Dental Wear and Early Childhood Diet Among Foragers in Southern Africa

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Arts

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ABSTRACT

Weaning and early childhood diet offer insight into resource availability and resource choice as well as cultural prescriptions of agency, normalcy, and health in early life. Weaning practices are the result of the interaction between biological, ecological, and cultural factors. When weaning is initiated, what foods are chosen for supplementation, how these foods are processed and who chooses the components of diet in early life inform on the biological, ecological, and cultural realities of groups in the past in turn. This thesis employs dental wear data to examine early childhood diet among foragers in southern Africa. Variation in dental wear has two primary determinants: the length of time teeth have been in occlusion (dental age) and the relative abrasiveness of the diet. The former is easily captured in young juveniles due to the accuracy of dental age estimates at this stage of life. The latter may be examined by variables influencing food choice and preparation. Until recently, methods of examining dental wear in deciduous teeth relied on standards borrowed from studies of wear on permanent teeth. These fail to accurately characterize wear. However, new methods of measuring deciduous dental wear quantitatively warrant an exploration of what kind of data can be drawn using this approach. Just as deciduous dental wear is understudied in the literature, so is weaning and early childhood diet among archaeologically-known foragers. This study analyzes wear in a sample of 47 juvenile foragers drawn from collections across South Africa. Individuals come from two distinct ecological regions, the Cape and the Karoo, within the Holocene (10 000 BP - present). Dental wear in the sample was expected to vary based on ecological differences between the Cape and Karoo, temporal differences due to the introduction of pastoralism to the region, and the length of time teeth had been in occlusion (dental age). Of the three variables, only dental age is significantly correlated with dental wear. The apparent uniformity in early childhood diet,

implied by the dental wear data presented in this study, emphasizes the need for further research. Currently, there is not enough comparative data on deciduous dental wear to establish a proper range of variation. Comparable studies will allow for cross-cultural comparison to identify dietary factors influencing dental wear during childhood. A lack of regional and temporal patterning in dental wear, and by implication diet, in this sample suggests unexpected homogeneity in this region. However, data on early childhood diet is not by itself sufficient to define cultural continuity across space and time. Future studies should interrogate broader cultural similarities and distinctions between Cape and Karoo foragers in Holocene southern Africa.

ACKNOWLEDGEMENTS

I would like to thank the Social Science and Humanities Research Council of Canada for their support of this research through the Joseph-Armand Bombardier Canada Graduate Scholarships Program: Master's Scholarship, the members of my examination committee: Dr. Sandra Garvie-Lok and Dr. Jack Ives, my supervisor Dr. Lesley Harrington for her instruction as well as her inspiring example as a scholar, and my sister for her constant support.

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CHAPTER 1 : INTRODUCTION AND BACKGROUND

This thesis investigates two understudied areas of research: weaning and early childhood diet among foragers in southern Africa, and deciduous dental wear. The lives of children in prehistoric foraging groups in southern Africa have only recently received attention in the literature. Two major ecological zones in southern Africa, the Cape and Karoo, are considered in this study. Of these two, foragers in the Cape have enjoyed the most interest. Studies have revealed the relative health of juveniles in this population (Harrington and Pfeiffer, 2008; Pfeiffer and Harrington, 2010) and their early inclusion in normal burial practices (Jerardino et al., 2000). The latter suggests that they attained status as persons within society at a young age. One study examined diet, specifically during weaning, however its findings were based on a single site in the Cape (Clayton et al., 2006). To date, no study has probed the diets, let alone lives of children living in the Karoo. !Kung ethnography may be used as a starting place to make inferences about children from archaeological contexts with cultural ties, however direct studies of childhood in this group are still required. The lack of data on early childhood diet among foragers in southern Africa is a major stumbling block to piecing together the overall picture of childhood in this population. Diet informs on resource availability and health, as well as cultural frameworks for food choice and preparation. In early life, diet is arguably even more informative. Weaning and early childhood diets are platforms on which cultures negotiate concepts of normalcy, health, status and agency. Cultural prescriptions influence the timing of food supplementation, what foods are chosen, and who makes these decisions in early childhood. Regional and temporal comparisons within archaeological skeletal assemblages offer two perspectives from which to begin to investigate variation in childhood diets. Ecological distinctions between the Cape and Karoo shape resource availability in these regions. Distinct resources suggest dietary variation between foragers in the two regions, however this has never been specifically addressed or confirmed in the literature. Temporally, potential change in diet relates to the introduction of pastoralism to southern Africa around 2000 BP and its progressive spread through the region (Sealy and Yates, 1994). This thesis probes the commonalities and differences between juvenile foragers in the Cape and Karoo, populations separated both regionally and temporally.

