanga female	15	-2.8	1.1			-2.4	1.3		
Sanga male	11	-4.1	1.2	2.23 **p = 0.0256**	2.72 p = **0.0120**	-3.1	0.9	2.02 **p = 0.0430**	1.60 p = 0.1250
Katoto female	16	-5.9	1.8			-4.3	1.1		
Katoto male	8	-6.7	0.96	1.32 p = 0.1880	1.2 p = 0.2413	-4.3	1.6	-0.03 p = 0.9756	0.11 p = 0.9152
Malemba-Nkulu female	7	-3.8	0.6			-3.2	0.7		
Malemba-Nkulu male	3	-2.7	0.4	-2.05 p = **0.0402**	-2.64 p = **0.0296**	-3.6	1.4	0.23 p = 0.8197	0.53 p = 0.6076
Kikulu female	6	-2.8	1.0			-2.6	0.2		
Kikulu male	5	-2.8	1.3	-0.27 p = 0.7842	-0.06 p = 0.9500	-1.7	0.9	-1.55 p = 0.1207	-2.39 p = **0.0406**
Katongo female	1	-7.9	-			-1.8	-		
Katongo male	4	-4.5	2.5	n/a	n/a	-1.7	0.3	n/a	n/a
Kamilamba female	2	-4.1	1.8			-3.3	0.5		
Kamilamba male	0	-	-	n/a	n/a	-	-	n/a	n/a

MWU*: Mann-Whitney U test



Figures 5.39A, B, C, D, E and F: $\delta^{13}C$ and $\delta^{18}O$ in enamel apatite for male and female skeletons from Sanga (A), Katoto (B), Malemba-Nkulu (C), Kikulu (D), Katongo (E), and Kamilamba (F). Note that there were no males at Kamilamba.

When bone collagen $\delta^{13}C$ values were plotted against enamel apatite $\delta^{13}C$ values for the same individuals (Figure 5.40), there was no significant correlation between the two ($y = 0.2885x-0.6395$, $r^2 = 0.0066$, $p = 0.7827$). The [lack of] relationship between $\delta^{13}C$ in bone collagen and enamel apatite is probably because the data are tightly clustered. There also are too few data points to make a meaningful comparison and we will have to await more $\delta^{13}C$ values from south-central Africa before this relationship can be explored in more detail.

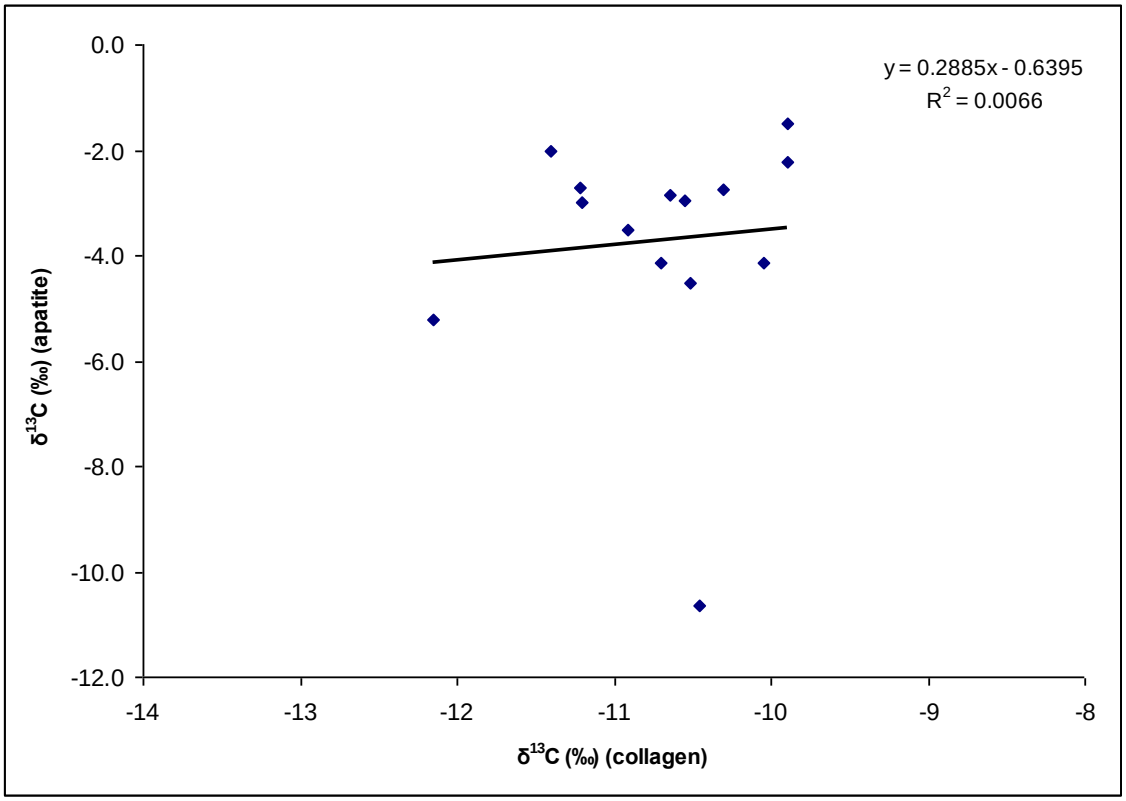


Figure 5.40: $\delta^{13}C_{apatite}$ (tooth enamel) plotted against $\delta^{13}C_{collagen}$ (bone) for the same individual.

Isotopic analyses were carried out on dental enamel from 90 individuals. For 31 individuals, more than one tooth was sampled, in order to compare the isotopic values of diets consumed at different ages. Of these 31 individuals, six presented with $\delta^{13}C$ values that were different for the early-forming teeth versus the late-forming ones (Table 5.35). A cut-off point of at least 2‰ was used as indicative of a substantial difference in $\delta^{13}C$ values between the teeth, as explained in Chapter 5. There was, however, no pattern for this change across the six individuals. Three had late-forming teeth with more enriched $\delta^{13}C$ values compared with early-forming teeth, while the

other three showed the opposite pattern. Interestingly, when the carbon isotope data is compared with observations on dental caries, the individuals whose diets changed to enriched $\delta^{13}C$ also presented with caries; while those whose $\delta^{13}C$ values became more depleted have no caries.

Only one individual showed a substantial shift in $\delta^{18}O$ values between early-forming versus late-forming teeth. Katoto T21C had a $\delta^{18}O$ value of -5.5‰ in the LUM1, but -7.8‰ for the LUM2. The $\delta^{13}C$ values, however, showed no significant change from the LUM1 (-6.7‰) to the LUM2 (-6.1‰). This individual is a child who died between the age of 7 and 9 years. The crowns of these two teeth form in a relatively short period of time: the M1 from 1-3 years and the M2 from 4-7 years (Buikstra & Ubelaker 1994). It is difficult to interpret the shift in the $\delta^{18}O$ values because of our poor understanding of regional patterning in $\delta^{18}O$, but it is possible that this child may have moved during childhood.

Table 5.35: Individuals showing substantial differences (≥ 2‰) in $\delta^{13}C$ values of early- compared with late-forming teeth.

Sample	Sex	Age	Time period	Dental caries	$\delta^{13}C$	$\delta^{18}O$	Difference in $\delta^{13}C$	Difference in $\delta^{18}O$
KAT T25 LUI1	F	25-40	Classic Kisalian	2	-7.8	-3.1	3.8	-0.2
KAT T25 LUM3	F	25-40	Classic Kisalian	2	-4.0	-3.3		
KAT T26 UC	M	50-70	Classic Kisalian	0	-5.9	-2.7	-2.3	-0.2
KAT T26 LUM3	M	50-70	Classic Kisalian	0	-8.2	-2.9		
KAT T50 LLM1	F	35-45	Classic Kisalian	2	-8.2	-3.6	2.4	-0.1
KAT T50 RLM3	F	35-45	Classic Kisalian	2	-5.8	-3.7		
KMI T10 LUI1	F	25-40	Ancient Kisalian	0	-2.9	-2.9	-2.5	-0.8
KMI T10 M3	F	25-40	Ancient Kisalian	0	-5.4	-3.7		
KTG T8 RUI1	M	25-40	Kabambian B	0	-4.5	-1.7	-3.5	-0.3
KTG T8 LUM3	M	25-40	Kabambian B	0	-8.0	-2.0		
KUL T2 RLM1	M	40-50	Kabambian A	3	-4.5	-1.7	3.1	0.4
KUL T2 RLM3	M	40-50	Kabambian A	3	-1.4	-1.3		

5.6 Dental Modification

Only adult and sub-adult individuals were assessed for dental modification. All individuals demonstrating modified teeth were over the age of 14 years at death. Overall, styles of modification that were identified in the Upemba Depression include filing and/or chipping of parts of the anterior teeth, intentional removal of maxillary or mandibular incisors, as well as a mix of the aforementioned modifications. Below, the observed styles are described in detail and their occurrence presented.

5.6.1 Tooth filing or chipping

A total of seven different filing/chipping styles were observed. Detailed descriptions and illustrations of these styles are presented in Table 5.36. Of 59 individuals with anterior dentition present, more than two-thirds (67.8%) had anterior teeth modified by chipping or filing (Table 5.37). The most popular style in the Upemba Depression was style 2 (35.0%), where both upper and lower incisors had been filed to a pointed shape (Figures 5.41 and 5.42). This was followed by style 1 (32.5%), where only the upper incisors were filed to points. Style 6 was the least prevalent (2.5%) of all filing/chipping styles, with only one individual, from Sanga, exhibiting it (Figures 5.41 and 5.43).

A look at the distribution of styles at individual sites shows that Sanga had the highest variation of filing/chipping styles. With the exception of style 5, all filing/chipping styles were found at Sanga, with style 2 being the most popular (47.6%). Only styles 1 and 5 were found at Katoto. No significant differences in the prevalence of filed/chipped teeth existed between Sanga and Katoto ($\chi^2 = 0.15$, $p = 0.7005$).
Both males (65.0%) and females (66.7%) demonstrate modified teeth, with females exhibiting style 1 (43.8%) as the most preferred style; while the males preferred style 2 (38.5%). Females demonstrate the widest variation of filed/chipped teeth, with all seven styles expressed, while their male counterparts exhibit five of the seven styles (Table 5.37 and Figure 5.41).

All but style 6 were found during both Kisalian and Kabambian periods. The singularly represented style 6 could not be assigned to any chronological period,

hence belonged to the Atypical period. During the Kisalian period, style 1 was the most popular (34.4%), followed by style 2 (25.0%). All other styles were encountered only once during the Kisalian period. Styles in the Kabambian period were evenly represented; no particular style was preferred over any other.

The frequency of tooth filing/chipping (i.e. individuals with filed teeth/total number of individuals) is neither significantly different in the Kisalian compared with the Kabambian period (χ^2 = 0.01, p = 0.9244), nor in the Kisalian compared with the Recent period (χ^2 = 0.10, p = 0.7491). Similarly, no changes in the prevalence of tooth filing/chipping existed between the Kabambian and Recent periods (χ^2 = 0.04, p = 0.8442). Therefore, it appears that the frequency of tooth filing/chipping was approximately similar in the Upemba Depression from around AD 1300 to recent (AD 1800) times.

Table 5.36: Description of the tooth filing styles seen in this population

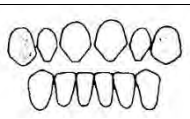
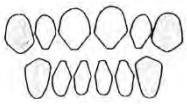
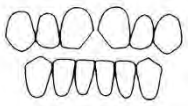
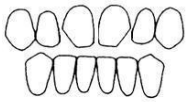
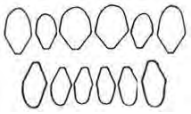
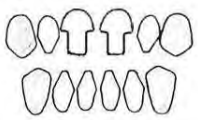
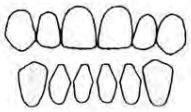
Type of modification	Description	Illustration
Style 1	Filing of all upper incisors to a pointed shape	
Style 2	Filing of all upper and lower incisors to a pointed shape	
Style 3	Filing of the mesial corners of upper central incisors to an inverted V-shape	
Style 4	Filing of the lateral corners of upper central incisors	
Style 5	Filing of all upper and lower incisors as well as canines to a pointed shape	
Style 6	Filing of upper central incisors to an hour-glass shape and upper lateral and all lower incisors to a pointed shape	
Style 7	Filing of all lower incisors to a pointed shape	

Table 5.37: Incidence of the different styles of tooth filing observed in the Upemba Depression

TOOTH FILING	SITES						SEXES			TIME PERIODS					
Styles	Sanga	Katoto	Malemba-Nkulu	Kikulu	Kamilamba	Katongo	Males	Females	Unknown	Kisalian	Kabambian	Recent	Atypical	**Total no. of individuals**	**%**
Style 1	7	4	1	1	0	0	3	7	3	11	2	0	0	**13**	**32.5**
Style 2	10	0	1	1	1	1	5	3	6	8	3	1	2	**14**	**35.0**
Style 3	1	0	1	1	1	0	2	1	1	1	2	1	0	**4**	**10.0**
Style 4	1	0	0	0	1	1	0	2	1	1	2	0	0	**3**	**7.5**
Style 5	0	1	1	0	0	0	1	1	0	1	1	0	0	**2**	**5.0**
Style 6	1	0	0	0	0	0	0	1	0	0	0	0	1	**1**	**2.5**
Style 7	1	0	0	1	0	1	2	1	0	1	2	0	0	**3**	**7.5**
None	9	2	4	1	1	2	7	8	4	9	5	2	3	**19**	**32.2**
Ntotal with modified teeth	21	5	4	4	3	3	13	16	11	23	12	2	3	**40**	**67.8**
Total no. of individuals	30	7	8	5	4	5	20	24	15	32	17	4	6	**59**	**100.0**
Percent	**70.0**	**71.4**	**50.0**	**80.0**	**75.0**	**60.0**	**65.0**	**66.7**	**73.3**	**71.9**	**70.6**	**50.0**	**50.0**	**67.8**	

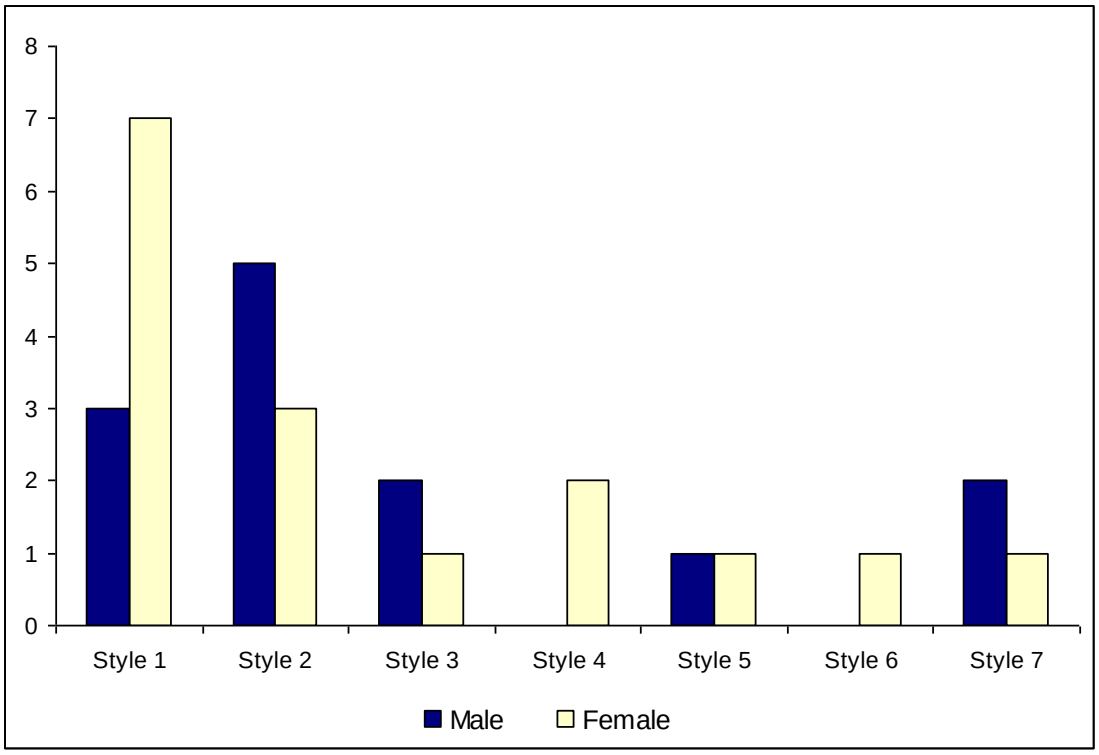


Figure 5.41: Distribution of tooth filing or chipping styles in males and females. Note that the "Unknown sex" category is not included in this figure, in order to highlight the patterns by sex.

Figures 5.42 & 5.43: Style 2 of tooth filing, Sanga T164 & style 6 of tooth filing, Sanga T22

5.6.2 Intentional tooth extraction

A total of five different extraction styles were observed. Detailed descriptions and illustrations of these styles are presented in Table 5.38. Unlike tooth filing, the practice of tooth extraction was less preferred in the Upemba Depression. Of the 66 individuals with at least one complete dental arcade (maxilla or mandible), only 13 (19.7%) had intentionally removed some of their anterior teeth (Table 5.39). The most popular of these styles was style 1 (38.5%), where lower incisors had been extracted to leave a gap. Style 2 was the least prevalent of all extraction styles, seen in only one individual (Table 5.39 and Figure 5.44).

The distribution of extraction styles at individual sites shows that Sanga had the highest variation of styles; only style 4 was not represented. Although Katoto had only 3 styles out of the five seen in the sample, it had the highest frequency (50.0%) of individuals with extracted teeth (Table 5.39). There were, however, no significant differences in the prevalence of tooth extraction between Sanga and Katoto ($\chi^2 = 2.27$, $p = 0.1319$).

Both males (25.0%) and females (16.7%) demonstrate intentionally extracted teeth, with females exhibiting style 1 (80.0%) as the most preferred style; while the males had no particular preference for any style (i.e. styles 3, 4 and 5 are all equally represented). Males demonstrate a wider variation of extraction styles, with three of the five styles expressed, while their female counterparts exhibit only two (Table 5.39).

Tooth extraction was more popular and more varied during the Kisalian than in the Kabambian period. Although not significantly different ($\chi^2 = 0.29$, $p = 0.5891$), nearly double the number of individuals had extracted their teeth during the Kisalian (22.2%) compared to the Kabambian (13.0%) period. Style 1 was the most preferred (8.3%) during the Kisalian period, whereas all styles found in the Kabambian period were represented equally.

As with tooth filing/chipping, it appears that tooth extractions were performed in the Upemba Depression from around AD 1300 to recent (AD 1800) times, without any major changes through time. When comparing the Kisalian and Recent periods, no

significant differences existed (χ^2 = 0.37, p = 0.5441). Similarly, no changes in the prevalence of tooth extraction existed between the Kabambian and Recent periods (χ^2 = 0.83, p = 0.3609).