Dental wear is shaped (primarily) by two factors: the length of time teeth have been in occlusion (age) and the relative abrasiveness of the diet. In early life, age can be estimated with relative accuracy using dental development and eruption. Juveniles therefore offer the ideal scenario under which to study diet using dental wear because one major variable, age, is constrained. Deciduous teeth best characterize early childhood diet because of they begin eruption around 4.5 months of age, (AlQahtani et al., 2010) just before solid foods are typically introduced to the diet. However, there is also a paucity of studies of deciduous dental wear. With a few exceptions (Clement and Freyne, 2012; Dawson and Brown, 2013; Mays and Pett, 2014; Mays, 2015; Skinner, 1997), studies examining wear on deciduous teeth have used methods developed for permanent teeth that fail to adequately characterize deciduous dental wear. The relatively recent development of methods measuring dental wear specifically for deciduous teeth opens up this area of study. This study employs a method of measuring dental wear developed by Clement in 2007 and applied by Clement and Freyne to deciduous teeth in 2012. Its capability is tested to determine if it can shed light on early childhood diet among foragers in southern Africa. As dental wear is shaped primarily by age and diet, the ability of the method to inform on both factors is examined. Considering age, the goal of this study is simple: does dental wear track dental age? Regarding diet, this study asks more. First, is it possible to gauge the onset of weaning as well as its duration using dental wear? Second, is it possible to examine differences in diet in southern Africa? Can dental wear data shed light on the character of early childhood diet among foragers in southern Africa and the variables that shaped it?

The remainder of this chapter outlines relevant literature on weaning and early childhood diets as well as dental wear. Chapter 2 focuses on the ecological and archaeological contexts of the sample in southern Africa, the existing literature regarding childhood in southern Africa, and ethnographic accounts of early childhood among related foraging groups. Chapter 3 outlines the materials and methodology used in this study. Chapter 4 relates the results of the dental wear analysis. Chapter 5 details a discussion of this data, any relevant trends, as well as possible conclusions and future directions for research.

1.1 WEANING

Definitions of weaning vary across the literature. For the purpose of this study, weaning will be defined as the process of transitioning an infant to solid foods. This begins when foods in addition to breastmilk are introduced into the infant's diet and ends when breastfeeding ceases entirely. Weaning practices are the product of the interaction between biology, culture, and ecology. The local environment impacts what foods are available to the child during the weaning period, however which foods are chosen and when they are given to the child depend on biological and cultural constraints. Weaning is a biologically and culturally mediated process because weaning strategies, particularly the length of weaning, are based not only on the physiological realities of infant health, but also cultural conceptions of health and identity for infants and mothers.

1.1.1 BIOLOGY AND WEANING

The biological determinants of breastfeeding centre primarily around the nutritional and immunological contents of the breast milk and the infant's development. During the period of exclusive breastfeeding, the health of the mother has the greatest impact on the infant's nutrition because the infant's sole source of nutrition is through breast milk. Breast milk is composed of macro and micronutrients, growth factors, hormones and immunological factors. The primary macronutrient components of breastmilk include protein, fat, and carbohydrates in the form of lactose. The relative concentration of these factors changes postpartum to adapt to the infant's needs (Ballard and Morrow, 2013). Colostrum is secreted in the first few days postpartum and, while rich in immunological factors, is poor in nutrition. Colostrum production ceases and transitional milk takes its place as soon as five days after birth (Ballard and Morrow, 2013). The nutritive components steadily rise for four to six weeks until the breastmilk is considered mature (Ballard and Morrow, 2013). At this point, the nutritional content of milk remains relatively consistent throughout the course of breastfeeding (Ballard and Morrow, 2013). While most of the macronutrient components are relatively consistent between populations, the micronutrient and fatty components of breastmilk vary based on the maternal diet and environment. Breastmilk is naturally low in vitamin K (Ballard and Morrow, 2013), however other maternal vitamin deficiencies can easily be passed on to the newborn. Infant vitamin D deficiency, for example, is relatively common in modern societies where the mothers are not exposed to adequate sunlight. The nutritional content of breastmilk is sufficient for the infant's needs until approximately six months postpartum, at which point supplementation is necessary to support continued growth and development (Dettwyler, 2004).

While the nutritive content of breast milk is the most obvious factor supporting infant health and development, the immunological support is equally vital. A child's immune response is only fully developed around age five (Newman, 1995) and so they must rely on the mother's antibodies, passed through breastmilk, to support their immune response and aid its development. The mother produces antibodies in response to her unique environment and therefore the immunoglobins are suited to the shared environment of the infant and mother (Newman, 1995). Beyond immunoglobins, breast milk contains a number of other factors that aid the infant's developing immune system. These include, but are not limited to, oligosaccarides, mucins, lactoferrin, interoferrin, fibronectin, and leukocytes (neutrophils, macrophages). Each has a different function and their relative concentration varies through time. For example, there is a distinct difference between the immunological composition of breastmilk and colostrum. Interoferrin and fibronectin are found in higher concentrations in colostrum (Newman, 1995) . The former has strong antiviral properties and the latter combats and repairs damage from inflammation. The immunological factors in breastmilk are one reason why diarrhea incidence, prevalence, and mortality is the lowest in infants that are exclusively breastfed (Lamberti et al., 2011). Breastfeeding confers most immunological benefit in the first six months (Popkin et al., 1990; Lamberti et al., 2011) after birth, although it still produces health advantages up to 23 months after birth (Lamberti et al., 2011). Risk of diarrheal disease is also reduced in exclusively breastfed infants because food is supplied directly from the breast without the chance for bacterial contamination. The introduction of any new food into the diet therefore increases the risk of disease and gastrointestinal illnesses (diarrheal diseases) that are the leading causes of infant mortality. The interaction between nutrition and immunological risk constitutes the weanling's dilemma; the trade off between the risk of introducing potentially contaminated foods into the diet with growth faltering if exclusive breastfeeding continues too long (Rowland, 1986; Hendricks and Badruddin, 1992; Lutter, 1992).