Table 5.38: Description of the tooth extraction styles seen in this population

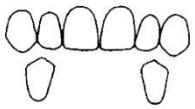
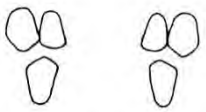
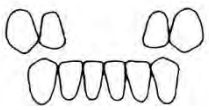
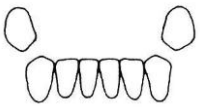
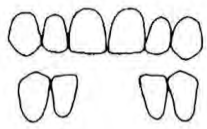
Type of modification	Description	Illustration
Style 1	Extraction of all lower incisors	
Style 2	Extraction of upper central and all lower incisors	
Style 3	Extraction of only upper central incisors	
Style 4	Extraction of all upper incisors	
Style 5	Extraction of only lower central incisors	

Table 5.39: Incidence of the different styles of extraction observed in the Upemba Depression

TOOTH EXTRACTION	SITES						SEXES			TIME PERIODS					
Styles	Sanga	Katoto	Malemba-Nkulu	Kikulu	Kamilamba	Katongo	Males	Females	Unknown	Kisalian	Kabambian	Recent	Atypical	**Total no. of individuals**	**%**
Style 1	1	1	0	1	1	1	0	4	1	3	1	1	0	**5**	**41.7**
Style 2	1	0	0	0	0	0	0	1	0	1	0	0	0	**1**	**8.3**
Style 3	1	0	1	0	0	0	2	0	0	0	1	0	1	**2**	**16.7**
Style 4	0	1	0	2	0	0	2	0	1	2	1	0	0	**3**	**25.0**
Style 5	1	1	0	0	0	0	2	0	0	2	0	0	0	**2**	**16.7**
None	26	3	11	7	2	4	18	25	10	28	20	0	5	**53**	**80.3**
Ntotal with modified teeth	4	3	1	3	1	1	6	5	2	8	3	1	1	**13**	**19.7**
Total no. of individuals	30	6	12	10	3	5	24	30	12	36	23	1	6	**66**	**100.0**
Percent	**13.3**	**50.0**	**8.3**	**30.0**	**33.3**	**20.0**	**25.0**	**16.7**	**16.7**	**22.2**	**13.0**	**100.0**	**16.7**	**18.2**	

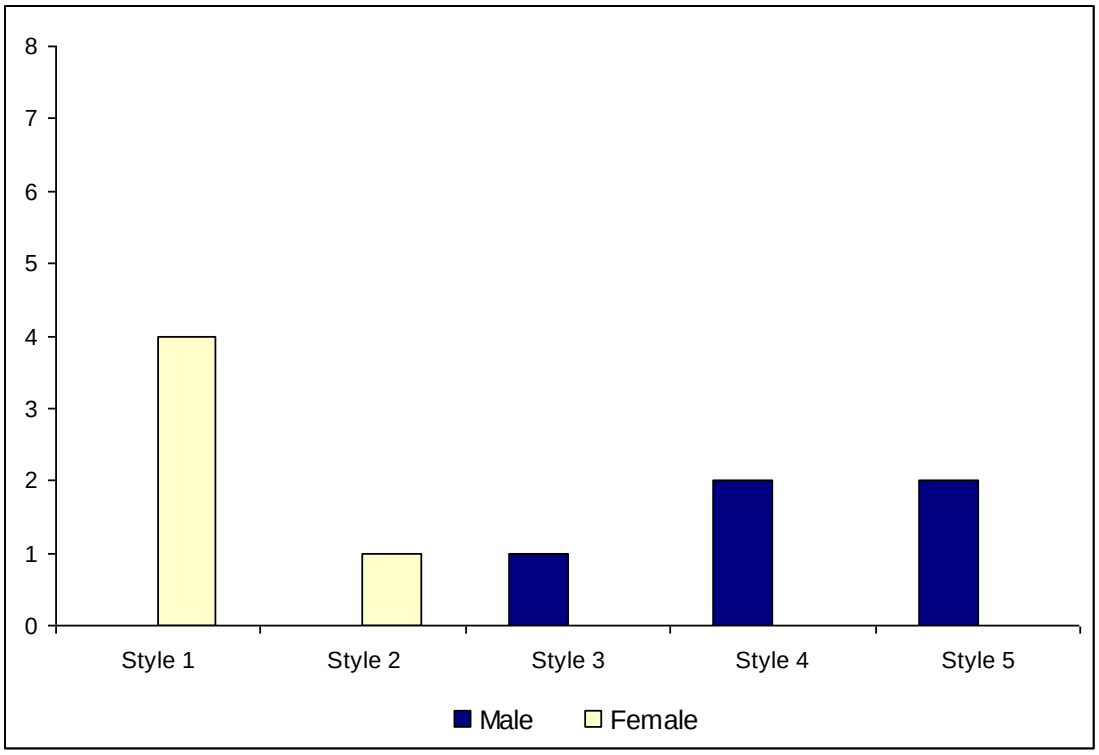


Figure 5.44: Distribution of tooth extraction styles by sex. Note that the "Unknown sex" category is not included in this figure, in order to highlight the patterns by sex.

5.6.3 Other styles

Five individuals exhibited styles that combined both tooth filing and extraction (Table 5.40). In all cases, the upper incisors were filed or chipped in various forms, while the lower incisors were always removed. Figure 5.45 is an example of one such complex style in which the upper central incisors had their mesial corners filed, while both central and lateral lower incisors had been removed.

With the exception of a single instance, all four lower incisors were intentionally extracted. Burial T149 from Sanga had a different pattern in which only the lower central incisors were removed. Both sexes demonstrated some form of this complex mixing of filing and extracting anterior teeth.

Table 5.40: Description of the combination styles seen in this population

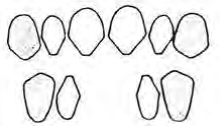
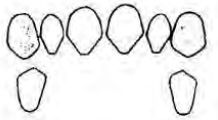
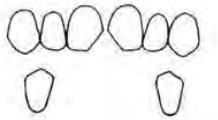
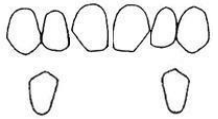
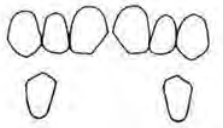
Case no.	Sex	Age	Filing	Extraction	Description	Illustration
SGA-T149	M	Adult	Style 2	Style 5	Filing of all upper and lower lateral incisors to a pointed shape and extraction of lower central incisors	
SGA-T116	F	20-30	Style 1	Style 1	Filing of all upper incisors to a pointed shape and extraction of all lower incisors	
KUL-T1(S)	F	20-25	Style 3	Style 1	Filing of the mesial corners of upper central incisors to an inverted V-shape and extraction of all lower incisors	
KMI-T7	?	15-25	Style 4	Style 1	Filing of the lateral corners of upper central incisors and extraction of all lower incisors	
KTG-T3	F	25-35	Style 3	Style 1	Filing of the mesial corners of upper central incisors to an inverted V-shape and extraction of all lower incisors	

Figure 5.45: Katongo T3 with a mixed style of modification, with filed mesial corners of upper central incisors and extraction of all lower incisors.

Summary of the most important findings from the data:

- The demographic profile of the Upemba Depression societies has shown that more females than males died as younger adults, possibly due to childbirth.
- There is a high degree of dental morphological continuity across the sexes, time periods and sites. Tooth sizes remained stable at all time periods and across sites. Both non-metric morphological traits and tooth diameters are bilaterally symmetrical. There is minimal sexual dimorphism between men and women, as indicated by mesio-distal and bucco-lingual diameters.
- Phytolith analyses suggest that plants consumed during each time period and at the different sites were similar and that the vegetation remained unchanged through time (from AD 700 to 1800).
- Males consistently have higher rates of dental diseases than females, but the differences are not statistically significant except for dental caries. As might be expected, older adults suffered to a greater extent than younger people from

caries, AMTL, dental abscesses, periodontal disease, and showed heavier tooth wear and heavier calculus deposits. This suggests that all dental diseases increase with age.

- The $\delta^{13}C$ values of the humans from Sanga, Malemba-Nkulu, Kikulu, Kamilamba and Katongo are suggestive of diets rich in C_4 plants or C_4-based animal protein, with a much smaller contribution from C_3 foods. C_3 foods were more important in the diets of the individuals from Katoto. Katoto individuals also had fewer caries, heavier dental wear, and less calculus. The opposite is true of individuals from Sanga; with higher caries rates, low wear scores, and heavier calculus. This is clearly a robust pattern, resulting from a significant dietary difference between the two sites.
- There are differences in tooth wear and dental caries between the Kisalian and Kabambian periods. People living during the Kisalian period had teeth that were less worn and more carious than people living during the Kabambian, but there are no significant differences in $\delta^{13}C$ between the two periods.
- A few individuals had substantial dietary shifts from early to late childhood as indicated by differing $\delta^{13}C$ values in the enamel of early compared with late forming teeth. Those whose diets changed to enriched $\delta^{13}C$ values also presented with caries; while those whose $\delta^{13}C$ values became more depleted have no caries.
- There is a wide diversity of tooth modification in the Upemba Depression. Seven different filing/chipping styles and five extraction styles were recorded. Both males and females demonstrate modified teeth. Females demonstrate the widest variation of filed/chipped teeth, while males prefer extraction over filing/chipping.
- In the next chapter, the findings from this study are assessed in light of studies of other peoples in different parts of Africa. This is done in order to place the Upembans in the wider context of early sub-Saharan African farming societies; understanding their biological relationships, subsistence activities and cultural behaviours.

Chapter 6: DISCUSSION

This chapter explores the patterns reported in the previous chapter in relation to the archaeology of the region, as outlined in Chapter 2, and in the context of the wider literature. The main goal of this research was to investigate the question of cultural continuity through time (as indicated by the archaeology of the Upemba Depression societies). Various aspects of the dental morphology and bone chemistry of these communities are documented for the first time.

The chapter is organised in three sections. First, it explores the data from dental morphological traits from the Upemba Depression and discusses the implications of the results in terms of these people's relatedness to one another and in relation to other sub-Saharan populations. Second, it looks at dietary indicators (dental diseases, phytoliths, and stable isotopes) as clues to dietary homogeneity/heterogeneity through time, and at different sites. Finally, this chapter looks at dental modification as a source of information about biological and/or cultural continuity of these populations.

6.1 Biological variation: genetic origins

6.1.1 Non-metric morphological dental traits

Since dental morphological traits are known to be under strict genetic control, they can provide useful means for evaluating biological relationships between different populations (Hanihara 1992, 2008; Scott & Turner 1997; Irish 1997, 1998; Stojanowski 2005; Ullinger *et al*. 2005; Taylor & Creel 2012). This study used dental morphological traits to address the question of continuity and affinity, and found a high degree of dental morphological similarity across the sexes, time periods and sites in early farming societies of the Upemba Depression.

The majority (94.9%) of non-metric trait frequencies were similar in the earlier Kisalian and later Kabambian periods, i.e. only two of 39 traits (UM1 Carabelli's trait and UC distal accessory ridge) showed significant differences between the two chronological periods. The 94.9% similarity (and other percentages of similarity in Tables 6.01 and 6.02) is calculated using the chi-squared tests calculated for each

compared trait, i.e. number of insignificant chi-squared tests as a percentage of the total number of chi-squared tests. It is not the same as heritability estimates mentioned in Chapter 3, but provides another estimate of relatedness between groups.

The prevalence of UM1 Carabelli's trait, a characteristic of Afridonty according to Irish (1993, 2013), is higher in the earlier Kisalian period (40.0%) than during later Kabambian times (13.0%). UC distal accessory ridge occurred on 40% of Kisalian teeth compared with 100.0% in the Kabambian. Although the "most sexually dimorphic trait" according to Scott and Turner (1997: 33), UC distal accessory ridge was not significantly different between the males and females in this study.

The overall frequency of Carabelli's trait in the Upemban sample is lower (28.2%) compared with historic-modern sub-Saharan Africans, amongst whom frequencies of 57.1% have been reported in the modern Congo and 55.2% for modern Kenyans (Irish 1993). The frequency amongst the Kisalians is, however, comparable to that of the 'ancient' African sample (39.7%), i.e. the Late Pleistocene-Holocene, in Irish's (2013) study.

Other studies that have looked at the geographic variation of Carabelli's trait in major world populations have found much lower frequencies of this trait among sub-Saharan Africans in comparison to Eurasian populations (Scott & Turner 1997; Hanihara 2008; Warren 2013). Hanihara (2008) reports a frequency of 22.6% for Carabelli's trait in Europe and 36.4% in West Asia, compared with only 17.1% in sub-Saharan Africans. Scott and Turner (1997) found a range of 20-30% in Western Eurasia and 15-20% in sub-Saharan Africa. The most striking problem with these comparisons is that different researchers used different cut-off points to calculate the frequencies of Carabelli's trait. For instance, Scott and Turner (1997) considered the trait to be present only if they observed tubercle and cusp forms (ASU grades 5-7) of expression. This study, Irish (1993, 2013), Hanihara (2008) and Warren (2013) include all degrees of expression (ASU grades 2-7). However, Scott and Turner (1997: 200) point out that cusp forms of Carabelli's trait are less common in sub-Saharan Africa than in Western Eurasia. Nevertheless, it appears that several researchers (this study; Hanihara 2008; Warren 2013) have found lower frequencies of Carabelli's trait in sub-Saharan Africans, contrary to the findings by Irish (1993, 2013).

The data from this study, Hanihara (2008), Irish (2013), and Warren (2013) show major variations in the frequencies of the same dental traits reported for sub-Saharan Africans. All these studies used the ASUDA system to score the traits, and used the same cut-off points for calculating trait frequencies. So, what is causing these major discrepancies in the data? An artefact of the methodology used, such as inter-observer error, is the most likely complication influencing this discrepancy. Comparison of small-scale versus large regional groups (i.e. sample size effects) might be another source of noise in the data. Nevertheless, these data offer an opportunity to compare the data from the current study in order to place the Upembans in the context of other sub-Saharan Africans.

The overall stability in the pattern of non-metric dental traits in the Upemba Depression shows that the genetic make-up of these people has remained similar through time despite repeated contact with neighbouring groups (Reefe 1981; de Maret 2012). The lack of morphological change through time is consistent with the archaeological evidence for cultural continuity. Perhaps, if there was gene flow into these populations, the source populations were not significantly different from the resident populations, unlike the genetic replacement seen in Nubians before the Final Neolithic period (Irish 2005). According to this study (Irish 2005), people from the Final Neolithic through Christian periods (5,700 BP– AD 350) exhibited relative homogeneity, which implies overall post-Pleistocene regional population continuity; whereas the Late Paleolithic (14,000–12,000 BP) sample from Jebel Sahaba is morphologically different from the later samples.

This research was also concerned with evaluating the similarities or differences between the Upembans and other sub-Saharan Africans; it therefore looked into the proposed Afridonty (Irish 2013), which distinguishes sub-Saharan Africans from other world populations. Afridonty comprises a suite of eleven traits, nine of which are found at high frequencies and two at low frequencies in sub-Saharan Africans compared to other world populations (Table 6.01). When the Upembans are compared with the 'ancient' Africa sample (Irish 2013), nine out of thirteen (69.2%) traits showed no significant differences (Table 6.01). When compared with the historic-modern samples from central and eastern Africa (Irish 2013), 53.8% of traits were not significantly different. More similar to Late Pleistocene-Holocene Africans than to

historic-modern populations, the Iron Age Upembans also demonstrate lower frequencies of LM1 cusp 7 and UM1 Carabelli's trait (Table 6.01). This disparity is suggestive of a temporal influence in the frequency of traits in sub-Saharan Africa.

Morphological trait frequencies from the current study were compared with those from neighbouring regions in sub-Saharan Africa, i.e. historic-modern groups from Congo and Kenya (Irish 1993). The Congo sample consists of individuals from historic-modern Teke (n = 22) and BaKongo (n = 4) groups who reside in the northwest of the Democratic Republic of the Congo. The Teke and BaKongo are Bantu-speakers but are otherwise considered culturally unrelated to the Luba people in the south-eastern part of the country. The sample from Kenya (Irish 1993) comprises historic Bantu-speaking groups, i.e. Kikuyu, Swahili, Chaga, Pare, and others from south-eastern Kenya and northern Tanzania (n = 114). A southern African Iron Age sample (n = 142), contemporaneous with the early Upembans, was also used for comparison (Warren 2013). Table 6.02 shows the frequencies of all 39 non-metric traits from this study and those from Irish (1993) and Warren (2013). It also shows the results of the chi-squared tests comparing frequencies from the respective studies.

As expected, the Upembans show the closest relationship with the Congo sample, with 32 of 36 (88.9%) trait frequencies compared showing no significant differences. The Upembans exhibit a higher frequency of the UC mesial ridge (68.0%) than the Congo sample (0.0%), but comparable to that reported by Warren (2013) in southern African Iron Age societies (69.1%). Although Warren's (2013) sample does not include any Khoesan individuals, some Khoesan genetic admixture into southern African Iron Age populations probably influences the high frequency of this feature. Genetic data show significant Khoesan gene flow into southern African Bantu-speaking populations (Tishkoff *et al*. 2009).

Mandibular torus was also more often present in the Upemba (45.2 %) compared with the Congo sample (0.0%). The southern African Iron Age societies were the only other sub-Saharan Africans that showed a slightly higher frequency of mandibular torus (25.0%) (Warren 2013). The frequency of two-rooted upper P1s (36.9%) was lower in the Upemba than in the Congo sample (63.6%), and more comparable to that seen in the Khoesan sample (36.7%) reported by Irish (1993). Only a minority of Upembans exhibited more than two lingual cusps on lower P2s (24.5%) in

comparison to their Congo neighbours (77.8%). The frequency of lower P2 lingual cusp number in the Upemba was similar to that found in Irish's (1993) Kenya sample (40.0%).

Table 6.01: Frequencies of the eleven Afridonty traits (nine high- and two low-frequency) plus two other high-frequency 'African' traits (midline diastema UI1 and labial curvature UI1) in the current study compared with 'ancient' Africa (Late Pleistocene to Holocene), and central and eastern Africa (Irish 2013). Bold p values are significant at the 0.05 level.

Trait	This study (south-central Africa)	Irish, 2013 ('ancient' Africa) %	χ2 test: This study vs. Irish 2013 (ancient Africa)	Irish, 2013 (central Africa) %	χ2 test: This study vs. Irish 2013 (central Africa)	Irish, 2013 (eastern Africa) %	χ2 test: This study vs. Irish 2013 (eastern Africa)
UM3 Presence (ASU +)	100.0	97.2	0.2793	97.2	0.2998	95.0	0.0903
Root number LM2 (ASU 2+)	95.5	86.4	0.0688	91.8	0.5440	90.2	0.2721
Root number UM2 (ASU 3+)	79.2	68.9	0.0907	79.0	0.9802	80.3	0.8342
Groove pattern LM2 (ASU Y)	75.0	67.0	0.2185	72.6	0.7140	67.6	0.2499
Canine mesial ridge UC (ASU 1-3)	68.0	20.3	**0.0000**	15.1	**0.0000**	11.2	**0.0000**
Labial curvature UI1 (ASU 2-4)	43.9	52.5	0.2393	50.5	0.4200	46.6	0.7233
Root number UP1 (ASU 2+)	36.9	53.7	**0.0157**	62.6	**0.0004**	67.0	**0.0000**
Midline diastema UI1 (≥ 0.5mm)	35.7	10.0	**0.0001**	15.0	**0.0073**	8.2	**0.0000**
Carabelli's trait UM1 (ASU 2-7)	28.2	39.7	0.0696	54.6	**0.0001**	56.6	**0.0000**
Enamel extension UM1 (ASU 1-3)	23.4	7.6	**0.0001**	2.0	**0.0000**	2.1	**0.0000**
Tome's root LP1 (ASU 3-5)	10.4	17.4	0.2301	20.5	0.1201	17.2	0.2384
Cusp 7 LM1 (ASU 2-4)	9.6	19.0	0.0549	23.4	**0.0133**	24.9	**0.0042**
Double shovel UI1 (ASU 2-6)	4.4	0.9	0.4740	0.0	0.1760	1.2	0.4180
Percentage of traits that are similar	**n/a**		**69.2**		**53.8**		**53.8**

Comparison with the sample from Kenya revealed that 27 of 36 (75.0%) traits were not significantly different. Three of the nine traits that were significantly different differed between this study, the Congo and Kenya samples (Irish 1993). Upper canine mesial ridge and the mandibular torus were found at much higher frequencies in this study, while UP1 root number was higher in the Congo and Kenya samples from Irish (1993).

Lastly, the Upembans show the greatest disparity in trait frequencies compared with their contemporaneous southern neighbours (Iron Age samples from South Africa, Zambia and Botswana [Warren 2013]). Only 50.0% of the 38 traits compared between these samples were similar. Of the three data sets (modern Congo, modern East Africa and Iron Age southern Africans), the southern Africans are the most morphologically dissimilar to the early inhabitants of central Katanga. Geographic proximity seems to be the primary influence leading to the differences seen between the compared groups, i.e. those closest to central Katanga (the BaKongo and Teke) are morphologically more similar to the Upembans than those farther away. Time and history (genetic admixture) appear to have had a secondary effect on the relatedness of these people with their neighbours, and best explains the disparity between ancient and modern populations observed by Warren (2013), and to a lesser extent by Irish (2013).

According to previous studies of dental morphology (Hanihara 2008, Irish 2013, Scott & Turner 1997), the best way to assess population relatedness is to use the largest number of traits for comparison. The more traits compared, the more confidence one can have in the conclusion. Comparisons between the Upembans and the Congo and Kenyan samples from Irish (1993) and Iron Age southern Africans (Warren 2013), can be interpreted with confidence because of the large number of traits used to shed light on these relationships.

In general, the Upembans do not show the consistent pattern of traits seen in other sub-Saharan Africans. For example, they demonstrate higher frequencies of UM1 enamel extension, low-grade UI1 shovelling, mandibular and palatal tori, and UM3 parastyle. Traits found at much lower frequencies in central Katanga when compared to the some sub-Saharan African samples (Irish 1993) include two-rooted UP1, Carabelli's trait, LP2 lingual cusp number, and cusp 7 LM1. What this means in terms

of the relatedness of the Upembans to other sub-Saharan Africans is not entirely clear, and is compounded by the high variability in the distribution of shared traits among the compared samples. They do point towards some degree of homogeneity among central and eastern Africans. The southern Africans are somewhat more different from the other groups, probably due to the incorporation of Khoesan genes into their gene pool. The homogeneity noted between some central and eastern Africans could be linked to the Bantu-speakers' expansion, which started between 4,000 and 3,000 BP when proto-Bantu speaking agriculturalists began to expand south and east from their homeland in the region of present-day Nigeria-Cameroon (Diamond & Bellwood 2003) (see Chapter 2 for a brief review).

Evidence for homogeneity among Bantu-speakers has been observed archaeologically (Diamond & Bellwood 2003). In the first half of the millennium AD, ceramic styles are very similar in eastern and southern Africa, tracking the rapid spread of Bantu-speaking farmers into southern Africa (Huffman 2005, 2007; Parkington & Hall 2010; Phillipson 1995). This population expansion is also confirmed by linguistic (Ehret 2000), genetic (Beleza *et al*. 2005), and morphological data (Froment 1998; Hiernaux 1974; Ribot 2010; Warren 2013). Ribot (2011) found continuity in the cranio-facial morphology between Early Iron Age (*c*. 1000 BC) and the modern Bantu-speaking populations, especially among western-Central Africans. Similarly, morphological continuity was found between the Iron Age Bantu-speakers and their modern counterparts in South Africa; thus providing bio-anthropological evidence that farming was brought to South Africa by an immigrant population around 400BP (Ribot *et al*. 2010).

In summary, this study was unable to identify the introduction of any new genetic material into these societies through the evidence of morphological traits. If the current study's dental patterns from ancient Upemba Depression accurately indicate the underlying genetic variation, it can be said that these past people were closely related to one another, with little evidence of gene inflow over time. They are also related to populations geographically close to them, as indicated by similarity in dental morphology. As such, this finding lends support to the hypothesis of genetic continuity from at least the Kisalian to the Kabambian periods.

Summary of information from the non-metric dental traits

1. Non-metric morphological traits remained stable during the last 1 000 years in central Katanga. Dental morphological differences between males and females were insignificant. Trait frequencies suggest that there was a high degree of dental homogeneity between the chronological periods. This homogeneity is explained as either genetic continuity or, if genetic material was introduced, it was sufficiently similar that it did not lead to any changes in tooth morphology.

2. In terms of their dental morphology, the Upembans are closest (88.9% of traits similar) to the historic-modern Teke and BaKongo sample described by Irish (1993). The early Upembans are also similar (75.0%) to the groups in the northeast (Kenya) (Irish 1993). It is clear that the Upembans are more different from their southern neighbours. The disparity (50.0%) between the Upembans and the Iron Age southern Africans (Warren 2013) is likely a result of the incorporation of Khoesan genes into the genetic pool of the latter.

3. The sample of only five recent (Luba) individuals (Appendix 2) is too small to draw meaningful conclusions as to whether new genes from the northeast of the Upemba Depression were introduced in the middle of the second millennium AD (AD 1600), as believed by the Luba. Therefore, the results of the current research can only draw conclusions about the first and second millennium AD Upembans up to AD 1600.

Table 6.02: Frequencies of all 39 non-metric traits in this study and those from Irish (1993: Congo and Kenya) and Warren (2013: southern Africa), and p-values of χ^2 tests comparing frequencies in the three studies. P-values shown in bold print are significant at the 0.05 level.

Trait	This study (south-central Africa) %	Irish, 1993 (Congo) %	χ2: This study vs. Irish 1993 (Congo)	Irish, 1993 (Kenya) %	χ2: This study vs. Irish 1993 (Kenya)	Warren, 2013 (southern Africa) %	χ2: This study vs. Warren 2013 (s. Africa)
Root number LM2 (ASU 2+)	95.5	100.0	0.9329	100.0	0.8675	98.0	0.6514
Root number UM1 (ASU 3+)	94.2	-	0.9999	-	0.9999	96.0	0.5654
Hypocone UM2 (ASU 3-5)	81.3	100.0	0.1023	78.0	0.6017	83.9	0.6498
Root number UM2 (ASU 3+)	79.2	72.7	0.5257	90.6	0.0437	89.7	0.0567
Groove pattern LM2 (ASU Y)	75.0	66.7	0.5139	83.3	0.6766	86.0	0.0852
Canine mesial ridge UC (ASU 1-3)	68.0	0.0	**0.0001**	13.0	**0.0000**	69.1	0.8971
Root number UM3 (ASU 3+)	64.3	-	0.9999	-	0.9999	66.2	0.8156
Shovel UI1 (ASU 2-6)	61.5	0.0	0.1415	7.1	**0.0014**	7.4	**0.0000**
Distal accessory ridge UC (ASU 2-5)	56.8	70.0	0.6936	36.6	0.0744	70.7	0.1643
Cusp number LM2 (ASU 5+)	53.0	88.9	0.0927	52.9	0.9948	100.0	**0.0000**
Deflecting wrinkle LM1 (ASU 2-3)	52.3	50.0	0.6631	33.3	0.2445	16.3	**0.0002**
Mandibular torus (ASU 2-3)	45.2	0.0	**0.0012**	0.0	**0.0003**	25.0	**0.0060**
Labial curvature UI1 (ASU 2-4)	43.9	33.3	0.8110	37.5	0.6493	20.0	**0.0045**
Anterior fovea LM1 (ASU 2-4)	42.9	60.0	0.7930	69.2	0.0907	87.7	**0.0000**
Root number UP1 (ASU 2+)	36.9	63.6	**0.0290**	68.6	**0.0010**	29.0	0.2783
Midline diastema UI1 (≥ 0.5mm)	35.7	30.0	0.9511	15.3	**0.0243**	49.0	0.3055
Tuberculum dentale UI2 (ASU 2-6)	31.1	0.0	0.4578	36.0	0.6765	12.0	**0.0100**
Parastyle UM3 (ASU 1-5)	30.5	5.3	0.0546	2.7	**0.0000**	7.7	**0.0002**
Carabelli's trait UM1 (ASU 2-7)	28.2	57.1	0.2446	55.2	**0.0005**	13.1	**0.0124**

Table 6.02 (continued): Frequencies of all 39 non-metric traits in this study and those from Irish (1993: Congo and Kenya) and Warren (2013: southern Africa), and p-values of χ^2 tests comparing frequencies in the three studies. P-values shown in bold print are significant at the 0.05 level.

Trait	This study (south-central Africa) %	Irish, 1993 (Congo) %	χ2: This study vs. Irish 1993 (Congo)	Irish, 1993 (Kenya) %	χ2: This study vs. Irish 1993 (Kenya)	Warren, 2013 (southern Africa) %	χ2: This study vs. Warren 2013 (s. Africa)
Protostylid LM1 (ASU 1-6)	27.0	14.3	0.7845	35.3	0.5017	1.1	**0.0000**
Interruption groove UI2 (ASU +)	24.5	20.0	0.7449	11.5	0.3025	0.0	**0.0000**
Lingual cusp number LP2 (ASU 2-9)	24.5	77.8	**0.0061**	40.0	0.2424	72.5	**0.0000**
Enamel extension UM1 (ASU 1-3)	23.4	5.0	0.1263	1.1	**0.0000**	3.5	**0.0000**
Peg-shaped UM3 (ASU P or R)	23.0	-	0.9999	-	0.9999	1.0	**0.0000**
Torsomolar angle LM3 (ASU +)	22.2	14.3	0.8133	12.5	0.6601	5.1	**0.0057**
Rocker jaw (ASU 1-2)	16.9	0.0	0.1730	14.3	0.9559	17.0	0.9486
Cusp 5 (metaconule) UM1 (ASU 2-5)	14.5	0.0	0.8073	14.8	0.9484	81.4	**0.0000**
Palatal torus (ASU 2-3)	13.9	3.4	0.3103	0.9	**0.0039**	3.0	0.0835
Tome's root LP1 (ASU 3-5)	10.4	28.6	0.1462	25.0	0.1218	9.1	0.8207
Cusp 7 (metaconulid) LM1 (ASU 2-4)	9.6	25.0	0.2927	11.1	0.8049	59.5	**0.0000**
Cusp number LM1 (ASU 6)	8.7	25.0	0.4130	5.6	0.9599	100.0	**0.0000**
Distal trigonid crest LM1 (ASU +)	7.4	0.0	0.7646	0.0	0.7611	24.0	**0.0191**
Double shovel UI1 (ASU 2-6)	4.4	0.0	0.2631	6.7	0.7324	0.0	0.3345
Root number LM1 (ASU 3)	1.5	7.7	0.7341	0.0	0.4779	2.8	0.9666
Odontome P1-P2 (ASU +)	0.0	0.0	0.9999	1.2	0.9552	-	0.9999
Congenital absence UM3 (ASU -)	0.0	0.0	0.9999	3.0	0.3497	1.0	0.8902
Peg-reduced UI2 (ASU P or R)	0.0	12.5	0.2588	0.0	0.9999	0.0	0.9999
Winging UI1 (ASU 1)	0.0	0.0	0.9999	4.0	0.6050	2.1	0.8198
Root number LC (ASU 2)	0.0	0.0	0.9999	0.0	0.9999	0.0	0.9999
Percentage of traits that are similar	**n/a**		**88.9%**		**75.0%**		**50.0%**

6.1.2 Metric dental traits

The results of the metric analyses corroborate the genetic stability of these people through time. Mean crown diameters (mesio-distal and bucco-lingual) were significantly different between the earlier and later periods for only three out of 20 teeth. Essentially, no major size differences were found between the two time periods, i.e. the sizes of teeth in the Kabambian period remained very similar to those in the Kisalian period. There is minimal sexual dimorphism; tooth crown diameters of men and women were not significantly different.

Both non-metric morphological traits and tooth diameters are bilaterally symmetrical. According to Moskona *et al*. (1996), bilateral asymmetry in size and morphology could increase under certain conditions of inbreeding and environmental stress, but it appears that neither of these factors had a significant influence on the people of central Katanga during the first and second millennium AD.

Mean mesio-distal and bucco-lingual tooth crown diameters from this study were compared with those from other sub-Saharan populations, and found to be very similar to southern African Sotho (Haeussler *et al*. 1989) and Iron Age people (Warren 2013) (Table 6.03 and Figure 6.01). As expected from the literature (Tobias 1972; Jacobson 1982; Haeussler *et al*. 1989; Hanihara & Ishida 2005), teeth in the Upemba Depression can be classified as mesodontic; their crown diameters are neither small (microdontic) like those seen in the Khoesan people, nor large (megadontic) as in the Australian aborigines (Hanihara & Ishida 2005). The Khoesan have relatively small teeth in comparison to the historic Sotho and to the early and late farming communities (Iron Age) of Bantu-speakers. Among sub-Saharan Bantu speaking Africans, there are minimal differences in tooth size to help in the assessment of population relatedness or affinity.

In summary, both metric and non-metric analyses suggest that the Upembans displayed a common pattern of dental variation and were phenotypically stable across the time sequences considered in this study.

Table 6.03: Comparative data on mean tooth crown diameters from this study, Haeussler *et al*. (1989), Scott & Turner (1988) and Warren (2013). Dashes indicate that data were not available.

Diameter	This study (Iron Age south-eastern DRC)	Haeussler *et al*. 1989 (historic Sotho)	Haeussler *et al*. 1989 (historic San)	Warren 2013 (Iron Age southern Africa)
LUP1-MD	7.2 ± 0.6	7.0 ± 0.5	6.6 ± 0.4	-
LUP2-MD	6.7 ± 0.4	6.6 ± 0.5	6.5 ± 0.7	-
LUM1-MD	10.3 ± 0.6	10.5 ± 0.6	10.1 ± 0.6	-
LUM2-MD	9.8 ± 0.7	10.2 ± 0.8	9.8 ± 0.7	-
LUM3-MD	8.9 ± 0.8	9.4 ± 1.2	8.6 ± 0.8	-
LUP1-BL	9.4 ± 0.7	9.3 ± 0.6	8.8 ± 0.6	-
LUP2-BL	9.4 ± 0.6	9.4 ± 0.6	8.7 ± 0.5	-
LUM1-BL	11.2 ± 0.7	11.3 ± 0.7	10.8 ± 0.6	-
LUM2-BL	11.1 ± 0.9	11.3 ± 0.8	10.8 ± 0.9	-
LUM3-BL	10.6 ± 0.9	11.1 ± 0.9	10.4 ± 0.9	-
LLP1-MD	7.1 ± 0.5	-	-	7.2 ± 0.5
LLP2-MD	7.2 ± 0.5	-	-	7.2 ± 0.6
LLM1-MD	11.2 ± 0.5	-	-	11.4 ± 0.7
LLM2-MD	10.7 ± 0.7	-	-	10.8 ± 0.8
LLM3-MD	10.8 ± 0.9	-	-	10.5 ± 0.7
LLP1-BL	8.0 ± 0.7	-	-	8.2 ± 0.6
LLP2-BL	8.3 ± 0.6	-	-	8.4 ± 0.6
LLM1-BL	10.5 ± 0.6	-	-	10.6 ± 0.6
LLM2-BL	10.2 ± 0.7	-	-	10.6 ± 0.7
LLM3-BL	10.1 ± 0.6	-	-	10.1 ± 0.6

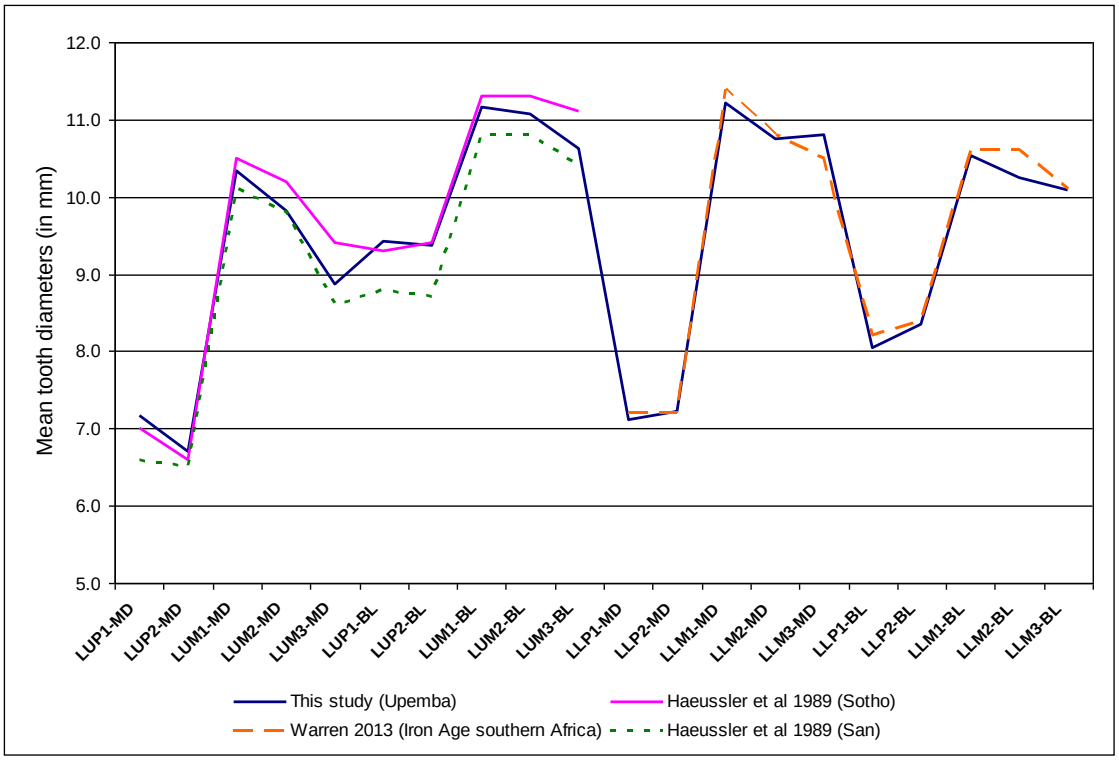


Figure 6.01: A line graph showing mean tooth crown diameters from this study, those of historic-modern Sotho and San from South Africa (Haeussler *et al*. 1989), and those of Iron Age farmers from southern Africa (Warren 2013).

6.2 Economic strategy: Oral health & diseases, phytoliths and stable isotopes

The overall frequency of caries in the Upemba Depression is high (10.9%), comparable to that of contemporaneous 'herders' (actually agro-pastoralists) from Zambia and Botswana (9.0%; Murphy 1996), and agro-pastoral communities from Ingombe Ilede and Isamu Pati (11.4%; Gibbon & Grimoud 2012) (Table 6.04). The 'herders' in Murphy's (1996) study had a significant proportion of cereals in their diets, and hence have higher caries rates in comparison to specialised pastoralists (e.g. the Masai of Kenya, with 0.4% of teeth carious [Price 1939]). All hunting-and-gathering groups in Table 6.04 have caries rates lower than 6.0% (Morris 1992; Walker & Hewlett 1990). With the exception of the farmers from Zambia and the DRC in Murphy's (1996) study, all other farming groups in Table 6.04 have caries rates above 8.0%.