1.1.2 CULTURE AND WEANING

Social determinants of breastfeeding are often related to cultural conceptions of what is "healthy" for the child and mother. Based on biological and life history markers, Dettweyler (2004) determined that the 'biological' age for the cessation of breastfeeding in humans could vary between 2.5 and 7 years. While initiating weaning by at least six months of age is necessary to avoid growth faltering, there is no clear biological marker dictating the cessation of breastfeeding. Wells (2006) argues that a 'natural' practice of breastfeeding or weaning does not exist due to the entanglement of the phenomenon with culture. In his analysis of weaning practices, he applies Foucault's concept of biopower, where the use of the body is regulated by social pressures. Social concepts of normalcy define 'appropriate' breastfeeding and weaning practices and these ideas are enforced through surveillance and subtle judgements (Wells, 2006). In North America, for example, extended breastfeeding is culturally stigmatized and mothers typically either cease breastfeeding at the culturally prescribed time or hide their deviance from the norm (Dettwyler, 2004)

Cultural ideals of normalcy and health may differ from weaning practices that are nutritionally and physiologically optimal for the infant and therefore have profound impacts on early childhood health. Niehoff and Meister's (1972) ethnographic survey of global breastfeeding and weaning practices identified a number of maladaptive cultural practices.

Groups in Mexico, Iran, Malaysia, Greece, and central Saharan Africa, for example, view colostrum as unnatural and unhealthy and therefore infants do not immediately take to the breast. Instead, they are given animal milk or a sweetened liquid until the mother produces ‘normal’ milk (Niehoff and Meister, 1972). This practice deprives the infant of the rich immunological factors in colostrum while at the same time exposing them to potentially contaminated supplemental foods. Cultural attitudes affect all aspects of weaning behaviour: duration of breastfeeding, onset of supplementation, and types of supplemental foods. Breastfeeding inhibits fertility (lactation amenorrhea) (Kennedy et al., 1989) and therefore prolonged breastfeeding comes at a reproductive cost to the mother. Social pressure to conceive more children often impacts weaning duration because the duration of breastfeeding is limited by the birth of another child or attempts at conception. Social stigma in a number of African groups dissuaded women from breastfeeding multiple children concurrently, while pregnant, or if they were attempting to conceive a child (Niehoff and Meister, 1972). Most societies introduced supplemental foods between three and six months postpartum, however a few dictated that the child’s health depended on immediate supplementation after birth or, alternatively, that supplementation should only begin one year after birth (Niehoff and Meister, 1972). Particular groups also associated the behaviour or character of the mother with the quality of her breastmilk (Wells, 2006). Therefore, children born to ‘illfit’ mothers may require early supplementation with particular foods in order to counteract the ill effects of their mother’s milk.

1.1.3 ECOLOGY, SUBSISTENCE AND WEANING

Katzenberg, Herring and Saunders (1996) identified three primary factors linking childhood morbidity and mortality with weaning: the health of the mother, quality of food and water available to the weaning child, and the subsistence practices of the group. The local ecology as well as the subsistence practices of a group impact the quality and content of the diet for the mother and child. The availability of nutritionally adequate weaning foods impacts the onset of weaning as well as its duration because mothers may need to delay supplementation until conditions improve. However, subsistence practices are not always closely correlated with cultural variation in weaning patterns (Sellen and Smay, 2001). Rather, Sellen and Smay (2001) conclude that weaning practices are primarily affected by the maternal work pattern and shifting weaning optimum. The maternal work pattern refers to gendered work practices that may necessitate separation between mother and child. In many cultures, infants are kept close to their mother during breastfeeding. The onset of weaning or the cessation of breastfeeding may be precipitated by the mother resuming a task that requires separation from the child. The shifting weaning optimum states that the length of breastfeeding will increase due to pathogen risk (an environmental variable), but will also be mediated by the social, physiological, and reproductive costs to the mother. Models suggesting that hunter-gatherers practice longer weaning are therefore not always correct. While they have reduced access to soft, starchy staples commonly used as weaning foods in agricultural societies (Niehoff and Meister, 1972), premastication of tougher starches or proteins is a common weaning practice in these groups (Niehoff and Meister, 1972; Sellen and Smay, 2001). Weaning practices must be culturally and ecologically contextualized rather than relying on assumptions based on subsistence practices.

1.1.4 WEANING AND THE LIVES OF CHILDREN

While weaning offers important insight into early childhood health and nutrition, it is also a lens through which to view social lives of children in the past. Halcrow and Tayles (2008) distinguish between the biological and social age of juveniles. Biological age refers to their chronological age, measured from birth. Social age refers to the perceived age and status of an individual in their society. Two measures of social maturity are autonomy and the assumption of adult roles. Changes in social age are visible archaeologically when particular practices are imprinted on the body (Perry, 2005; Martin et al., 2013) and weaning practices have the potential to leave these imprints. Weaning is an important time of transition, where a subadult moves from a period of complete dependency to one of increasing self-sufficiency. Biologically, by ten months, children have the physiological development and motor skills to start to self-feed and by the beginning of their second year, their neurological development allows them to distinguish between food and non-food items (Hendricks and Badruddin, 1992). The ability of the child to perform tasks autonomously or take on new roles can be marked by rituals. Significance is sometimes attached to the initiation of weaning. Among the Chamar in India, for example, a child is given a naming ceremony once rice is introduced to the diet (Niehoff and Meister, 1972). The termination of weaning may also be dictated by the ability to perform particular tasks. Among the Gond in India, children are weaned when they can walk and feed themselves and among the Maori of New Zealand, breastfeeding ceases once the child can turn over on its own (Niehoff and Meister, 1972). In each case, this marks an advancement in the social age of the subadult.

Weaning practices and social age have a reciprocal relationship; each affects the other. As children develop physiologically, neurologically, and socially, they may start to self-provision. In this way, they begin to contribute to their own diets and take on more mature roles. Among modern Hadza foragers in Tanzania, children begin to self-provision as they are being weaned (Crittenden et al., 2013). As early as two or three years of age, they are left behind in the camp while their mothers forage. The children themselves forage in and around the camp, procuring food for themselves and their peers. Children often make different foraging decisions than adults (Bird and Bliege Bird, 2000; Crittenden et al., 2013; Eerkens and Bartelink, 2013) and therefore self-provisioning has the potential to significantly impact early childhood diet.

1.2 DENTAL WEAR

Dental wear refers to the loss of dental tissue and can be divided into three types: attrition, abrasion, and erosion. This classification system was originally posited by Hunter's *The Natural History of Human Teeth* in 1778 and has largely persisted in both clinical and research settings (d'Incau et al., 2012). Dental erosion refers to the chemical degradation of dental tissues and will not be discussed for the purposes of this thesis. In contrast, attrition and abrasion are both physical processes that abrade dental tissues. Dental attrition refers to wear produced by tooth-on-tooth contact, producing wear on the occlusal surface or on interproximal places of contact between teeth (d'Incau et al., 2012). Tooth-on-tooth contact occurs during food mastication, however it may also be the result of bruxism (habitually grinding the teeth together). Dental abrasion is created by the interaction of the teeth with foreign abrasive objects, nutritive or non-nutritive, in the mouth (d'Incau et al., 2012). Both attrition and abrasion operate in conjunction during food mastication as teeth come into contact both with each other and the food particles. Unpacking the relationship between attrition and abrasion is difficult and the two are sometimes conflated in the literature. For example, Hillson describes abrasion as a "general loss of surface detail" caused by abrasive objects in the mouth (1996:231) and attributes all food-related wear to attrition. This alternate definition is common, however, for the purposes of this thesis, the definitions from Hunter's (1778) original model and the body of clinical research on dental wear based upon it will be used. When referring to dental attrition and abrasion together, the general term 'dental wear' will be used. Dental wear may also be divided into active and passive wear. Active or intentional wear refers to purposeful modification of the dentition, often through filing, ablating, or decorating the teeth. Passive (unintentional) wear occurs as the result of habitual processes performed without the intention of modifying the dentition: food mastication, bruxism, or the use of teeth as tools.

Dental wear may be affected by a number of factors: age, diet, extramasticatory wear, cusp morphology, enamel thickness, occlusal patterns, tooth angulation, and the biomechanics of the jaw (McKee and Molnar, 1988). Among this multiplicity of factors, two show the strongest and most consistent relationship to dental wear: age and diet. At its base level, dental wear reflects the length of time the individual's teeth have been in occlusion (their age) and the density or abrasiveness of the foods eaten (diet), a relationship that persists in deciduous teeth (Aiello et al., 1991). Extramasticatory wear, resulting from the introduction of non-food items into the mouth, is the most frequent exception to this rule. Stephan (1972) observed that extramasticatory wear was prevalent in hunter-gatherer groups where individuals frequently chewed on twigs and stems as they were out gathering. In the case of children, some dental studies have identified non-nutritive chewing during teething in cases where wear patterns failed to correlate with age or diet (Bullington, 1991; Warren et al., 2002). One of the most commonly investigated mechanisms behind non-nutritive dental wear patterns is the use of 'teeth as tools' (Molnar, 1971, 2008, 2011; Hinton, 1981; Larsen, 1985; Cruwys, 1988; McKee and Molnar, 1988; Clement and Hillson, 2012). The use of teeth as a 'third hand' can typically be identified by a deviation from the normal or expected pattern of dental wear. In Molnar's 2011 review of the field, she identified eight atypical dental features used to examine extramasticatory wear: notching and grooving (on the incisal/occlusal edge), cuts, scrapes and polished surfaces, interproximal grooves and striations, periapical lesions, lingual tilting, injury to the temporomandibular joint, chipping, and antemortem tooth loss. Other researchers have also used excessive occlusal load, particularly in the anterior dentition, to identify the use of 'teeth as tools' (Cruwys, 1988; Molnar, 2008; Clement and Hillson, 2012). While there is no standardized system for studying extramasticatory wear, the consensus is that it is easily identifiable as a deviation from the normal pattern. In cases of normal wear, it is still possible to deconstruct wear patterns to examine the two primary variables: age and diet.