In the Upemba Depression, evidence for the consumption of cereals comes from the recovery of phytoliths of Poaceae species in the dental calculus of 43 individuals (58.1%) dating to the earlier Kisalian period. Although archaeo-botanical evidence from the Upemba Depression is scarce, there are carbonised remains of finger millet (*Eleusine corocana*) from Kikulu grave number 3, dated to the Kabambian period (de Maret 1992; see also Chapter 2 for details). In addition, carbonised remains of *Eleusine* found at Inyanga in Zimbabwe, dating to the 8th century AD, confirm the cultivation of this cereal in southern Africa in the first millennium AD (Summers 1958). Because of the north-south migration route of domesticated cereals in Africa, the evidence from Zimbabwe suggests that the domestication and cultivation of finger millet in central Africa likely pre-dates the 8th century AD (Harlan 1971, 1992). Millet (*Eleusine corocana*) and sorghum (*Sorghum bicolor*) are important crops still cultivated in the Katanga Province and other parts of the DRC today. These crops have the potential to become cariogenic when gelatinised, i.e. cooked above 80°C (Lanfranco & Eggers 2012; http://en.wikipedia.org/wiki/Staple_food; http://fnic.nal.usda.gov/food-composition/usda-nutrient-data-laboratory), and their inclusion in the diet could result in elevated caries development. Therefore, this could partly explain the relatively high caries rate in the Upemba Depression.

Iron Age farmers from South Africa, however, had much higher caries rates (18.3% [Warren 2013] and 16.4% [Steyn 1994]) compared with those from the Upemba Depression (Table 6.04). This is suggestive of heavier reliance on starchy cereal crops than in the Upemba Depression. Evidence for carbonised cereals, grain bins and grinding stones attests to the well-established farming way of life of the Iron Age people in southern Africa (Huffman 1989; Inskeep 1978; Phillipson 2005; Vogel 1995). Behavioural factors such as methods of food preparation and oral hygiene may also have contributed to the differing caries rates among the early farmers in southern Africa (South Africa, Zambia and Botswana).

Archaeological food-waste strongly suggests that the subsistence strategy in central Katanga was very mixed. Food remains from these sites are dominated by wild fauna such as fish, wild bovids, birds and reptiles (see Chapter 2) rather than domesticated animals (de Maret 1985a, 1992). In addition, the wet climate in central Katanga is less suited to growing grain crops like sorghum and millet, compared with the drier climate of southern Africa. Although millet (and possibly sorghum) was grown in central Katanga during the Iron Age (see Chapter 2), the extent to which it was cultivated and consumed was probably not as extensive as in the Iron Age of southern Africa.

Other crops that the Upembans probably consumed include tubers, yams and papyrus, which are better suited to wetter environments. Most yams and root crops contain less than 40% glycaemic carbohydrates and are much less cariogenic in comparison to most grain staples, which contain more than 70% glycaemic carbohydrates (http://en.wikipedia.org/wiki/Staple_food, http://fnic.nal.usda.gov/food-composition/usda-nutrient-data-laboratory). Yams and most root crops are also less sticky in comparison to grain staples. Phytoliths from plants in the family *Cyperaceae*, which includes papyrus, were recovered in the dental calculus of the Upembans. Papyrus is an aquatic plant that grows abundantly in many African swamps (including the swamps in central Katanga). Apart from its popular use for making paper in Egyptian times, papyrus can also be used as food. The pith or central core of papyrus can be eaten as a food source, while the starchy rhizomes and lowermost part of the stems can be consumed raw, boiled or roasted (Duke 1983). Therefore, papyrus, yams and other root crops were likely more important in the diets of the Upembans, as

suggested by their lower caries rates in comparison to the South African farming societies.

As expected of people with mixed agricultural diets, dental wear was generally low in the Upemba Depression populations. Because teeth with more convoluted surface morphology are more susceptible to caries (Larsen 1997; Aufderheide & Rodriguez-Martin 1998), the majority of caries in the Upemba Depression were found in the posterior teeth, especially in the molars; the incisors and canines were least affected. Third molars were the most frequently affected by caries, followed by the second and then first molars. This is related to tooth wear: third molars retain their grooves and fissures because they erupt later than first or second molars. A similar pattern was found in some rural Africans by Manji *et al*. (1989) and the archaeological farming populations from Ingombe Ilede and Isamu Pati in Zambia (Murphy 1996). In addition, interproximal caries account for more than two-thirds of lesions found in the Upemba. This also lends support to the hypothesis that their diet included some cariogenic foods typical of farming or mixed communities.

The incidence of dental abscesses in the Upemba Depression is high (38.0% of individuals), and comparable to that among agro-pastoralists from Toutswe in Botswana (30.4% of individuals [Warren 2013]) and those from Ingombe Ilede and Isamu Pati in Zambia (37.5% of individuals [Gibbon & Grimoud 2012]). As with caries, the early and late farming communities from South Africa show slightly higher frequencies of abscesses (47.2% of individuals; Warren 2013) than the other samples. High rates of abscessing are strongly correlated with high frequencies of dental caries, because a carious lesion can open up a path to the pulp chamber leading to bacterial infection around the root (Roberts & Manchester 1995; Aufderheide & Rodriguez-Martin 1998; Burns 1999); but heavy dental wear, trauma and periodontal diseases can also cause abscesses (see Chapter 3 for details).

The distribution of abscesses in the Upemba Depression follows the same pattern as dental caries: the majority of abscesses were found on molars. Thus, dental caries were likely the primary cause of abscesses in the Upemba Depression. Since dental wear was moderate, rather than heavy, abscesses are unlikely to have been caused by wear. Periodontitis is high in this sample (see below), and likely contributed to the

development of abscesses. Lastly, trauma in the form of intentional modification of the anterior teeth is another likely cause of abscesses in the Upemba Depression. Filing and chipping of anterior teeth is traumatic and can produce pulp mortification and peri-apical infections. The relationship between abscesses and dental modifications has been described in several anthropological (Gibbon & Grimoud 2012; Reichart *et al*. 2008; Morris 1993) and clinical studies (Bataringaya *et al*. 2005; Iriso *et al*. 2000). Since tooth modifications are common in the Upemba Depression, it seems likely that they contributed to the prevalence of abscesses seen in these people. Twelve of the 78 abscesses recorded were associated with incisors – the teeth primarily involved in intentional modification.

Table 6.04: Comparison of the frequencies of dental diseases in this study and other contemporaneous and historic-modern populations from Africa. In all studies, caries, AMTL, and calculus percentages were calculated as no. of diseased teeth/alveoli as a percentage of the total number of teeth. % Abscess and % periodontitis indicates % of individuals with this condition. Mean wear scores indicate wear for all teeth present in each sample.

Research results	Age (AD)	Subsistence strategy	Caries (%)	AMTL (%)	Abscess (%)	Mean wear score	Calculus (%)	Periodontitis (%)
Upemba Depression (This study)	700 - 1600	Mixed agricultural	10.9	8.2	38.0	2.7	70.5	62.6
K2, South Africa (Steyn 1994)	1000 – 1300	Agro-pastoral	16.4	5.4	-	3.0	-	-
Farmers, Zambia & DRC (Murphy 1996)	1000 - 1400	Agricultural	5.0	5.4	6.7	1.8	-	-
'Herders', Zambia & Botswana (Murphy 1996)	900 - 1200	Pastoral/ Agro-pastoral	9.0	7.9	25.0	2.1	-	-
Iron Age southern Africa (Warren 2013)	400 - 1700	Agro-pastoral	18.3	-	47.2	-	-	48.1
Toutswe, Botswana (Warren 2013)	700 - 1300	Agro-pastoral	18.3	-	30.4	-	-	48.0
Riet River, South Africa (Morris 1992)	1060 - 1840	Foraging/ Pastoral	4.3	6.1	-	2.4	-	-
Ingombe Ilede & Isamu Pati (Gibbon & Grimoud 2012)	800 - 1600	Agro-pastoral	11.4	17.5	37.5	~2.0	0.6	-
Boyela ('Bantu'), DRC (Walker & Hewlett 1990)	Historic-modern	Horticultural	8.1	13.1	-	-	-	-
Efe, DRC & CAR (Walker & Hewlett 1990)	Historic-modern	Hunting & gathering	6.0	20.0	-	-	-	-
Mbuti, DRC (Walker & Hewlett 1990)	Historic-modern	Hunting & gathering	6.0	17.2	-	-	-	-
Aka, DRC & CAR (Walker & Hewlett 1990)	Historic-modern	Hunting & gathering	5.2	16.6	-	-	-	-

As expected, older adults in the Upemba Depression suffered to a greater extent than younger adults from caries, AMTL, dental abscesses, periodontal disease, and showed heavier tooth wear and heavier calculus deposits. Thus, all dental pathological conditions increase with age. High caries rates are accompanied by high rates of AMTL and both increase with age. For example, in younger adults, 8.6% of the teeth had caries and 7.3% had been lost antemortem. Among older adults, 20% of teeth were carious and 15.7% had been lost ante-mortem. This is in contrast with previous research on caries and AMTL prevalence by age (Morris 1992; Murphy 1996; Patterson & Larsen 1997), which reported higher caries rates and lower AMTL in younger adults. The pattern is reversed in older adults, with lower caries rates, but higher AMTL. In older adults, the teeth lost antemortem are assumed to have been lost due to caries (Morris 1992; Murphy 1996; Patterson 1984).

With an overall frequency of 8.2% for AMTL, the Upembans had a moderate loss of teeth in comparison to the agro-pastoralists from Ingombe Ilede and Isamu Pati (17.5%) (Gibbon & Grimoud 2012) and historic groups from Walker and Hewlett's (1990) study (Table 6.04). Considering the above, we can deduce that tooth loss in the Upemba Depression was due not only to caries, but that other causes of AMTL should be looked into to explain the pattern of tooth loss in these populations. Other possible causes for AMTL include trauma, intentional (cultural) extraction of teeth, and periodontitis (see Chapter 3 for details).

Calculus is common in the Upemba Depression; more than two-thirds (70.5%) of all teeth examined were affected by calculus. Among the agro-pastoralists in Zambia, calculus is almost negligible (0.6% [Gibbon & Grimoud 2012]). This is surprising considering their relatively high caries rates (11.4%), which the authors have linked to the consumption of some carbohydrates and trauma from cultural modification of teeth (Gibbon & Grimoud 2012). The calculus rate in this study is comparable to, though slightly lower than, that reported by Delgado-Darias *et al*. (2006) for the tumuli burials (80.0%) from Gran Canaria. These individuals had a marine diet mainly consisting of fish and shellfish. Their caries rates (6.3%) are lower than those in the current study (10.9%). According to the authors, the high calculus rate among these tumuli individuals is related to their high consumption of protein and less carbohydrates (Delgado-Darias *et al*. 2006).

The combination of high caries rates and thicker calculus deposits has been observed in populations that consumed a high carbohydrate diet (White 1994). However, Lieverse (1999) cautions that calculus is not necessarily diet-related. The formation of calculus is also influenced by a number of non-dietary factors, which include oral hygiene, the mineral content of drinking water, the rate of salivary flow, culturally derived patterns of behaviour, and the use of the teeth as tools (Lieverse 1999).

The frequency of periodontitis in the Upemba Depression is higher (62.6%) than seen among the Iron Age southern Africans (48.1%) and the Toutswe community (48.0%) in Botswana (Warren 2013). Because of the close relationship between calculus and periodontitis, it is not surprising to find a high incidence of periodontitis in the Upemba population. The high incidence of calculus is indicative of this population's poor oral hygiene (Hillson 2008), and to some extent, to the consumption of carbohydrates that promote plaque development (Brothwell 1981; Lukacs 1989; Cassidy 1984).

Evidence from stable isotopes show that $\delta^{13}C$ values of the archaeological skeletons from the Upemba Depression are enriched in the heavy isotope (^{13}C), as expected of people subsisting largely on aquatic and C_4-based foods found in their environment (see Chapter 5). As already mentioned, finger millet was cultivated at these sites; this crop follows a C_4 photosynthetic pathway. Another edible C_4 crop that was likely grown and eaten in this environment during the Iron Age is sorghum. Although no archaeological evidence for sorghum was found at these sites, evidence from phytoliths (from 36 individuals and at all sites, but Kamilamba) tentatively suggests that these people might have consumed this crop (see Phytolith section in Chapter 5). Papyrus, which grows wild in the many lakes of the Upemba Depression (Duke 1983), is another C_4 plant that was likely consumed by these communities.

The bone collagen $\delta^{13}C$ values for skeletons from Sanga (-10.6 ± 0.9‰; n = 19) are comparable to those from other farming populations in southern Africa, especially those from Bambandyanalo (-10.4 ± 1.3‰; n = 13) (Lee-Thorp *et al.* 1993; see Table 6.05). However, they are marginally less enriched than those from Ingombe Ilede (-9.1 ± 0.6‰; n = 11) (Murphy 1996). Two $\delta^{13}C_{collagen}$ values from Katoto (-14.1 and -14.7‰) are significantly more depleted than those from Sanga and from the other

farming populations in Table 6.05, but are more similar to those of the modern Elmolo (-14.3 ± 0.7‰; n = 20) and Dassanech (-14.6 ± 0.4‰; n = 27) people from Lake Turkana in Kenya (Kiura 2008). The depleted $\delta^{13}C$ values from Katoto and the modern Kenyan groups imply a substantial proportion of C_3-based foods in their diets. Apart from the C_4 plants mentioned above, almost all other edible plants in the Upemba Depression are wild C_3 species. The implication from the dental caries that some Iron Age farmers from the Upemba Depression (especially at Katoto) relied less heavily on agricultural products and included more wild (C_3) resources in their diets is supported by the data from stable isotopes.

C_3 plants that were cultivated in central Katanga during the first and second millennium AD include squashes (Cucurbitaceae) and gourds (*Lagenaria* sp.); but wild C_3 yams (*Dioscorea* sp.) and other native root crops were probably foraged. Scalloped phytoliths, typically from *Cucurbita* species, were recovered from the dental calculus of 17 individuals, from all sites and time periods. The archaeological record from the Upemba Depression shows indirect evidence for the cultivation of squashes and gourds in the form of ceramic pots in the shape of these cultigens (de Maret 1979, 1985a, 1992; see Chapter 2). These calabash-shaped pots belong to the Kisalian period, thus suggesting that these vegetables were exploited pre-AD 1400. Today, *Cucurbita* and *Lagenaria* make a major contribution to the diets of many African societies. All parts of *Cucurbita* are eaten. The flesh of *Lagenaria* is also eaten; but these plants are usually cultivated for their outer shell for storage purposes, as utensils, and for making musical instruments. In addition, squashes and gourds, their leaves and seeds, have a low cariogenic potential.

$\delta^{15}N$ values for bone collagen from Sanga (9.0 ± 0.8‰; n = 19) and Katoto (8.4 and 9.0‰) are low in comparison to those of some Iron Age farming populations from southern African and to the modern groups from Lake Turkana (Table 6.05). At Bambandyanalo, Skutwater, Taukome, and among the Dassanech, Gabra and Elmolo, $\delta^{15}N$ values are much higher than at Sanga and Katoto. There is an ecological influence on the higher $\delta^{15}N$ values from Bambandyanalo, Skutwater, Taukome, and of the Dassanech and Gabra people. Their high $\delta^{15}N$ values are likely due to the drier conditions at these sites compared to the sites in the Upemba Depression. The people at the lowest annual rainfall regions (Skutwater, Bambandyanalo, and Lake Turkana)

have the most enriched $\delta^{15}N$ values compared with those in the wetter areas. Annual rainfall at the drier sites ranges from 300 to 600mm, while the Upemba Depression receives above 1200mm of rain per annum. This is a substantial difference that is likely influencing the nitrogen isotope ratios of the humans (and animals) in these regions (Hedges & Reynard 2007).

Cattle and caprine remains were found in abundance at Early and Late Farming Community sites in southern Africa, as well as in the refuse pits of the modern Kenyan groups (Voigt 1983; Plug & Voigt 1985; Kiura 2008). These grazing domesticates, however, usually have low $\delta^{15}N$ values, especially in comparison to fish (Mosothwane 2010). Thus, we would expect those people that rely heavily on fish to have higher $\delta^{15}N$ values than those subsisting on terrestrial bovids.

The people of central Katanga had a prolific fishing economy. Animal protein was obtained primarily from fish found in the lakes and rivers, from wild fauna (bovids and reptiles), and from domesticated caprines and chickens. Similar to the Elmolo people in Kenya (Kiura 2008), the early Upembans do not show high $\delta^{15}N$ values expected from humans who subsist on large quantities of aquatic resources. This could be because they ate mostly low-trophic level or bottom-feeder species of fresh-water fish. Catfish, the remains of which were found in abundance at these sites, are bottom feeders. These fish have diets consisting mainly of insects, small fish and vegetation, but are known also to eat decaying fish and aquatic plants from the bottom of the body of water in which they live (Teugels 1986). According to Katzenberg (1989), the stable nitrogen isotope ratios of fish species reflect their trophic position. A study by van der Merwe *et al*. (2003) showed that a population with a terrestrial diet in a well-watered environment had elevated $\delta^{15}N$ values. They attributed the elevated $\delta^{15}N$ values of the Moatfield (Ontario) people to their consumption of higher-trophic level species of fish from the nearby lake.

Although plants are low in proteins, they also contributed to the protein component of the diets of the early Upembans. Sources of plant proteins include leafy greens such as *Amaranthus* leaves, *Cucurbita* leaves, seeds, peanuts (*Arachis*), and so on. Plant protein, in contrast to animal protein, is less enriched in ^{15}N because plants are a trophic level below animals (Minigawa & Wada 1984). As a result, individuals who obtain most of their energy sources from plants are expected to have depleted $\delta^{15}N$

values. This picture is consistent with that of most contemporary sub-Saharan African diets consisting of a high proportion of a carbohydrate staple (such as cassava or maize meal) with a vegetable accompaniment (generally leafy greens such as amaranth, pumpkin and sweet potato leaves). Meat or fish and their by-products are not a regular part of a meal; they make a small contribution and not usually eaten in large amounts (Fiple *et al*. 2000; Hill *et al*. 1979; Okeke *et al*. 2009; http://www.fao.org/docrep/u8480e/U8480E07.htm#Staple foods What do people eat).

Therefore, the low $\delta^{15}N$ values of the humans from the Upemba Depression could be an indication of individuals who relied more heavily on plant protein than on animal protein. If the humans at these sites were eating a lot of fish, we expect to see $\delta^{15}N$ values of around 11-13‰, based on the 3-5‰ trophic level enrichment (Minigawa & Wada 1984; see Hedges & Reynard 2007 for a review). $\delta^{15}N$ values at Sanga (9.0 ± 0.8‰) and at Katoto (8.4 and 9.0‰) are, however, below this expected range and rather at a similar trophic level to the single catfish sample analysed (8.2‰). Alternatively, if we consider that the protein component of the human diets in Iron Age central Katanga came from both animal and plant sources, we might get closer to the reasons for the low $\delta^{15}N$ values from the human bone collagen. When averaging all analysed samples of plants and animals (both archaeological and contemporary) and adding 3-5‰ to account for the trophic level effect, we get a range of 8.9-10.9‰ for humans. This range is much closer to reality than the above scenario of looking at animal or plant protein sources separately. The range of $\delta^{15}N$ values for humans from Sanga and Katoto is 7.5-11.2‰.

Table 6.05: Comparison of the mean bone collagen $\delta^{13}C$ and $\delta^{15}N$ values from this study and those from other contemporaneous and modern African populations.

Research results	Sample size N	Age (A.D)	Subsistence strategy	Annual rainfall	Mean $\delta^{13}C_{collagen}$	Mean $\delta^{15}N_{collagen}$
Sanga, DRC (This study)	19	700 - 1600	Mixed agricultural	1200-1400 mm	-10.6 ± 0.9	9.0 ± 0.8
Katoto, DRC (This study)	2	700 - 1300	Mixed agricultural	1200-1400 mm	-14.1 and -14.7	8.4 and 9.0
Bambandyanalo, South Africa (Lee-Thorp *et al*. 1993)	13	1000 - 1300	Agro-pastoral	330 mm	-10.4 ± 1.3	11.3 ± 1.0
Skutwater, South Africa (Lee-Thorp *et al*. 1993)	4	pre 1300	Agro-pastoral	330 mm	-11.3 ± 0.8	13.4 ± 1.1
Taukome, Botswana (Mosothwane 2010)	5	900 - 1000	Agro-pastoral	400-600 mm	-9.5 ± 1.4	10.9 ± 0.9
Kgaswe, Botswana (Mosothwane 2010)	17	1200 - 1250	Agro-pastoral	400-600 mm	-9.4 ± 0.9	9.7 ± 0.7
Ingombe Ilede, Zambia (Murphy 1996)	11	600 – 1400	Agricultural	400-600 mm	-9.1 ± 0.6	8.5 ± 0.9
Dassanech, Kenya (Kiura 2008)	27	modern	Agro-pastoral	< 300 mm	-14.6 ± 0.4*	13.9 ± 1.4*
Gabra, Kenya (Kiura 2008)	24	modern	Pastoral	< 300 mm	-17.1 ± 0.8*	10.9 ± 1.0*
Elmolo, Kenya (Kiura 2008)	20	modern	Fishing	< 300 mm	-14.3 ± 0.7*	8.0 ± 0.6*

* Mean $\delta^{13}C$ and $\delta^{15}N$ values from hair keratin (Kiura 2008)

Despite the archaeological evidence that suggests a stable dietary regime over the thousand years of occupation in the Upemba Depression, the dental evidence suggests that it was not entirely uniform. Table 6.06 provides a comparative summary of the data from dental diseases and wear, phytoliths and carbon stable isotopes seen in the human remains from the Upemba Depression. Three distinctive patterns can be seen in the data, i.e. a temporal difference between the Kisalian and Kabambian periods, a difference between males and females and between the sites of Sanga and Katoto (Table 6.06).

6.2.1 Temporal differences

Caries, AMTL and abscesses occur at higher frequencies in the earlier Kisalian period than in the later Kabambian period (Table 6.06). Periodontitis and calculus are low in the Kisalian period compared to the Kabambian. In addition, people living during the Kisalian period had teeth that were less worn than those in the Kabambian. It has been shown that slight to moderate wear can be beneficial in the prevention of dental caries, since the grooves and fissures of posterior teeth can be smoothed out and thus remove the areas where caries often start (Powell 1985). Likewise, moderate amounts of dental calculus have been associated (at individual level) with lower caries rates because calculus requires mineralisation of dental plaque (Nancollas & Johnsson 1994; Hillson 2001). Thus, it is possible that the heavier tooth wear and thicker calculus on the teeth of the individuals from the Kabambian period offered them some protection from caries.

So, we ask this question - what types of foods were cariogenic in the diets of the early Upembans, especially those pre-AD 1400? Based on the nutritional facts and cariogenicity of cereal versus root staple crops, the lower caries rates among individuals from the Kabambian period might result from the inclusion of more root crops in their diets. Since root crops are C_3 plants, we would expect this to result in more depleted $\delta^{13}C$ values in the humans. There were, however, no significant differences in $\delta^{13}C$ values between the Kisalian and Kabambian periods, making this explanation untenable. $\delta^{13}C$ from enamel apatite for both the Kisalian (excluding Katoto samples and 3 outliers, n = 33) and the Kabambian (excluding 1 outlier, n = 39) periods gave very similar values (-3.3 ± 1.1‰ and -3.2 ± 1.0‰, respectively).

Thus, the diets consumed by people in both chronological periods were similar, at least in terms of their carbon isotope composition. These diets were predominantly from C_4 sources.

An alternative explanation for the differing dental caries rates between the two periods is that the diets consisted of the same kinds of foods but the methods of preparation differed, leading to differential dental pathologies. Food preparation and cooking methods, as well as behavioural practices are known to influence dental pathologies (Oranje *et al*. 1935; van der Merwe *et al*. 2011). We have little direct archaeological evidence for food preparation and cooking techniques during the two periods. Kisalian and Kabambian pottery differ only in shape and decoration (de Maret 1999, see Chapter 2 for details). The archaeological evidence available to us is uninformative about food processing techniques such as grinding or pounding; more finely ground carbohydrates are likely to be sticky and therefore cariogenic.

The possibility of differential practice of some form of oral hygiene cannot be ruled out. Ethnographic evidence for cleaning teeth with sticks or ash has been recorded among many groups in Africa, for example, among the modern Esan of Nigeria (Idu 2009). As mentioned above, phytoliths from woody plants were found in abundance in the dental calculus of the Upembans. Thus, it is possible that oral hygiene was practised in the Upemba Depression pre-AD 1400, but that it became more entrenched post-AD 1400. However, dental calculus in the Kabambian is more common than in Kisalian times; this does not support the possibility of practising oral hygiene or brushing teeth with sticks or ash. Whatever the causes, it is difficult to discern what drove the differences in dental diseases during the two chronological periods. So far, the possibility of differential food preparation and cooking methods is more compelling than any other scenario.

Table 6.06: Summary of oral pathologies, phytoliths and stable carbon isotope ratios observed in the Upemba Depression, between comparable groups from time periods, sites, sexes and ages.

Observations	Kisalian	Kabambian	Statistical significance
Caries (teeth)	high	low	yes
AMTL (alveoli)	high	low	yes
Abscesses (alveoli)	high	low	no
Wear (mean)	low	high	yes
Calculus (teeth)	low	high	yes
Periodontitis (individuals)	low	high	no
Phytoliths	more unique	less unique	no
$\delta^{13}C_{mean}$	low (depleted)	high (enriched)	no

Observations	Sanga	Katoto	Statistical significance
Caries (teeth)	high	low	yes
AMTL (alveoli)	high	low	no
Abscesses (alveoli)	low	high	no
Wear (mean)	low	high	yes
Calculus (teeth)	high	low	yes
Periodontitis (individuals)	high	low	no
Phytoliths	more unique	less unique	no
$\delta^{13}C_{mean}$	low (depleted)	high (enriched)	yes

Observations	Male	Female	Statistical significance
Caries (teeth)	high	low	yes
AMTL (alveoli)	high	low	no
Abscesses (alveoli)	high	low	no
Wear (mean)	high	low	no
Calculus (teeth)	high	low	no
Periodontitis (individuals)	high	low	no
Phytoliths	-	-	-
$\delta^{13}C_{mean}$	low (depleted)	high (enriched)	yes (at Sanga)

Observations	Younger adult	Older adult	Statistical significance
Caries (teeth)	low	high	yes
AMTL (alveoli)	low	high	yes
Abscesses (alveoli)	low	high	yes
Wear (mean)	low	high	yes
Calculus (teeth)	low	high	yes
Periodontitis (individuals)	low	high	yes
Phytoliths	-	-	-
$\delta^{13}C_{mean}$	-	-	-

6.2.2 Sex differences

When it comes to differences between men and women, the results from the Upemba Depression present an opposite picture from the trend seen in other studies, in which females usually present with higher frequencies of dental diseases than males (Warren 2013; Murphy 1996; Steyn 1994; Morris 1992; Larsen *et al*. 1991). All dental pathological conditions (caries, periodontitis, abscesses and antemortem tooth loss) are found at higher frequencies in men than in women in the Upemba societies, but the differences are not statistically significant except for dental caries (Table 6.06). The differences in caries prevalence between males and females suggest differences in food consumption or behaviour between the sexes.

In agricultural societies, the higher incidence of caries among females has been attributed to a higher consumption of carbohydrates (and perhaps less access to animal foods), and more frequent 'snacking on' cariogenic food during food preparation (Larsen *et al*. 1991). Females of reproductive age are also more susceptible to dental caries, especially during pregnancy (Silk 2008; Watson *et al*. 2010), because of a reduction in salivary flow, lower oral pH and increased cariogenic oral bacteria (Lukacs & Largaespada 2006; Lukacs 2008). Hence, it is surprising that the men in the Upemba Depression are more affected by caries than the women and this is likely to indicate a culturally based difference in diet between men and women.

When looking at non-dietary causes for caries, such as cultural modification of teeth in the form of chipping or filing, heavy or low dental wear, trauma, and so on, it is apparent that these other causes had very little influence over the observed frequencies of caries between males and females. Both males and females demonstrate modified teeth. The males in this population show slightly more worn teeth than the females, as well as more calculus deposits, but these were not statistically significant.

Diet was therefore probably the primary cause of the different rates of caries observed between (and within) the sexes in these societies. Perhaps certain behaviours by the men were responsible for their higher caries rates. Behaviours that involve the use of teeth as tools can predispose teeth to trauma or uneven rapid wear, as has been seen

among the Middle Neolithic people of Sweden (Molnar 2008). Trauma that leads to cracks or breaks in the tooth enamel can create pathways through which cariogenic bacteria can enter the pulp cavity and cause caries. Uneven rapid heavy wear can lead to pulp exposure or exposure of the softer dentine, rendering a tooth more susceptible to caries (Morris 1992). Examination of trauma did not, however, form part of this study. It remains unclear why the men in this population have more caries than among the women.

Phytoliths from palms (spheroid echinate and ellipsoid echinate) were found in abundance in dental calculus from all chronological periods and at all sites in the Upemba Depression. Carbonised and charred fragments of nuts of the oil palm (*Elaeis*) were recovered at all sites in the Upemba Depression from as early as the Kamilambian period (AD 600 – 700; see Chapter 2). Palms grow throughout the Upemba Depression, and have played an important role from antiquity to modern times. They provide oil, fruits and are also tapped for their sap, which can be made into wine (Obahiagbon 2012). The consumption of palm products, especially wine, could explain the differing caries rates between men and women.

Palm wine, which is still locally produced from tapped palm sap, has been produced for centuries in central Katanga. Palm wine is acidic and has a high sucrose content, and when consumed regularly, can lead to lowered oral pH that favours demineralisation of the enamel through fermentation by oral bacteria (Chandrasekhar *et al*. 2012). Palm wine also contains a wide range of bacteria, some of which are known to cause dental caries (Chandrasekhar *et al*. 2012). If men in the Upemba Depression drank more palm wine and/or consumed it more frequently than women, this might account for the unusual pattern of higher caries rates among men than among women.

Mean values for enamel apatite among males (-4.7 ± 2.2‰, n = 32) and females (-4.2 ± 2.0‰, n = 47) showed no significant differences (see Chapter 5, Table 5.34). On the basis of the carbon isotope evidence, both men and women had more or less similar diets. However, when sexes are compared at each site separately, $\delta^{13}C$ values of males and females differed significantly at Sanga. $\delta^{13}C$ values from enamel apatite indicate that the males there (-4.1‰, n = 11) were consuming more C_3-based foods than the females (-2.8‰, n = 15) (see Chapter 5). Simultaneously, the males at Sanga have

more caries per individual compared to the females (23.0% vs. 14.9% carious teeth, respectively).

Interestingly, when all 17 males from Sanga were removed from the analysis, the caries rates of males (sites and chronological periods pooled) drops to almost half that of the females, i.e. from 15.4% to 5.3% for males compared with 9.8% for females (χ^2 = 4.55, p = 0.0329). Thus, it is clear that the males from Sanga were driving the apparent differences between the sexes. Since the $\delta^{13}C$ values of males from Sanga are more depleted than those of females, it appears that the different C_3 food(s) consumed by the males is relatively cariogenic, leading to more caries per male individual affected. It also seems that this food was not eaten by all males at Sanga, as indicated by the frequency of dental caries within the males, i.e. 58.8% of male individuals were affected versus 73.7% of females. Once again, the habit of drinking palm wine predominantly or exclusively by some men is a possibility at this site. Palms are C_3 plants, and significant consumption of palm products will lead to depleted $\delta^{13}C$ values in the consumer, consistent with the results for the males at Sanga (-4.7 ± 2.2‰, n = 32).

In terms of differential access to certain foods between men and women, it is well documented that in many African societies, there is a special reservation for men to get more meat, as well as to prohibit consumption of certain foods, such as eggs and parts of a carcass, by women (http://www.fao.org/docrep/w0078e/w0078e08.htm#P7404_499006). The stable isotopes, however, show no measurable discrepancy in $\delta^{15}N$ values that would support greater consumption of meat by males than females. $\delta^{15}N$ values from bone collagen of males and females at Sanga are comparable and it therefore appears that men and women had similar access to meat at this site. With this small data set (n = 14), however, caution should be exercised when evaluating these arguments as a different trend could appear with a larger sample.

In summary, differential access to some resources or different behaviours likely caused the differences (in dental diseases and stable isotopes) observed between males and females at Sanga.

6.2.3 Site differences

Due to small sample sizes, inter-site comparisons are restricted to Sanga and Katoto. Overall, individuals from Sanga have poor oral health in comparison to those from Katoto. With the exception of abscesses, all other dental pathologies were found at higher frequencies at Sanga than at Katoto (Table 6.06). Interestingly, dental wear is also significantly lower at Sanga in comparison with that at Katoto. The differing caries rates between Sanga and Katoto could indicate differences in the types of food consumed or differences in preparation and cooking methods used. As far as preparation and cooking techniques are concerned, however, the archaeological evidence points to a lack of difference in the utensils (i.e. pots and grinding stones) found at the two sites (see Chapter 2 for details). With that in mind, a significant dietary difference between the two sites seems the most probable reason.

The $\delta^{13}C$ values of the humans from Sanga, Malemba-Nkulu, Kikulu, Kamilamba and Katongo are suggestive of diets rich in C_4 plants or C_4-based animal protein, with a much smaller contribution from C_3 foods. C_3 foods were more important in the diets of the individuals from Katoto. $\delta^{13}C$ values at Katoto are relatively low at -14.1 and -14.7‰, for bone collagen (n = 2) and -6.2 ± 1.5‰, for enamel apatite (n = 42).
As already mentioned, C_3 plants that were likely eaten include root crops, such as *Dioscorea* yams, squashes (*Curcubita*), and gourds (*Lagenaria*). Based on the nutritional information and low cariogenicity of squashes and root crops presented above, perhaps the diets of the individuals from Katoto included more of these crops in their diets, as indicated by their lower $\delta^{13}C$ values and lower caries rates in comparison to those from Sanga. It, thus, seems that the diets at Sanga consisted of more C_4 grain staples, which are known to be more cariogenic than yams and root crops, hence their enriched $\delta^{13}C$ values and higher caries rates.

Cassava, though not native to Africa, today dominates the agriculture of most western and central African countries. In 2002, 99.1 million tonnes of cassava production came from Africa. Nigeria, for example, is the world's largest producer of cassava (Nweke 2005). This C_3 crop was brought into Africa by the Portuguese at the beginning of the 16th century (Nweke 2005; Okigbo 1980). Thus, the influence of cassava in the diets of the early Upembans is not expected pre-AD 1500. As already

mentioned above, there are some local species of root crops (mainly *Dioscorea* sp. yams) that early populations probably consumed (Coursey 1975). It is worth noting that the only enamel sample from the Recent (Luba) period (post-AD 1600) analysed in this study had a depleted $\delta^{13}C$ value of -7.9‰. This result might indicate the possibility of the influence of cassava on the diets of the people in central Katanga post-AD 1600.

It was unexpected to note significant differences in the dental diseases, phytoliths and stable isotopes pointing towards different diets between Sanga and Katoto. These two sites are only 130 kilometres apart. The intra-site sex differences were also surprising. These observations raise some important questions about social organisation at the different sites, such as between men and women. They are also relevant to questions about social status. It is well understood that these societies were hierarchical (Nenquin 1967; Hiernaux *et al*. 1967, 1971; de Maret 1979, 1985a, 1992). Evidence for socio-political hierarchy comes from unequal quantities of grave goods, and special items in the burials (see Chapter 2). Perhaps some of the differences seen at the sites could be indicative of high-status versus low-status individuals who were buried separately, such as seen at Mapungubwe and K2 (Steyn 1994). Since it was not the intention of this thesis to investigate the influence of socio-political hierarchy within these societies, this issue will be dealt with in the future.

It is also possible that some kind of complementary subsistence patterns existed between the societies at the different sites, i.e. that the society at Sanga may have been more specialized agriculturists, while that at Katoto specialised in a fishing way of life. Examples of complementary existence are known between the fishermen and farmers in the region of Kindondja, DRC (de Maret 1979) and between the Bantu-speaking horticulturists and the Efe hunter-gatherers in the Ituri Forest (Walker & Hewlett 1990). However, there is no evidence of this from the archaeology of the six sites.

$\delta^{18}O$ values in tooth enamel from Sanga and the other four sites in the north-eastern part of the research area are more enriched than those from Katoto. All the sites are located between 550 and 650m above sea level, so variations in $\delta^{18}O$ cannot be attributed to differences in altitude. Sanga, Katongo, Malemba-Nkulu, Kikulu and Kamilamba are located on the banks of lakes (Kisale, Kalombwe and Kabamba), and

its inhabitants probably obtained their drinking water from the lakes. Given the high temperatures in the Upemba Depression (average minimum and maximum temperatures range from 8 to 31°C [www.worldclimateguide.co.uk]), lake water is likely to have undergone a considerable amount of evaporation, leaving the remaining water enriched in ^{18}O. Drinking water at Katoto, on the other hand, probably came from the nearby Upper Congo River. Rivers are subject to less evaporation than lakes (Dansgaard 1964; Levin *et al*. 2006), so $\delta^{18}O$ values for individuals from Katoto are more depleted (and more varied).

The inter-site differences described above tell us that communities were largely geographically segregated. There are, however, a few individuals for whom we have evidence of mobility. Differing $\delta^{13}C$ values in the enamel of early compared with late forming teeth indicate that some individuals had experienced substantial dietary shifts. Three individuals (Katoto grave no. 25 and no. 50, and Kikulu grave no. 2) whose diets changed to more enriched $\delta^{13}C$ values also presented with caries; while three (Katoto grave no. 26, Kamilamba grave no. 10, and Katongo grave no. 8) whose $\delta^{13}C$ values became more depleted have no caries (see Chapter 5, Table 5.36). The substantial change in $\delta^{13}C$ values (>2‰ [DeNiro & Schoeninger 1983]) implies either a shift in diet or migration from an area with diets of a different isotope composition.

Four individuals (Sanga grave no. 140, Kamilamba grave no. 7, Katongo grave no. 8, and Kikulu grave no. 10) also yielded carbon isotope ratios substantially depleted in ^{13}C compared to the rest of the group (i.e. outliers). Interestingly, they also presented with less dental caries; only two had a few caries (Sanga grave no. 140 (n = 4), Kamilamba grave no. 7 (n = 1)). Their different $\delta^{13}C$ values suggest a diet different from that of the society at large. These individuals, too, may present us with an opportunity to investigate the possibility of immigration or different origins. It may be possible, in future studies, to gain greater clarity as to whether these individuals were immigrants - for example, by measuring strontium isotopes ratios ($^{87}Sr/^{86}Sr$) in the teeth. These reflect the geology of the area where the person lived. Such an approach would be a good start to probe deeper into the origins and possible movement patterns of these individuals.

Three of the four individuals with depleted $\delta^{13}C$ values (Sanga grave no. 140, Katongo grave no. 8, and Kikulu grave no. 10) yielded nothing unusual in terms of grave goods and burial position. Kamilamba grave no. 7 was aged 15-25 years at death, but the sex could not be determined due to poor preservation. On the basis of the associated grave goods, this individual is likely to have been male. He was buried with an abundance of rich grave goods, including an iron ceremonial axe. His teeth were also modified: the upper central incisors were filed at lateral corners, while all four lower incisors were extracted. His style of modification is unique, and is one of the uncommon 'combination' styles seen only in five of 72 individuals with modified teeth (see Chapter 5). It appears that the individual buried in Kamilamba grave no. 7 had a high social status, his diet was different from that of the society at large, and he had very good oral health (only one small occlusal cavity on LLM1 out of 22 teeth present).