1.2.1 DENTAL WEAR AND AGE

Dental wear can estimate relative age using an ordinal scale to seriate specimens. Brothwell's 1963 and 1981 charts for dental wear age classification are a classic example of such a method. Wear stages developed by Murphy (1959), Molnar (1971), and Scott (1979), among others, are frequently utilized to place individuals into age categories or life stages. The accuracy of these assignments is debatable, especially considering the influence of diet on wear. Regardless, such methods are subjective and provide only relative age estimates. 'True' age estimation using dental wear is only possible where the rate of wear for the population is known or can be estimated based on an analogous population (Miles, 2001). In order to estimate chronological age from wear, the relative eruption schedule of the permanent teeth, particularly the molars, is used. This approach relies on the assumption that the sequence and timing of tooth eruption is relatively consistent across populations, with the first, second and third molars erupting at approximately six, twelve, and eighteen years, respectively. Assuming that the nature of the diet is constant through the lifespan, it is possible to approximate the rate of wear using the implied intervals between molar eruption. Although each used a different method to measure wear, notable standards for age estimation using dental wear include Miles (1969), Dreier (1994), and Mays, de la Rua and Molleson (1995).

Dental wear age estimates are less straightforward than they appear. They assume a consistent diet; the accuracy of estimates decreases through the lifespan, often underestimating age in older individuals, and many methods fail to distinguish the age of individuals beyond 40 or 60 years of age (Miles, 2001). These limits are imposed by the maximum exposure of dentine on the occlusal surface of the teeth, antemortem tooth loss (related to age), and the shortcomings of the samples from which the methods were developed. Only the first has implications for the use of deciduous dental wear to estimate age in juveniles. While a number of studies have linked deciduous dental wear with age (Bullington, 1991; Kreulen et al., 2010; Clement and Freyne, 2012; Mays and Pett, 2014; Torlinska-Walkowiak et al., 2014; Schmidt et al., 2016), the estimation of age using deciduous dental wear remains largely unexplored in the literature for two reasons. First, most methods of classifying wear were developed for permanent teeth. Second, age estimates using dental development and eruption are more accurate and less likely to be skewed by environmental factors. There are a few instances in which a general estimate of age using wear on deciduous teeth may be useful, in the case of an isolated tooth or a co-mingled grave for example, however this thesis focuses on the more tractable approach of using wear to study diet. Dental age can be reliably determined in individuals with deciduous and mixed dentition and so comparisons of dental wear in individuals of similar dental age allow researchers to isolate and study the effect of diet on dental wear in a population.

1.2.2 DENTAL WEAR AND DIET

Dental wear is affected by the type of foods in the diet as well as their preparation. Research probing the link between dental wear and diet pervades the literature, with special attention being paid to distinguishing the dental signatures of different subsistence practices. Data on occlusal wear, interproximal wear, angle of wear, and the character of wear facets indicates that hunter-gatherers and agriculturalists differ in both pattern and degree of dental wear (Pedersen, 1947; Molnar, 1971; Hinton, 1981, 1982; Smith, 1984; Powell, 1985; McKee and Molnar, 1988; Lubell et al., 1994; Deter, 2009). Foraging diets contain a wide range of foods, many of which are tough or fibrous, and which are minimally processed in comparison to agriculturalists. This tough diet increases the rate of overall dental wear and increases overall occlusal loading on the anterior teeth because heavily worn molars are more frequently exfoliated. Therefore, hunter-gatherer diets typically affect more severe dental wear with greater wear on the anterior teeth. This pattern persists across multiple regions (Smith, 1984) and age classes (Deter, 2009). Agricultural diets are softer, often rely heavily on processed (i.e., ground) and/or cooked carbohydrates. The diet itself produces minimal wear, however it can introduce abrasive elements if grit is introduced during the grinding process (Hinton, 1981). Research examining variation within the same subsistence strategy, as is attempted in the present study, is rare. However, studies have revealed the potential to investigate regional and temporal distinctions among hunter-gatherers (Keenleyside, 1998; Bernal et al., 2007; Lieverse et al., 2007; Littleton et al., 2013; Molnar et al 1989). Molnar and colleagues (1989) were able to differentiate between groups exploiting terrestrial versus riverine resources among foraging groups in Australia. Age estimates were not available for the original study, prompting Littleton and colleagues (2013) to revisit and expand it. They found both regional and gendered differences in the rate of molar wear, overall wear, and the degree of anterior tooth wear. Lieverse and colleagues (2007) also found regional differences in the patterning of wear among foragers in mid-Holocene Cis-Baikal. Temporal changes in diet were identified in Holocene Patagonia (Bernal et al., 2007). In this sample, the rate of wear decreased through time in association with the change in food processing techniques. The success of these previous studies in parsing out small differences within foraging populations helps inspire the approach used in this study.

Wear on deciduous teeth has only recently been explored in the literature, however it offers a unique window into weaning and early childhood diet because primary teeth begin to erupt when the infant is about four and a half months of age (AlQahtani et al., 2010), just before it becomes necessary to supplement the diet. Deciduous dental wear therefore offers the opportunity to study characteristics of weaning and early childhood diets from the moment solid foods are introduced. A dental wear approach complements stable isotope studies on weaning and early childhood diet. Prowse and colleagues (2008) initiated this type of study, combining dental wear with isotopic, paleopathological, and historic evidence to investigate weaning practices in Roman Italy. Dental wear data confirmed the timing of the onset of weaning suggested by isotopic analysis. Other researchers have since followed this approach, including Mays (2015) with material from Medieval England and Schmidt and colleagues (2016) at a Greek colonial site in Bulgaria.

However, dental wear data may also be used alone as an alternative to isotopic analysis where it is difficult to procure permission for destructive analysis. The first study to measure deciduous dental wear was performed by Davies and Pedersen (1955) to examine variation in early childhood diet among a group of Inuit children in Greenland. A subsequent study of primate deciduous dentitions by Aiello and colleagues (1991) suggested that, despite the multitude of factors that could influence deciduous dental wear, the majority of variation between primate species could be attributed to differences in diet and weaning practices. Bullington's (1991) study of deciduous dental microwear found that while the quality of the diet varied between Middle Woodland horticulturalists and Mississipian agriculturalists, age at onset of weaning did not. Skinner's (1997) study comparing early childhood diet of Middle Paleolithic Neanderthal juveniles with Upper Paleolithic modern humans found the opposite trend; the onset of weaning occurred approximately one year later in the Middle Paleolithic, though the character of weaning diets was similar. Dawson and Brown (2013) used differences in the degree of deciduous dental wear in Medieval England to infer a softer and therefore higher status diet. Clement and Freyne (2012) and Warren and colleagues (2002) both used deciduous dental wear to examine diet in modern populations. Clement and Freyne's (2012) study is of particular importance because it departs from the existing literature by using a quantitative method of measuring deciduous dental wear rather than an ordinal one. Their method allows for a detailed study of variation in rates of wear of different tooth types through time without relying on standards developed for permanent teeth.

1.2.3 WHY STUDY DECIDUOUS DENTAL WEAR?

Studies of dental wear have focused on permanent teeth, using qualitative and quantitative methods to sort individuals into broad age groups and subsistence categories. Records of deciduous dental wear are rare in the literature and, until recently, they relied on standards developed for permanent teeth. Recent development of quantitative methods of measuring wear specific to deciduous teeth raises the question, what can the study of dental wear in deciduous teeth offer that their permanent counterparts cannot? The life-span of deciduous teeth in the mouth is brief, they begin eruption around 4.5 months of age and are exfoliated by 12.5 years. The deciduous incisors, canines, and premolars are in occlusion for variable lengths of time. During childhood, age can be determined with relative accuracy using standards for dental development and eruption. Studies of deciduous dental wear therefore offer a unique opportunity where one of the primary determinants of wear, age, is tightly constrained. Deciduous dental wear studies may therefore allow a more controlled study of diet compared to studies using permanent teeth.

1.2.4 METHODS OF MEASURING DENTAL WEAR

Classic methods for measuring and ranking dental wear in the literature have largely been limited to stage based or ordinal ranking. Methods developed by Scott (1979), Molnar (1971) and Murphy (1959), for example, use illustrated diagrams and descriptions of wear on the occlusal surface of the tooth to classify wear into particular stages. However, these methods were developed for permanent teeth, making it difficult to interpret deciduous and mixed dentition. Differences in the morphology of deciduous teeth change the appearance and patterning of dental wear facets (Clement and Freyne, 2012). Enamel on deciduous teeth also wears differently compared to the permanent dentition because it is thinner and softer (Hillson, 1996; Johansson et al., 2001). To address this problem, Skinner (1997) developed an ordinal system for use on deciduous teeth. It was recently modified due to difficulties in assigning teeth to stages (Dawson and Brown, 2013). Ordinal approaches share two disadvantages. First, while it is useful to rank wear for comparison, qualitative methods have limited interpretive value because rankings can only be interpreted relative to one another. Ordinal ranks can be subjected to limited statistical tests or mathematical models. Second, comparison between studies is difficult because observations are subjective and prone to inter-observer error.