Summary of information from dental diseases, phytoliths, and stable isotopes

1. The data from this study show consistency with a mixed agricultural economy with changing dynamics around AD 1300. Evidence for a mixed subsistence or economic strategy is supported by lower caries rates in the Upemba Depression compared to contemporaneous farming societies in southern Africa. This is further supported by evidence from phytoliths; with more woody and herbaceous plants dominating the phytolith assemblage from the Upemba, while grasses were less commonly present. Lastly, the results from stable isotope partly concur with the data from dental diseases and phytoliths, i.e. inclusion of wild C_3-based foods (plants and animals) in the diet, at least suggested by $\delta^{13}C$ values from Katoto.

2. The faunal and floral isotope samples used in this study to create a baseline from which to interpret the human isotope ratios were too few and did not capture the range of variation of likely foods. In order to improve our understanding of the diet of these past people, larger and more varied samples, especially of fresh-water fish, are needed to create a better baseline from which to interpret human diets. It would also be useful to do isotope and phytolith analyses on the food residues from the pottery and grinding stones from these sites, to better understand the differing isotope and dental disease patterns at different chronological periods and sites.

3. Lastly, poor preservation of bone collagen (expected to some extent) limited the reconstruction of diets, especially of the protein component. In addition, the comparison between childhood and adulthood dietary signatures was compounded by poorly preserved collagen. It may be possible to extract collagen from tooth dentine, which is often better preserved than post-cranial bone. Investigation of dentine is planned for future studies in order to resolve this problem.

6.3 Dental modification

How does the evidence from dental modification pair up with the findings from dental anthropology and stable isotopes from this study? Does dental modification suggest different cultural patterns in the later and earlier chronological periods in the Upemba Depression?

Although all styles were done during the different chronological periods, there seems to have been a preference for filing of incisors over other forms of modifying teeth during the Kisalian period. The uniformity in tooth modification during the Kisalian period lends support for the strong social cohesion that characterises this period (de Maret 1999; see Chapter 2 for details). It could be argued, therefore, that the uniformity or consistency in style during the Kisalian period is suggestive of society-driven reasons for performing tooth modifications. Less variation is expected in cases where modifications are done for group identification purposes (van Reenen 1986; Alt & Pichler 1998).

The lack of preference for a specific style of tooth modification in the Kabambian period parallels the lack of uniformity seen in the burial ritual during this period (de Maret 1999; see Chapter 2 for details). The diversity in styles seen during the Kabambian is suggestive of individuality or personally driven reasons for modifying teeth (see Chapter 3 for a review). The variation could also indicate, in part, the nature of the diversity and inclusive manner of these societies that were possibly comprised of small chiefdoms of different cultures as exemplified by the Luba of Katanga (Reefe 1981; Childs & de Maret 1996; de Maret 1999).

Furthermore, both men and women modified their teeth; but women showed more diversity in style and preferred filing/chipping their teeth, while males preferred extraction. The differing styles observed between the sexes are suggestive of the rite of passage as one of the most plausible reasons for performing modifications by these societies, as sexes would be treated differently in this setting (see Chapter 3 for a review).

It is also probable that the diversity of styles among women could be an indication of a 'foreigner' status in these societies, i.e. that women could have been outsiders or non-locals. However, the data from non-metric tooth morphology and stable isotopes indicate that the place of origin for the women was not different from that of the men in the Upemba Depression since no differences were observed between men and women.

The wide diversity of tooth modification styles seen in the early-late farming communities of the Upemba Depression was also noted during historic times. Nineteen different styles were observed and recorded by Starr (1909) in 1905-6 among the Baluba of Katanga. However, only five of the same styles were also recorded in the current research.

The issue of using tooth modification as a group marker or identifier is complicated by the limited choice of forms to modify teeth. There can only be so many styles that people can make on their teeth. Eventually, these are shared between unrelated groups and this makes it difficult to distinguish one group from another. In addition, it is possible that other groups adopt a style of their neighbours, as seen in the case of the Khoesan of Namibia (for example, see Jones 1992; van Reenen 1986). Similar styles observed in the Upemba Depression have been reported elsewhere in sub-Saharan Africa; both in antiquity (Shaw 1931; Morris 1993, 1998; Steyn 1994; Murphy 1996; Mosothwane 2003; Reichart *et al*. 2008) and in contemporary societies (Jones 1992; Price 1939; van Reenen 1978, 1986). For example, groups that file their teeth to points include the M'baka, Houssa of West-Central Africa (Konnild 1987; dianabuja.wordpress.com); the Wakamba, Wawiya/Mawiya, Zanaki, Makonde of East Africa (Konnild 1987); and the Chokwe, Lamba, Luvale, Mbunda, Zulu, Xhosa of southern Africa (Jones 1992; van Reenen 1986; Shaw 1931; see Chapter 3 for a detailed review).

In summary, there appears to be some uniformity in the styles during the earlier Kisalian period, while more diversity is seen in the later Kabambian period. As for reasons for modifying teeth, there might be a connection with what is happening in society, which subsequently influences the styles encountered between the different time periods.

Chapter 7: CONCLUSIONS

The main goal of this research was to study the human skeletal remains from the Upemba Depression of Central Katanga, DRC in order to shed light on the contradiction between the archaeological (material cultural) evidence, which points towards cultural continuity over the past millennium or more, and the oral traditions and ethnohistory of the current occupants of the region, the Luba. The Luba trace their origins to an incomer who supplanted the previous ruler, bringing new political and economic practices. As such, they reject the existence of ancestral relationships with the skeletal remains found in archaeological sites in the region. The Luba's rejection of ancestral relations to the people buried in the Upemba Depression is based on geographic origin and perhaps cultural differences, and not on biological or morphological differences.

This research has evaluated the biological variation (specifically, non-metric and metric dental traits) of the populations living in the Upemba Depression between AD 700 and 1600. These data now contribute to our understanding of the dental morphology and biological affinities of prehistoric sub-Saharan Africans. The questions about population continuity or replacement relate to broader questions about the emergence and history of farming societies and kingdoms of south-central Africa pre-AD1800.

Assessment of the dental morphology of skeletons from the Kisalian (AD 700-1300) and Kabambian (AD 1300-1600) periods has shown a high degree of homogeneity, supporting the hypothesis of continuity through this period of time in the Upemba Depression. There are too few dental morphological data from historic-modern Luba to compare with those from the early inhabitants. As a result, the question of the relatedness of the early inhabitants of the Upemba Depression to present-day Luba people remains open and deserves to be fully explored in future studies. Inclusion of more skeletal remains post-dating AD 1600 would be useful in solving this issue. Therefore, it is important to stress that the current results cannot refute the possibility that the people buried in the archaeological sites in the Upemba Depression were not related to modern Luba people. They do, however, point to morphological continuity from AD 700 up to 1600.

Dental morphology observed among the Upembans is broadly consistent with the patterns documented among sub-Saharan Africans in general (Hanihara 2008; Irish 2013; Warren 2013). Minor differences in trait frequencies between this study and those in the literature can be explained by inter-observer error and by the use of samples from different periods, i.e. prehistoric versus historic-modern. As mentioned above, geographic origin and cultural differences form the basis for the Luba's rejection of the people buried in the Upemba Depression. It is, thus, probable that these 'enemies of their ancestors' (as referred to by the Luba [de Maret 1979]) were biologically or morphologically very similar to the early Upembans. Much like the similarity in cranio-facial morphology seen by Ribot (2011) and Froment (1998), it appears that although sub-Saharan Africans show high intra-population variation (Ribot 2011; Irish 1997; Cavalli-Sforza *et al*. 1996), it is nevertheless difficult to see significant population differentiation within geographic regions, i.e. southern, western, central and eastern Africa.

The morphological similarity of sub-Saharan Africans can be largely attributed to the expansion of Bantu-speakers, and can be traced from the Iron Age to modern times. This continuity has been demonstrated by archaeology and linguistics, but its biological expression is less well understood, including questions of the extent to which expanding populations absorbed and incorporated prior inhabitants of the region. This thesis, therefore, represents a significant contribution to the understanding of biological continuity, and by extension genetic continuity, in one of Africa's less understood and yet critically important regions - central Africa.

Second, this thesis was concerned with tracking dietary continuity or change using analyses of stable carbon and nitrogen isotopes, tooth-wear, dental diseases and phytoliths from dental calculus. Together, these data showed no temporal changes, suggesting broad continuity in diet throughout the Iron Age. Domesticated C_4 crops and domesticated animals clearly contributed part of the diets of the humans from these sites, especially those in the northern end of the Depression. This is supported by the relatively high occurrence of dental caries, especially at Sanga, as well as archaeo-botanical evidence of finger millet (*Eleusine corocana*) at Kikulu.

During the period AD 700 to 1600, farming, fishing, hunting, and (goat) herding were important parts of the lives and diets of the early Upembans. Although all six sites in

the research area have revealed archaeological evidence for a diversity of subsistence strategies, there has up to now been little understanding of the relative importance of each. Based on the isotope results, hunting and foraging appear to have been at least as important as farming, especially at Katoto. Wild fauna such as fish, wild bovids, birds and reptiles dominated the faunal assemblage at these sites. The bulk of wild plant and animal resources were C_3 based. However, it is not possible to quantify the relative proportions of domesticated C_3 plants (e.g. squashes (*Curcubita*), gourds (*Lagenaria*), beans, other leafy greens, etc.) and gathered wild C_3 plants, such as yams (*Dioscorea*), and so on.

Although no temporal changes were detected, diet seems to have been regionally controlled. We know from the archaeology that the people at Katoto had a different (pottery) culture from those in the north of the Depression, but the remarkable difference in stable carbon isotope values, showing that diets at Katoto included substantially more C_3 based foods, was a surprise. This finding also suggests residential stability; as a corollary, one might hypothesise that there was only limited (if any) intermarriage between the inhabitants of Katoto and the other sites studied here. This issue could be investigated in more detail in future work on these remains. A contemporary anthropological study of differing knowledge of indigenous wild edible plants may be relevant to our understanding of the differences between Katoto and the other sites. In the Tshopo District of the Orientale Province, DRC, Turumbu agriculturalists have a much wider knowledge of edible wild plants than their neighbours, the Mbole and Bali (Termote 2012). This is intriguing considering that all three groups have equal access to the forest and its resources, but can be explained by differential inherited indigenous knowledge, cultural preferences and values attached to these plants by the various groups. The dietary differences between sites in the northern end of the Depression and Katoto in the south, could therefore be indicative of similar cultural differences in the exploitation of wild resources, and/or the availability of such resources.

Overall, the similarity in carbon and nitrogen isotope ratios between the sexes suggests that men and women had similar diets. Variation in oral disease prevalence, however, can be attributed to physiological (hormonal) differences, and behaviours.

Some men at Sanga show signs of greater access to cariogenic foods (possibly palm wine), which their female counterparts did not consume to the same extent.

The evidence for social and regional variations in diet documented in this thesis provides new information on the diversity and complexity of these societies. The reconstruction of past people's dietary behaviours based on archaeological vestiges remains a challenging issue in archaeology, and this study has reiterated the difficulties of using archaeological remains to reconstruct past lifeways, especially given that the vast majority of excavated evidence from the Upemba Depression derives from graves, rather than settlement sites. The numerous fish bones, fishing implements (hooks and braziers) from these sites do not necessarily attest to equal exploitation of the aquatic resources by all societies in this region. The relevance of these findings demonstrate that population dynamics and socio-political dimensions should be kept in mind when interpreting the extent to which resources were exploited by past peoples. Lastly, it is clear that human behaviour is influenced by a complex interaction of environmental, cultural and biological factors.

The last objective of the study was to evaluate bio-cultural traits, specifically dental modification, and its implication for people's origins and/or relatedness. Of all the three lines of evidence used in this research, this assessment was the least helpful in identifying people's origins and/or relatedness. This is largely due to the fact that a wide diversity in dental modification styles was found in these societies. There was also no discernable pattern between the different chronological periods, apart from a slight uniformity during the earlier Kisalian period. In addition, dental modification styles are widespread across many unrelated cultures in sub-Saharan Africa and outside of Africa. The fact is dental modification styles are limited and end up being shared across cultural lines, even across borders and continents. Nevertheless, the diversity and antiquity of this behaviour in central Katanga supports the idea of a culturally diverse, yet biologically similar people, already by the 14th century AD.

The skeletal remains from the Upemba Depression provided a rich opportunity for understanding patterns of migration, gene flow and relatedness through time. In the sub-Saharan African context, no such study has previously been done on a population with such a deep history. Indeed, human remains from consecutively occupied sites

within a long time sequence are extremely rare in the archaeological record, especially from central Africa. Finally, this thesis leaves the issue of continuity with the modern Luba open for further exploration, due to the lack of human remains post dating AD 1600. Undoubtedly, a lot of work remains to be done in order to reach a consensus about the origins of the ancient cultures of the Upemba Depression. However, I hope this work has made a contribution to unravelling the history of this part of south-central Africa.

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Appendices

Appendix 1: Inventory of all human skeletal remains studied.

Burial no.	Sex	Age	Chronological period	Uncalibrated radiocarbon date
SANGA				
T5	n/a	7-10	Classic Kisalian	none
T8	n/a	7-9	Atypical	none
T9	F	30-40	Kabambian A	none
T10	M	50-70	Classic Kisalian	(B-264): 1070 ± 200 bp
T11	M?	Adult	Kabambian A	none
T12	n/a	5-8	Kabambian A	none
T13	F	30-50	Atypical	none
T14	F?	25-40	Atypical	none
T15	M?	Adult	Atypical	none
T18	?	30-40	Early Kisalian	(B-263): 1240 ± 120 bp
T21	F	55-75	Early Kisalian	none
T22	F?	Adult	Atypical	none
T23	?	Adult	Recent (Luba)	none
T24/35	F?	25-40	Classic Kisalian	none
T34	n/a	0.5-0.75	Classic Kisalian	none
T36	1.5-3.5	n/a	Atypical	none
T40	?	Adult	Atypical	none
T42	F?	30-40	Kabambian B	none
T45	?	Adult	Kabambian B	none
T47	M	35-55	Atypical	none
T48A	n/a	3-5	Recent (Luba)	none
T49	n/a	6-9	Classic Kisalian	none
T50	M	18-23	Kabambian B	none
T53A	M	35-55	Kisalian	none
T53B	?	25-40	Kisalian	none
T53C	n/a	3-5	Kisalian	none
T57	n/a	4-6	Classic Kisalian	none
T58	F	40-60	Classic Kisalian	none
T62	F	30-40	Classic Kisalian	none
T65	F	45-65	Atypical	none
T68	F	15-18	Classic Kisalian	none
T71B	n/a	11-14	Classic Kisalian	none
T76	M	30-40	Classic Kisalian	none
T80	F	35-45	Kabambian A	none
T83	F	25-35	Classic Kisalian	none
T85	M	45-65	Classic Kisalian	none
T86	M	25-40	Atypical	none
T88	F	15-18	Classic Kisalian	none
T90	n/a	4-6	Classic Kisalian	none
T102	n/a	5-7	Classic Kisalian	none
T103	M	Adult	Classic Kisalian	none
T105	n/a	7-9	Classic Kisalian	none
T107	n/a	5-7	Classic Kisalian	none
T111	M	30-40	Classic Kisalian	none
T112	M	20-30	Classic Kisalian	none
T116	F	20-30	Classic Kisalian	none

Appendix 1 (continued): Inventory of all human skeletal remains studied.

Burial no.	Sex	Age	Chronological period	Uncalibrated radiocarbon date
Sanga				
T119	M	35-50	Classic Kisalian	none
T124	n/a	3-5	Classic Kisalian	none
T126	F	35-45	Classic Kisalian	none
T140	M	25-35	Classic Kisalian	none
T143	n/a	7-9	Classic Kisalian	none
T149	M?	Adult	Early Kisalian	(Hv 6609): 1205 ± 105 bp
T151	n/a	4-5	Classic Kisalian	none
T153	?	35-45	Classic Kisalian	(Hv 6610): 655 ± 125 bp
T154	M?	45-65	Classic Kisalian	none
T160	F	40-60	Classic Kisalian	(Hv 6612): 875 ± 75 bp
T161	?	Adult	Atypical	none
T164	F	30-40	Classic Kisalian	none
T170	?	25-35	Classic Kisalian	none
T172	F	25-35	Classic Kisalian	(Hv 6613): 770 ± 95 bp
T173	?	Adult	Classic Kisalian	(Hv 8490): 1110 ± 70 bp
T175	?	Adult	Classic Kisalian	(Hv 6614): 855 ± 90 bp
T176	?	Adult	Kabambian A	(Hv 6615): 495 ± 105 bp
T189	M?	25-40	Atypical	none
66				
KATOTO				
A radiocarbon date on charcoal of AD 1190 ± 60 (B-760) makes Katoto contemporaneous with the Classic Kisalian period (Hiernaux et al. 1967).				
T2A	?	25-45	Katotian	none
T11	?	15-20	Katotian	none
T13	n/a	7-10	Katotian	none
T15	n/a	6-8	Katotian	none
T17	n/a	3-5	Katotian	none
T20	30-40	F	Katotian	none
T21A	M	35-50	Katotian	none
T21B	F	20-30	Katotian	none
T21C	n/a	7-9	Katotian	none
T22	n/a	0.5-0.75	Katotian	none
T25	F	25-40	Katotian	none
T26	M	50-70	Katotian	none
T30	n/a	9-12	Katotian	none
T31	n/a	3-5	Katotian	none
T34	M	20-25	Katotian	none
T37	F?	15-18	Katotian	none
T38	M	45-65	Katotian	none
T41	n/a	9-12	Katotian	none
T42	n/a	6-9	Katotian	none
T43	n/a	6-9	Katotian	none
T48	F	25-40	Katotian	none
T49	F	40-60	Katotian	none
T50	F	35-45	Katotian	none

Appendix 1 (continued): Inventory of all human skeletal remains studied.

Burial no.	Sex	Age	Chronological period	Uncalibrated radiocarbon date
KATOTO				
A radiocarbon date on charcoal of AD 1190 ± 60 (B-760) makes Katoto contemporaneous with the Classic Kisalian period (Hiernaux et al. 1967).				
T51	n/a	2-3	Katotian	none
T59	n/a	1.5-3	Katotian	none
T61	n/a	4-6	Katotian	none
T62	F?	20-30	Katotian	none
T63	F	40-60	Katotian	none
T64	M	35-45	Katotian	none
T66	n/a	6-8	Katotian	none
30				
MALEMBA-NKULU				
T1	M	30-55	Kabambian	none
T2A	M*	14-17	Kabambian A	(Hv 7506): 420 ± 55 bp
T2B	n/a	1.5-3	Kabambian	none
T3	F	25-40	Kabambian A	(Hv 7516): 495 ± 55 bp
T6	n/a	3-5	Kabambian	none
T8 bis	n/a	5-7	Kabambian	none
T8 ter	n/a	0.125-0.25	Kabambian B	none
T9	n/a	0.5-0.75	Kabambian	none
T10	n/a	4-6	Classic Kisalian	(Hv 7513): 785 ± 210 bp
T11	n/a	0	Kabambian	none
T12	M	25-40	Kabambian	none
T13	M*	Adult	Kabambian B	(Hv 8495): 375 ± 40 bp
T15	n/a	2-3	Kabambian	none
T17	F*	35-55	Kabambian	none
T18	n/a	6-8	Kabambian	none
T19	?	22-30	Kabambian B	(Hv 8496): 100.1 ± 0.5 bp
T21	n/a	7-10	Kabambian	none
T22	n/a	1.5-3	Kabambian	none
T26	?	40-60	Kabambian A	(Hv 7495): 520 ± 50 bp
T27	?	30-45	Kabambian	none
T33	n/a	7-8	Kabambian	none
T35	F	Adult	Kabambian B	(Hv 8497): 860 ± 55 bp
T35 bis	?	Adult	Kabambain	
T36	F	30-40	Kisalian	none
T37	F	14-17	Classic Kisalian	(Hv 7499): 1005 ± 65 bp
25				

Appendix 1 (continued): Inventory of all human skeletal remains studied.