Quantitative methods of measuring dental wear can be divided into two types: those that measure crown height, and those that measure the area of the occlusal wear facet relative to the area of the occlusal surface. Crown height studies began as a way of evaluating ordinal wear stages; Molleson and Cohen (1990) experimentally ground unworn teeth in an effort to match loss of crown height with Brothwell's (1963) stages. They concluded that wear stages did not accurately represent loss of dental tissue, particularly in the upper stages. Using crown height as a method of quantifying dental wear has since been developed (Mays et al., 1995; Mays, 2002; Benazzi et al., 2008). The precise method varies, however the average crown height is typically calculated by averaging multiple transects starting from the cemento-enamel junction. By plotting crown height on permanent molars with age (known or dental), researchers have identified an approximately linear relationship in most cases, with the exception of a population of 20th century Sardinians (Benazzi et al., 2008). This method was recently expanded for application on deciduous premolars (Mays and Pett, 2014) and central incisors (Mays, 2015). Approaches that measure the wear facet compare the area of exposed dentine to the total area of the occlusal surface (Walker, 1978; Richards and Brown, 1981; Molnar et al., 1983; Richards, 1984; Aiello et al., 1991; Kambe et al., 1991; Clement, 2007; Clement and Hillson, 2012, 2013). Measurements are typically taken from photographs in which the occlusal surface of the tooth is aligned in parallel to the camera lens. Early studies enlarged and projected the photographs so that the occlusal surfaces and dentine wear facets could be traced and the respective areas measured using a planimeter. More recent studies trace the occlusal surfaces and facets using a graphics tablet or a cursor and use imaging software to calculate area measurements. Many studies report significant correlations between wear facet proportions and age (Richards and Brown, 1981; Molnar et al., 1983; Kambe et al., 1991), and with diet (Walker, 1978; Richards, 1984; Aiello et al., 1991; Clement, 2007; Clement and Hillson, 2012, 2013). Measurement of wear facet proportion was applied to deciduous teeth in a sample of modern Nubian children (Clement and Freyne, 2012) to investigate both the timing of weaning and early childhood diet.

CHAPTER 2 : ECOLOGICAL, ARCHAEOLOGICAL AND CULTURAL CONTEXT OF SOUTHERN AFRICA

Human occupation of southern Africa has a long history, however this thesis focuses on the Holocene (10 000 BP - present). Two groups were selected for study: Later Stone Age (LSA) foragers living on the South African Cape and Karoo. The LSA sample from the Cape is derived from archaeological sites dated to throughout this period (Morris, 1992a; Barham and Mitchell, 2008) whereas the sample from the Karoo is protohistoric (Morris, 1992b). Craniometric (Morris, 1992b; Stynder et al., 2007) and dental morphological (Irish et al., 2014) data suggest the two samples are biologically homogenous, both related to historic Khoe-san foragers. Archaeological evidence indicates groups in the Cape and Karoo both practiced a hunter-gatherer subsistence and a significant body of research has examined the diets and lives of adults living in the Cape. However, there is a paucity of data on childhood diet for both regions. The effect of ecological and possible cultural variation between these two groups on the diet, health, and lives of juveniles provides the focus of this study.

2.1 FORAGERS IN THE CAPE

The South African Cape refers to the coastal region of South Africa leading up to the Cape Fold mountain belt. It spans the Western and Eastern Cape provinces, encompassing three biomes. On the southwestern coast, the fynbos biome is characterized by a Mediterranean climate with hot dry summers and mild wet winters. The mean annual temperature is 16.6ºC and annual rainfall between 200 and 600 mm (Stock and Pfeiffer, 2004). The southern coast features the forest biome, where the climate is more temperate. The mean annual temperature is 16.9ºC and annual rainfall between 500 and 1200 mm (Stock and Pfeiffer, 2004). Finally, the eastern Cape represents a transitional biome where fynbos slowly gives way to grassland (Pfeiffer, 2016). Each of these regions are part of the Greater Cape Floristic Region (GCFR) and therefore, despite differences in the exact species present, they share the GCFR's characteristically high diversity in flora and fauna (Meadows and Sugden, 1993). Plant species include berries and fruits as well as a large number of underground storage organs or geophytes. Small browsers dominated the fauna, however some larger ungulates are also present (Stock and Pfeiffer, 2004; Barham and Mitchell, 2008). Terrestrial resources on the Cape were likely consistent throughout the Holocene (Meadows and Sugden, 1993; Barham and Mitchell, 2008). Marine resources, including fish, molluscs, and sea mammals, were accessible along coastlines in both the forest and fynbos. Coastal groups regularly accessed these resources, as evidenced by the presence of large shell middens (Mitchell, 2002) and isotopic evidence consistent with diets high in marine resources (Sealy and van der Merwe, 1988). However the degree to which foragers regularly moved between the terrain of the Cape Fold mountains and the coast to access marine resources is the subject of debate (Parkington, 1972, 2001; Sealy et al., 1986, 1995, 2006; Sealy and Merwe, 1988; Sealy, 1989, 1997; Marean et al., 2014). Archaeological evidence suggests that groups may have moved seasonally to and from the coast, however isotopic evidence indicates a distinct division between terrestrial and marine diets on the Cape. Marean and colleagues (2014) use analogies with hunter-gatherer groups in similar environments in Australia and California to assert that the GCFR was too small for groups not to have contact with the ocean. They suggest that movement to and from the coast did not occur seasonally, but rather over a generational time scale. Their hypothesis could explain the discrepancy between archaeological and isotopic evidence. Observations of dental wear among LSA Cape foragers indicate high levels of wear consistent with a tough or abrasive diet (Ginter, 2009; Pfeiffer, 2007; Sealy et al., 1992).