Burial no.	Sex	Age	Chronological period	Uncalibrated radiocarbon date
KIKULU				
T1	F	20-25	Recent (Luba)	(Hv 7507): 100.8 ± 1.2 bp
T2	M	40-50	Kabambian A	(Hv 7517): 685 ± 50 bp
T3	?	Adult	Kabambian A	none
T4	F?	25-35	Kabambian A	none
T7	M	25-35	Kisalian	none
T8	n/a	9-10	Classic Kisalian	(Hv 7514): 765 ± 50 bp
T9	M	Adult	Atypical	none
T10	?	Adult	Kabambian A	none
T13	M	40-60	Atypical	(Hv 7503): 765 ± 60 bp
T14	F?	40-60	Early Kisalian	(Hv 8494): 1295 ± 45 bp
T15	F	20-30	Kabambian A	none
T17	M	30-40	Recent (Luba)	none
T19	F	30-40	Kabambian A	(Hv 7515): 920 ± 50 bp
T20	F	25-35	Kabambian A	(Hv 7505): 795 ± 65 bp
14				
KAMILAMBA				
T2	?	Adult	Kabambian	(Hv 8491): 155 ± 130 bp
T5	?	25-45	Kabambian A	(Hv 7501): 470 ± 120 bp
T7	?	15-25	Kisalian	(Hv 7498): 1105 ± 150 bp
T10	F	25-40	Early Kisalian	(Hv 8492): 1645 ± 160 bp
T11	?	25-40	Kisalian	none
T12	n/a	6-9	Kisalian	none
6				
KATONGO				
T2	M	35-50	Classic Kisalian	(Hv 6616): 660 ±190 bp
T3	F	25-35	Kabambian B	none
T6	F	25-35	Recent (Luba)	(Hv 6617): 190 ± 65 bp
T7	?	Adult	Classic Kisalian	none
T8	M	25-40	Kabambian B	(Hv 6621): 250 ± 85 bp
T9	F?	40-50	Kisalian	none
6				
Total No. of Individuals Studied = 145				

Appendix 2: Frequencies of all 39 non-metric traits (in alphabetic order) for Kisalian and Kabambian periods (left antimeres only; sexes and sites combined). $\chi 2$ values are for comparisons of frequencies between chronological periods (Kisalian vs. Kabambian); p-values at the 0.05 level – bold p-values are significant.

Trait	Frequency: Kisalian	% Kisalian	Frequency: Kabambian	% Kabambian	Calculated χ^2 value	p value
Anterior fovea LM1	14/35	40.0	6/12	50.0	0.07	0.7900
Canine mesial ridge UC	23/33	69.7	9/11	81.8	0.15	06959
Carabelli's trait UM1	19/47	40.4	3/23	13.0	4.18	**0.0410**
Congenital absence UM3	0/37	0.0	0/27	0.0	n/a	n/a
Cusp 5 (metaconule) UM1	6/47	12.8	6/26	23.1	1.30	0.2550
Cusp 7 (metaconulid) LM1	6/44	13.6	1/24	4.2	0.66	0.4177
Cusp number LM1	4/42	9.5	2/22	9.1	0.16	0.6928
Cusp number LM2	18/37	48.6	15/23	65.2	1.57	0.2098
Deflecting wrinkle LM1	17/29	58.6	6/14	42.9	0.94	0.3315
Distal accessory ridge UC	10/25	40.0	7/7	100.0	5.68	**0.0172**
Distal trigonid crest LM1	3/37	8.1	1/16	6.3	0.11	0.7404
Double shovel UI1	2/28	7.1	0/14	0.0	0.07	0.7978
Enamel extension UM1	10/44	22.7	5/25	20.0	0.00	0.9684
Groove pattern LM2	25/34	73.5	17/21	81.0	0.09	0.7620
Hypocone UM2	38/45	84.4	17/23	73.9	1.09	0.2961
Interruption groove UI2	8/32	25.0	4/14	28.6	0.01	0.9116
Labial curvature UI1	20/37	54.1	12/24	20.0	3.73	0.0534
Lingual cusp number LP2	5/25	20.0	3/15	42.1	1.58	0.2083
Mandibular torus	21/51	41.2	8/19	50.0	0.52	0.4727
Midline diastema UI1	4/15	26.7	3/8	37.5	0.00	0.9505
Odontome P1-P2	0/42	0.0	0/23	0.0	n/a	n/a
Palatal torus	3/21	14.3	2/12	16.7	0.10	0.7481
Parastyle UM3	10/28	35.7	4/21	19.0	0.92	0.3378
Peg-reduced UI2	0/35	0.0	0/16	0.0	n/a	n/a
Peg-shaped UM3	6/31	19.4	6/21	28.6	0.60	0.4389
Protostylid LM1	10/37	27.0	5/21	23.8	0.00	0.9657
Rocker jaw	4/41	9.8	6/18	33.3	3.41	0.0649
Root number LC	0/44	0.0	0/21	0.0	n/a	n/a
Root number LM1	0/36	0.0	1/25	4.0	0.03	0.8533
Root number LM2	35/35	100.0	20/23	87.0	2.52	0.1123
Root number UM1	42/45	93.3	28/30	93.3	0.22	0.6366
Root number UM2	29/38	76.3	19/24	79.2	0.00	0.7937
Root number UM3	18/25	72.0	13/23	56.5	1.25	0.2627
Root number UP1	13/33	39.4	7/24	29.2	0.64	0.4244
Shovel UI1	15/24	62.5	6/12	50.0	0.51	0.4733
Tome's root LP1	2/26	7.7	1/15	6.7	0.25	0.6163
Torsomolar angle LM3	4/14	28.6	4/16	25.0	0.04	0.8469
Tuberculum dentale UI2	6/29	24.1	3/11	27.3	0.04	0.8380
Winging UI1	0/21	0.0	0/6	0.0	n/a	n/a

Appendix 2 (continued): Frequencies of all 39 non-metric traits (in alphabetic order) for Kisalian and Recent (Luba) periods (left antimeres only; sexes and sites combined). $\chi 2$ values are for comparisons of frequencies between chronological periods (Kisalian vs. Recent (Luba); p-values at the 0.05 level – bold p-values are significant.

Trait	Frequency: Kisalian	% Kisalian	Frequency: Recent (Luba)	% Recent (Luba)	Calculated χ^2 value	p value
Anterior fovea LM1	14/35	40.0	0/1	0.0	0.05	0.8172
Canine mesial ridge UC	23/33	69.7	1/3	33.3	0.41	0.5224
Carabelli's trait UM1	19/47	40.4	0/3	0.0	0.62	0.4324
Congenital absence UM3	0/37	0.0	0/3	0.0	n/a	n/a
Cusp 5 (metaconule) UM1	6/47	12.8	0/3	0.0	0.07	0.7975
Cusp 7 (metaconulid) LM1	6/44	13.6	0/2	0.0	0.26	0.6077
Cusp number LM1	4/42	9.5	0/2	0.0	n/a	n/a
Cusp number LM2	18/37	48.6	0/2	0.0	0.38	0.5378
Deflecting wrinkle LM1	17/29	58.6	0/1	0.0	0.02	0.8912
Distal accessory ridge UC	10/25	40.0	2/2	100.0	n/a	n/a
Distal trigonid crest LM1	3/37	8.1	0/1	0.0	2.50	0.1136
Double shovel UI1	2/28	7.1	0/2	0.0	n/a	n/a
Enamel extension UM1	10/44	22.7	1/3	33.3	n/a	n/a
Groove pattern LM2	25/34	73.5	½	50.0	0.01	0.9281
Hypocone UM2	38/45	84.4	4/4	100.0	n/a	n/a
Interruption groove UI2	8/32	25.0	0/1	0.0	0.37	0.5416
Labial curvature UI1	20/37	54.1	1/2	50.0	n/a	n/a
Lingual cusp number LP2	5/25	20.0	1/2	50.0	0.01	0.9218
Mandibular torus	21/51	41.2	1/1	100.0	0.02	0.8751
Midline diastema UI1	4/15	26.7	1/1	100.0	0.17	0.6761
Odontome P1-P2	0/42	0.0	0/3	0.0	n/a	n/a
Palatal torus	3/21	14.3	0/1	0.0	1.18	0.2781
Parastyle UM3	10/28	35.7	1/1	100.0	0.06	0.8002
Peg-reduced UI2	0/35	0.0	0/0	n/a	n/a	n/a
Peg-shaped UM3	6/31	19.4	0/1	0.0	0.66	0.4160
Protostylid LM1	10/37	27.0	1/2	50.0	0.01	0.9176
Rocker jaw	4/41	9.8	0/1	0.0	1.95	0.1628
Root number LC	0/44	0.0	0/2	0.0	n/a	n/a
Root number LM1	0/36	0.0	0/2	0.0	n/a	n/a
Root number LM2	35/35	100.0	2/2	100.0	n/a	n/a
Root number UM1	42/45	93.3	3/3	100.0	n/a	n/a
Root number UM2	29/38	76.3	3/3	100.0	n/a	n/a
Root number UM3	18/25	72.0	1/1	100.0	n/a	n/a
Root number UP1	13/33	39.4	1/3	33.3	n/a	n/a
Shovel UI1	15/24	62.5	1/1	100.0	0.09	0.7659
Tome's root LP1	2/26	7.7	1/2	50.0	0.46	0.4979
Torsomolar angle LM3	4/14	28.6	0/2	0.0	0.00	1.0000
Tuberculum dentale UI2	6/29	24.1	1/1	100.0	0.29	0.5915
Winging UI1	0/21	0.0	0/1	0.0	0.62	0.4324

Appendix 2 (continued): Frequencies of all 39 non-metric traits (in alphabetic order) for Kabambian and Recent (Luba) periods (left antimeres only; sexes and sites combined). $\chi 2$ values are for comparisons of frequencies between chronological periods (Kabambian vs. Recent (Luba)); p-values at the 0.05 level – bold p-values are significant.

Trait	Frequency: Kabambian	% Kabambian	Frequency: Recent (Luba)	% Recent (Luba)	Calculated χ^2 value	p value
Anterior fovea LM1	6/12	50.0	0/1	0.0	0.01	0.9360
Canine mesial ridge UC	9/11	81.8	1/3	33.3	0.86	0.3540
Carabelli's trait UM1	3/23	13.0	0/3	0.0	0.09	0.7675
Congenital absence UM3	0/27	0.0	0/3	0.0	n/a	n/a
Cusp 5 (metaconule) UM1	6/26	23.1	0/3	0.0	0.03	0.8558
Cusp 7 (metaconulid) LM1	1/24	4.2	0/2	0.0	2.62	0.1054
Cusp number LM1	2/22	9.1	0/2	0.0	n/a	n/a
Cusp number LM2	15/23	65.2	0/2	0.0	1.11	0.2922
Deflecting wrinkle LM1	6/14	42.9	0/1	0.0	0.04	0.8327
Distal accessory ridge UC	7/7	100.0	2/2	100.0	n/a	n/a
Distal trigonid crest LM1	1/16	6.3	0/1	0.0	3.74	0.0533
Double shovel UI1	0/14	0.0	0/2	0.0	n/a	n/a
Enamel extension UM1	5/25	20.0	1/3	33.3	n/a	n/a
Groove pattern LM2	17/21	81.0	½	50.0	0.01	0.9069
Hypocone UM2	17/23	73.9	4/4	100.0	n/a	n/a
Interruption groove UI2	4/14	28.6	0/1	0.0	0.30	0.5850
Labial curvature UI1	12/24	20.0	1/2	50.0	n/a	n/a
Lingual cusp number LP2	3/15	42.1	1/2	50.0	0.29	0.5916
Mandibular torus	8/19	50.0	1/1	100.0	0.00	0.9674
Midline diastema UI1	3/8	37.5	1/1	100.0	0.01	0.9056
Odontome P1-P2	0/23	0.0	0/3	0.0	n/a	n/a
Palatal torus	2/12	16.7	0/1	0.0	1.00	0.3180
Parastyle UM3	4/21	19.0	1/1	100.0	0.44	0.5053
Peg-reduced UI2	0/16	0.0	0/0	n/a	n/a	n/a
Peg-shaped UM3	6/21	28.6	0/1	0.0	0.27	0.6015
Protostylid LM1	5/21	23.8	1/2	50.0	0.00	0.9708
Rocker jaw	6/18	33.3	0/1	0.0	0.17	0.6839
Root number LC	0/21	0.0	0/2	0.0	n/a	n/a
Root number LM1	1/25	4.0	0/2	0.0	n/a	n/a
Root number LM2	20/23	87.0	2/2	100.0	n/a	n/a
Root number UM1	28/30	93.3	3/3	100.0	n/a	n/a
Root number UM2	19/24	79.2	3/3	100.0	n/a	n/a
Root number UM3	13/23	56.5	1/1	100.0	n/a	n/a
Root number UP1	7/24	29.2	1/3	33.3	n/a	n/a
Shovel UI1	6/12	50.0	1/1	100.0	0.01	0.9360
Tome's root LP1	1/15	6.7	1/2	50.0	0.38	0.5363
Torsomolar angle LM3	4/16	25.0	0/2	0.0	0.01	0.9202
Tuberculum dentale UI2	3/11	27.3	1/1	100.0	0.14	0.7119
Winging UI1	0/6	0.0	0/1	0.0	0.01	0.9360

Appendix 2 (continued): Frequencies of all 39 non-metric traits (in alphabetic order) for Kisalian, Kabambian, Recent (Luba), and Atypical periods (left antimeres only; sexes and sites combined). $\chi 2$ tests for the Atypical period were not calculated.

Traits	Frequency: Kisalian	% Kisalian	Frequency: Kabambian	% Kabambian	Frequency: Recent (Luba)	% Recent (Luba)	Frequency: Atypical	% Atypical
Anterior fovea LLM1	14/35	40.0	6/12	50.0	0/1	0.0	1/1	100.0
Bushman Canine LUC	23/33	69.7	9/11	81.8	1/3	33.3	1/3	33.3
Carabelli's trait LUM1	19/47	40.4	3/23	13.0	0/3	0.0	0/5	0.0
Congenital absence LUM3	0/37	0.0	0/27	0.0	0/3	0.0	0/9	0.0
Cusp 5 (metaconule) LUM1	6/47	12.8	6/26	23.1	0/3	0.0	0/7	0.0
Cusp 7 (metaconulid) LLM1	6/44	13.6	1/24	4.2	0/2	0.0	0/3	0.0
Cusp number LLM1 (6)	4/42	9.5	2/22	9.1	0/2	0.0	0/3	0.0
Cusp number LLM2 (5+)	18/37	48.6	15/23	65.2	0/2	0.0	2/4	50.0
Deflecting wrinkle LLM1	17/29	58.6	6/14	42.9	0/1	0.0	0/0	n/a
Distal accessory ridge LUC	10/25	40.0	7/7	100.0	2/2	100.0	2/3	66.7
Distal trigonid crest LLM1	3/37	8.1	1/16	6.3	0/1	0.0	0/0	n/a
Double shovel LUI1	2/28	7.1	0/14	0.0	0/2	0.0	0/1	0.0
Enamel extension LUM1	10/44	22.7	5/25	20.0	1/3	33.3	2/5	40.0
Groove pattern LLM2 (Y)	25/34	73.5	17/21	81.0	½	50.0	2/3	66.7
Hypocone LUM2	38/45	84.4	17/23	73.9	4/4	100.0	6/8	75.0
Interruption groove LUI2	8/32	25.0	4/14	28.6	0/1	0.0	1/4	25.0
Labial curvature LUI1	20/37	54.1	12/24	20.0	1/2	50.0	1/3	33.3
Lingual cusp number LLP2	5/25	20.0	3/15	42.1	1/2	50.0	1/5	20.0
Mandibular torus	21/51	41.2	8/19	50.0	1/1	100.0	4/8	50.0
Midline diastema UI1	4/15	26.7	3/8	37.5	1/1	100.0	2/4	50.0

Appendix 2 (continued): Frequencies of all 39 non-metric traits (in alphabetic order) for Kisalian, Kabambian, Recent (Luba), and Atypical periods (left antimeres only; sexes and sites combined). $\chi 2$ tests for the Atypical period were not calculated.

Traits	Frequency: Kisalian	% Kisalian	Frequency: Kabambian	% Kabambian	Frequency: Recent (Luba)	% Recent (Luba)	Frequency: Atypical	% Atypical
Odontome LP1-P2	0/42	0.0	0/23	0.0	0/3	0.0	0/8	0.0
Palatine torus	3/21	14.3	2/12	16.7	0/1	0.0	0/2	0.0
Parastyle LUM3	10/28	35.7	4/21	19.0	1/1	100.0	3/9	33.3
Peg-reduced LUI2	0/35	0.0	0/16	0.0	0/0	n/a	0/4	0.0
Peg-shaped LUM3	6/31	19.4	6/21	28.6	0/1	0.0	2/8	25.0
Protostylid LLM1	10/37	27.0	5/21	23.8	1/2	50.0	1/3	33.3
Rocker jaw	4/41	9.8	6/18	33.3	0/1	0.0	1/5	20.0
Root number LLC	0/44	0.0	0/21	0.0	0/2	0.0	0/7	0.0
Root number LLM1	0/36	0.0	1/25	4.0	0/2	0.0	0/4	0.0
Root number LLM2	35/35	100.0	20/23	87.0	2/2	100.0	6/6	100.0
Root number LUM1	42/45	93.3	28/30	93.3	3/3	100.0	8/8	100.0
Root number LUM2	29/38	76.3	19/24	79.2	3/3	100.0	6/7	85.7
Root number LUM3	18/25	72.0	13/23	56.5	1/1	100.0	4/7	57.1
Root number LUP1	13/33	39.4	7/24	29.2	1/3	33.3	3/5	60.0
Shovel LUI1	15/24	62.5	6/12	50.0	1/1	100.0	2/2	100.0
Tome's root LLP1	2/26	7.7	1/15	6.7	1/2	50.0	1/5	20.0
Torsomolar angle LLM3	4/14	28.6	4/16	25.0	0/2	0.0	0/4	0.0
Tuberculum dentale LUI2	6/29	24.1	3/11	27.3	1/1	100.0	3/4	75.0
Winging LUI1	0/21	0.0	0/6	0.0	0/1	0.0	0/2	0.0

Appendix 3: Mean mesio-distal diameters of all teeth measured (all sexes and time periods); only left measurements are presented.

	P1	P2	M1	M2	M3
Male					
no. of teeth	31	35	26	36	30
Mean	7.31	6.99	10.88	10.45	9.89
SD	0.62	0.36	0.63	0.60	0.66
Female					
no. of teeth	48	55	49	55	48
Mean	7.04	6.93	10.60	10.10	9.64
SD	0.46	0.45	0.60	0.71	0.81
Unknown sex					
no. of teeth	39	32	63	44	32
Mean	7.11	6.99	10.87	10.34	10.09
SD	0.57	0.58	0.61	0.69	0.93
Kisalian					
no. of teeth	65	65	82	73	51
Mean	7.12	7.08	10.91	10.31	9.88
SD	0.44	0.47	0.63	0.78	0.89
Kabambian					
no. of teeth	37	41	42	45	41
Mean	7.01	6.76	10.51	10.19	9.74
SD	0.53	0.39	0.47	0.54	0.81
Recent (Luba)					
no. of teeth	4	5	5	5	4
Mean	7.69	7.14	10.53	10.38	9.63
SD	0.29	0.61	0.53	0.53	0.90
Atypical					
no. of teeth	12	11	9	12	14
Mean	7.46	6.97	10.94	10.33	10.04
SD	0.76	0.27	0.61	0.73	0.73

Appendix 3 (continued): Mean bucco-lingual diameters of all teeth measured (all sexes and time periods); only left measurements are presented.

	P1	P2	M1	M2	M3
Male					
no. of teeth	29	37	30	36	31
Mean	8.88	8.90	10.98	10.89	10.39
SD	0.72	0.59	0.74	0.72	0.76
Female					
no. of teeth	49	52	47	55	49
Mean	8.75	8.83	10.78	10.59	10.21
SD	0.63	0.63	0.58	0.75	0.72
Unknown sex					
no. of teeth	38	35	65	42	33
Mean	8.60	8.85	10.83	10.55	10.54
SD	0.69	0.61	0.67	0.91	0.88
Kisalian					
no. of teeth	66	67	83	72	53
Mean	8.74	8.89	10.83	10.62	10.30
SD	0.60	0.56	0.62	0.80	0.78
Kabambian					
no. of teeth	35	41	45	45	40
Mean	8.68	8.78	10.83	10.64	10.30
SD	0.70	0.67	0.69	0.76	0.83
Recent (Luba)					
no. of teeth	4	5	5	5	4
Mean	9.38	9.05	10.95	10.76	10.43
SD	0.47	0.97	0.61	0.15	0.78
Atypical					
no. of teeth	11	11	9	11	16
Mean	8.63	8.83	11.00	10.83	10.65
SD	0.92	0.57	0.85	1.09	0.63

Appendix 4: Morphotypes and counts of phytoliths in dental calculus samples from the Upemba Depression (all time periods).

Present morphtypes	Kisalian	Kabambian	Recent	Atypical	Total Count
Achene	0	0	0	1	**1**
Bilobate convex long	1	0	0	0	**1**
Blocky facetate	14	0	0	0	**14**
Blocky psilate	7	0	0	0	**7**
Blocky verrucate	1	0	0	0	**1**
Commelina bulliform	0	6	0	0	**6**
Cylindroid ciliated	11	0	0	0	**11**
Ellipsoid scalloped	2	0	0	0	**2**
Irregular psilate (seed)	0	25	0	0	**25**
Irregular scalloped	3	0	0	0	**3**
Parallelipiped sinuate	0	1	0	0	**1**
Polyhedral	3	0	0	0	**3**
Polyhedral (seed)	0	13	0	0	**13**
Polyhedral psilate	10	0	0	0	**10**
Polylobate	2	0	0	0	**2**
Rugose	0	8	0	0	**8**
Saddle collapsed	1	0	0	0	**1**
Saddle ovate	2	0	0	0	**2**
Saddle squat	1	0	0	0	**1**
Scalloped phytolith	0	25	0	0	**25**
Sclereid (seed)	0	13	0	0	**13**
Scutiform	4	0	0	0	**4**
Seed phytolith	0	20	0	0	**20**
Spheroid granulate	24	0	0	0	**24**
Spheroid psilate (leaves)	87	0	0	0	**87**
Spheroid scalloped	136	0	0	0	**136**
Spheroid starlet	1	1	0	0	**2**
Starlets (leaves)	98	0	0	0	**98**
Tracheids scabrate	0	6	0	0	**6**
Trapezoid	2	0	0	0	**2**
Trichome	1	0	0	0	**1**
Bilobate short concave	7	3	0	0	**10**
Bilobate short flattened	1	1	0	0	**2**
Blocky echinate	0	7	0	3	**10**
Blocky scabrate	20	2	0	0	**22**
Bulliform	3	3	0	0	**6**
Cylindroid scabrate	1	2	0	0	**3**
Epidermal cell	1	3	0	0	**4**

Appendix 4 (continued): Morphotypes and counts of phytoliths in dental calculus samples from the Upemba Depression (all time periods).

Present morphtypes	Kisalian	Kabambian	Recent	Atypical	Total Count
Irregular facetate	36	0	0	7	**43**
Irregular verrucate	179	174	0	0	**353**
Parallelipiped echinate	6	0	0	1	**7**
Parallelipiped psilate	1	1	0	0	**2**
Platelet	7	15	0	0	**22**
Prickle	2	0	0	1	**3**
Starlet	37	6	0	0	**43**
Tower horned	2	0	1	0	**3**
Tower wide	3	5	0	0	**8**
Bilobate short convex	6	19	3	0	**28**
Cross	8	8	7	0	**23**
Cylindroid psilate	1	4	0	1	**6**
Ellipsoid psilate	29	26	0	2	**57**
Ellipsoid scabrate	27	8	0	10	**45**
Facetate	1	1	0	5	**7**
Honeycomb spheroid	5	2	0	5	**12**
Polyhedral scabrate	2	5	0	1	**8**
Saddle	6	4	0	1	**11**
Saddle plateau	3	1	0	6	**10**
Sclereid	95	78	0	15	**188**
Spheroid globular	96	6	0	1	**103**
Spheroid rugose	39	50	4	0	**93**
Ellipsoid echinate	23	8	4	3	**38**
Indeterminable	22	21	2	12	**57**
Irregular echinate	40	30	3	3	**76**
Irregular psilate	26	31	3	11	**71**
Irregular scabrate	97	52	4	39	**192**
Rondel	4	2	1	3	**10**
Spheroid echinate	208	123	17	63	**411**
Spheroid psilate	492	197	6	50	**745**
Spheroid scabrate	334	197	7	35	**573**
Spheroid verrucate	438	206	6	135	**785**
Tracheid	227	126	22	77	**452**
71					
TOTAL	**2946**	**1545**	**90**	**491**	**5072**

Appendix 4: Morphotypes and counts of phytoliths in dental calculus samples from the Upemba Depression (all sites).

Present morphotypes	Sanga	Katoto	Malemba-Nkulu	Kikulu	Katongo	Kamilamba	Total Count
Achene	0	0	0	1	0	0	**1**
Bilobate convex long	0	1	0	0	0	0	**1**
Bilobate short flattened	2	0	0	0	0	0	**2**
Blocky echinate	10	0	0	0	0	0	**10**
Blocky facetate	14	0	0	0	0	0	**14**
Blocky psilate	7	0	0	0	0	0	**7**
Blocky verrucate	0	1	0	0	0	0	**1**
Commelina bulliform	0	0	0	0	6	0	**6**
Cylindroid ciliated	0	0	0	0	11	0	**11**
Ellipsoid scalloped	2	0	0	0	0	0	**2**
Irregular psilate (seed)	25	0	0	0	0	0	**25**
Irregular scalloped	3	0	0	0	0	0	**3**
Parallelipiped sinuate	0	0	1	0	0	0	**1**
Polyhedral psilate	10	0	0	0	0	0	**10**
Polylobate	2	0	0	0	0	0	**2**
Rugose	8	0	0	0	0	0	**8**
Saddle collapsed	1	0	0	0	0	0	**1**
Saddle ovate	2	0	0	0	0	0	**2**
Saddle squat	1	0	0	0	0	0	**1**
Scalloped phytolith	0	0	0	0	0	25	**25**
Sclereid (seed)	13	0	0	0	0	0	**13**
Seed phytolith	20	0	0	0	0	0	**20**
Spheroid granulate	0	24	0	0	0	0	**24**
Spheroid psilate (leaves)	0	87	0	0	0	0	**87**
Spheroid starlets	1	0	0	0	0	0	**1**
Tracheids scabrate	0	0	6	0	0	0	**6**
Trapezoid	0	2	0	0	0	0	**2**
Trichome	1	0	0	0	0	0	**1**
Cylindroid scabrate	1	0	0	2	0	0	**3**
Epidermal cell	3	1	0	0	0	0	**4**

Appendix 4 (continued): Morphotypes and counts of phytoliths in dental calculus samples from the Upemba Depression (all sites).

Present morphotypes	Sanga	Katoto	Malemba-Nkulu	Kikulu	Katongo	Kamilamba	Total Count
Facetate	6		1	0	0	0	**7**
Parallelipiped echinate	5	2	0	0	0	0	**7**
Parallelipiped psilate	1	0	0	0	1	0	**2**
Platelet	0	7	0	15	0	0	**22**
Polyhedral	1	2	0	0	0	0	**3**
Polyhedral (seed)	10	0	3	0	0	0	**13**
Polyhedral scabrate	7	0	0	1	0	0	**8**
Prickle	1	2	0	0	0	0	**3**
Saddle plateau	9	0	0	1	0	0	**10**
Scutiform	3	0	0	0	1	0	**4**
Spheroid globular	97	0	0	6	0	0	**103**
Starlet	41	0	0	0	2	0	**43**
Starlet (leaves)	11	87	0	0	0	0	**98**
Bilobate concave short	6	0	0	1	3	0	**10**
Bilobate convex short	9	0	13	6	0	0	**28**
Blocky scabrate	18	0	2	0	2	0	**22**
Bulliform	0	2	3	0	1	0	**6**
Cylindroid psilate	2	0	0	1	3	0	**6**
Honeycomb spheroid	8	2	0	2	0	0	**12**
Indeterminable	48	0	5	4	0	0	**57**
Irregular facetate	15	27	0	0	1	0	**43**
Rondel	3	4	0	3	0	0	**10**
Saddle	7	0	3	1	0	1	**12**
Tower horned	1	0	1	0	1	0	**3**
Tower wide	2	1	5	0	0	0	**8**
Ellipsoid scabrate	37	0	4	1	3	0	**45**
Irregular echinate	48	0	6	9	13	0	**76**
Cross	9	2	4	6	2	0	**23**
Ellipsoid echinate	19	2	6	8	3	0	**38**
Ellipsoid psilate	39		3	3	7	5	**57**
Irregular psilate	33	6	18	7	0	7	**71**
Irregular scabrate	125	0	12	24	2	29	**192**
Irregular verrucate	167	54	69	20	43	0	**353**
Sclereid	83	20	58	21	0	6	**188**
Spheroid rugose	21	6	43	9	14	0	**93**
Spheroid scalloped	104	13	14	3	2	0	**136**
Spheroid psilate	354	149	96	44	95	7	**745**
Spheroid scabrate	295	78	74	67	27	32	**573**
Spheroid verrucate	427	139	40	116	18	45	**785**
Tracheid	254	35	44	74	36	9	**452**
Spheroid echinate	216	33	36	82	36	8	**411**
71							
TOTAL	**2668**	**789**	**570**	**538**	**333**	**174**	**5072**

Appendix 5: Enamel apatite $\delta^{13}C$ and $\delta^{18}O$ values of all archaeological human remains from the six sites in the Upemba Depression.

Enamel Samples	$\delta^{13}C$	$\delta^{18}O$
SANGA n = 41		
Sanga T4 LLM1	-6.39	-3.42
Sanga T5 LUM1	-3.72	-3.46
Sanga T8 LLI1	-3.31	-3.20
Sanga T9 M3	-2.36	-3.09
Sanga T10 LUM3	-5.13	-3.45
Sanga T11 LUM1	-4.81	-3.76
Sanga T12 RLM1	-1.56	-4.56
Sanga T13 LLM3	-5.61	-5.30
Sanga T14 M3	-3.53	-1.43
Sanga T21 LUM3	-2.69	-4.84
Sanga T22 M3	-2.70	-1.93
Sanga T24/35 P2	-4.15	-3.10
Sanga T40 M3	-4.79	-1.32
Sanga T42 RUM1	-3.42	-1.49
Sanga T42 LLP2	-2.26	-0.99
Sanga T47 LUM3	-4.21	-2.10
Sanga T49 RLM1	-4.55	-3.96
Sanga T50 M1	-2.01	-1.76
Sanga T53A LUM1	-3.44	-3.59
Sanga T57 M1	-1.91	-3.85
Sanga T58 I2	-2.51	-1.61
Sanga T58 M3	-1.12	-2.04
Sanga T68 M3	-2.22	-2.53
Sanga T71B M1	-1.51	-1.35
Sanga T76 M1	-4.52	-3.43
Sanga T76 M3	-5.09	-3.24
Sanga T83 M3	-2.94	-3.54
Sanga T85 M3	-2.97	-3.71
Sanga T86 M3	-5.22	-2.18
Sanga T88 M3	-2.98	-0.84
Sanga T90 M1	-2.55	-2.23
Sanga T102 M1	-4.16	-1.80
Sanga T103 M3	-4.78	-2.45
Sanga T105 LLI1	-2.84	-2.65
Sanga T107 M1	-3.47	-1.21
Sanga T116 M1	-2.75	-1.32
Sanga T126 M3	-1.46	-1.85
Sanga T140 M3	-10.64	-3.37
Sanga T173 RUI1	-3.42	-1.71
Sanga T175 LUM3	-2.39	-0.65
Sanga T189 LUP2	-2.35	-4.86
mean	**-3.52**	**-2.66**
min	**-10.64**	**-5.30**
max	**-1.12**	**-0.65**
SD	**1.69**	**1.20**

Appendix 5 (continued): Enamel apatite $\delta^{13}C$ and $\delta^{18}O$ values of all archaeological human remains from the six sites in the Upemba Depression.

Enamel Samples	$\delta^{13}C$	$\delta^{18}O$
KATOTO n = 42		
Katoto T2A LLM1	-7.76	-2.36
Katoto T11 LLC	-2.99	-5.05
Katoto T11 LLM3	-4.65	-6.15
Katoto T13 LUM1	-6.33	-6.19
Katoto T13 RLM3	-6.05	-6.47
Katoto T15 RLM1	-5.23	-5.21
Katoto T17 LLI2	-7.49	-3.63
Katoto T21A RUM1	-7.29	-6.36
Katoto T21A RUM3	-6.25	-6.34
Katoto T21B LUM1	-3.27	-5.64
Katoto T21B LUM3	-3.09	-5.44
Katoto T21C LUM1	-6.74	-5.47
Katoto T21C LUM2	-6.12	-7.76
Katoto T25 LUI1	-7.75	-3.08
Katoto T25 LUM3	-3.95	-3.32
Katoto T26 UC	-5.87	-2.66
Katoto T26 RUM2	-7.77	-3.55
Katoto T26 LUM3	-8.23	-2.91
Katoto T30 LUI2	-5.71	-3.22
Katoto T31 RLM1	-4.51	-5.38
Katoto T34 LUM3	-5.68	-5.72
Katoto T37 RLM1	-6.02	-4.32
Katoto T37 RUM3	-5.82	-5.20
Katoto T41 RLM2	-7.63	-5.43
Katoto T42 RLM1	-5.98	-5.47
Katoto T43 RLM1	-6.41	-5.48
Katoto T48 LLM1	-4.69	-3.35
Katoto T48 RUM3	-5.42	-4.10
Katoto T49 LUM1	-9.00	-2.78
Katoto T49 RLM3	-8.14	-3.16
Katoto T50 LLM1	-8.23	-3.59
Katoto T50 RLM2	-7.05	-3.94
Katoto T50 RLM3	-5.78	-3.65
Katoto T51 RLM1	-5.99	-4.36
Katoto T59 LLI1	-6.99	-3.39
Katoto T61 RLI2	-7.81	-3.02
Katoto T62 LLM3	-4.63	-6.25
Katoto T63 LLM1	-6.46	-5.71
Katoto T63 RLM3	-5.64	-4.86
Katoto T64 LLM1	-6.96	-4.48
Katoto T64 LLM2	-5.92	-2.66
Katoto T66 LLI2	-8.56	-2.57
mean	**-6.24**	**-4.52**
min	-9.00	-7.76
max	-2.99	-2.36
SD	**1.47**	**1.37**

Appendix 5 (continued): Enamel apatite $\delta^{13}C$ and $\delta^{18}O$ values of all archaeological human remains from the six sites in the Upemba Depression.

Enamel Samples	$\delta^{13}C$	$\delta^{18}O$
MALEMBA-NKULU n = 17		
Malemba-Nkulu T1 LUM1	-2.20	-2.15
Malemba-Nkulu T1 M3	-2.82	-3.61
Malemba-Nkulu T3 M1	-3.74	-2.61
Malemba-Nkulu T3 RUP1	-3.66	-3.33
Malemba-Nkulu T13 LLM1	-3.05	-4.93
Malemba-Nkulu T17 LU1	-3.32	-2.96
Malemba-Nkulu T17 RLM1	-3.92	-3.77
Malemba-Nkulu T19 M1	-3.68	-5.47
Malemba-Nkulu T19 M3	-3.68	-5.32
Malemba-Nkulu T21 LLM1	-4.01	-2.98
Malemba-Nkulu T23 M3	-3.64	-4.95
Malemba-Nkulu T26 M1	-3.92	-4.38
Malemba-Nkulu T26 M3	-2.38	-3.89
Malemba-Nkulu T27 LLM1	-4.44	-5.34
Malemba-Nkulu T35 (B1) RUM1	-2.98	-2.93
Malemba-Nkulu T35 (B1) LUM3	-3.88	-2.59
Malemba-Nkulu T37 LUM1	-5.07	-4.42
mean	**-3.55**	**-3.86**
min	-5.07	-5.47
max	-2.20	-2.15
SD	**0.71**	**1.08**
KIKULU n = 15		
Kikulu T2 RLM1	-4.45	-1.67
Kikulu T2 RLM3	-1.38	-1.25
Kikulu T3 LLM1	-3.47	-1.96
Kikulu T3 LLM3	-2.11	-2.33
Kikulu T3 unident. molar	-2.78	-1.59
Kikulu T4 LUM1	-3.92	-2.72
Kikulu T4 LUM3	-3.56	-2.48
Kikulu T4 mixed frags	-2.59	-2.88
Kikulu D2T7 LLI1	-3.47	-2.50
Kikulu D2T7 mixed frags	-3.12	-2.68
Kikulu ET10 RUP1	-5.35	-3.07
Kikulu D3T13 LUM3	-1.42	-0.58
Kikulu T15 LUM1	-3.36	-2.52
Kikulu T15 LUM2	-1.82	-2.51
Kikulu T15 RUM3	-1.63	-2.48
mean	**-2.96**	**-2.22**
min	-5.35	-3.07
max	-1.38	-0.58
SD	**1.16**	**0.68**

Appendix 5 (continued): Enamel apatite $\delta^{13}C$ and $\delta^{18}O$ values of all archaeological human remains from the six sites in the Upemba Depression.

Enamel Samples	$\delta^{13}C$	$\delta^{18}O$
KAMILAMBA n = 7		
Kamilamba T2 M1	-2.23	-2.75
Kamilamba T2 M3	-1.86	-1.58
Kamilamba T5 RLM1	-3.96	-3.22
Kamilamba T5 RLM1 frags	-3.97	-1.46
Kamilamba T7 RUM1	-7.90	-2.65
Kamilamba T7 LUM3	-9.51	-3.48
Kamilamba T10 LUI1	-2.86	-2.90
Kamilamba T10 M3	-5.43	-3.66
mean	**-4.72**	**-2.71**
min	-9.51	-3.66
max	-1.86	-1.46
SD	**2.74**	**0.81**
KATONGO n = 5		
Katongo T2 LLI2	-3.57	-1.38
Katongo T2 M3	-2.04	-1.67
Katongo T6 mixed frags	-7.87	-1.76
Katongo T8 RUI1	-4.52	-1.69
Katongo T8 LUM3	-8.04	-2.03
mean	**-5.21**	**-1.71**
min	-8.04	-2.03
max	-2.04	-1.38
SD	**2.66**	**0.23**