2.1.1 CHILDREN IN THE CAPE

Recent research has shed some light on the lives of children in the Cape. LSA juveniles appear to be healthy, displaying low frequencies of cribra orbitalia, growth arrest lines, and following normal patterns of growth despite a small body size (Harrington and Pfeiffer, 2008; Pfeiffer and Harrington, 2010). The burial context of LSA infants and children indicate that they were initiated into the social group soon after birth (Jerardino et al., 2000) and held status within their society (Mitchell, 2002). It is unlikely that they began to fully adopt adult subsistence roles at least until late adolescence. Harrington's (2010) biomechanical study revealed that gendered differences in limb robusticity observed in adults (Stock and Pfeiffer, 2004; Cameron, 2013) were not consistently present in juveniles. Data on childhood diet is relatively sparse. Sealy and van de Merwe's (1988) stable isotopic study concluded that children are consuming a diet similar to adults, however, the sample of children was quite small. Clayton, Sealy and Pfeiffer (2006) performed an isotopic weaning study using bone collagen from a small sample of juveniles at the Matjes River Rock Shelter. Juvenile diets were elevated a trophic level higher than the adults for the first 18 months of life and decreased to adult levels between 2 and 4 years after birth. This pattern is consistent with ethnographic accounts of Kalahari hunter-gatherer weaning practices, where children were weaned between 3 and 4 years of age (Lee, 1979).

2.2 FORAGERS IN THE KAROO

Climate and ecology in the Karoo differ significantly from the Cape. The region is arid, with greater daily and annual variations in temperature. The mean annual temperature is 18.6ºC and annual rainfall varies wildly between 50 and 600 mm (Desmet and Cowling, 1999). The Karoo can be divided into two ecological regions, the Nama-Karoo and the succulent Karoo. Both hold incredible diversity in flora and fauna, albeit with slight differences in species between them (Meadows and Watkeys, 1999). Succulent shrubs, geophytes, berries, and fruits predominate, providing sustenance for a variety of fauna ranging from large-medium grazers and small bovids (Mitchell, 2002). Plant resources likely made up a significant portion of the diet (Morris, 1992b; Smith, 1999; Youngblood, 2004; Barham and Mitchell, 2008). Due to the aridity and variable rainfall, geophytes were probably the most reliable and plentiful vegetation to be exploited (Smith, 1999; Youngblood, 2004; Barham and Mitchell, 2008). Other edible plants in the region are highly dependent on rainfall and were likely only intermittently available. Archaeological evidence indicates regular exploitation of ostrich eggs and small browsers (Smith, 1999). Only one isotopic study sheds light on diet among foragers in the Karoo. Lee-thorp and colleague's (1993) isotopic study of adult diet among Iron Age and a few LSA Karoo sites found considerable dietary variation between both biomes and settlements.

Excavations of settlements and burials associated with Karoo hunter-gatherers around Koffiefontein and Augrabies Falls indicate a foraging economy dating between the eleventh and early nineteenth centuries with similar material culture to LSA groups in the Cape (Morris, 1992b). The presence of metal tools indicates some contact with Iron Age peoples living in the region, however it is unlikely that they adopted wholesale the pastoral practices of their neighbours. Youngblood's (2004) investigation of edible flora in the Karoo suggests that the diversity of edible material in the environment would have made a transition to pastoralism unnecessary and, based on ethnographic analogy with the Hadza of Tanzania, undesirable. The Hadza exploit similar resources hypothesized to characterize foraging diets in the Karoo. Like groups in the Karoo, they have access to a wide variety of edible flora and fauna (Youngblood, 2004). However, despite the abundance of wild game, meat only constitutes 40% of their overall diet (Youngblood, 2004). Youngblood (2004) hypothesizes that their choice to include significantly more plant material in their diet is based on the efficiency of foraging in a plant-rich environment and therefore its relative stability. The Hadza had already chosen to limit their reliance on game and therefore the increased and stable access to animal domesticates offered by pastoralism was unattractive to them. Youngblood (2004) asserts a similar dismissal of pastoralism among Karoo foraging groups. Dental evidence supports this claim; Morris (1992b) observed significant wear in the adult dentition consistent with a hunter-gatherer subsistence. There are few comparative studies of hunter-gatherers in the Cape and Karoo, however Cameron's (2013) biomechanical study identified significant differences in activity patterns. Where groups on the Cape exhibit gendered differences in robusticity and bilateral asymmetry (Stock and Pfeiffer, 2004), Karoo foragers do not display this trend. In addition, relative robusticity indicates that groups in the Karoo engaged in activities with higher diaphyseal loading. This difference is likely related to ecological differences, but could be indicative of cultural distinctions. Currently, there are no studies of juveniles in the Karoo. Differences in subsistence practices between foragers in the Cape and Karoo remain unclear based on existing evidence, necessitating further study into diet in these regions. This study addresses that gap from the perspective of childhood diet.

2.3 PASTORALISM AND CHANGE IN SUBSISTENCE THROUGH TIME

Subsistence practices in southern Africa were not constant through the Holocene. Animal domesticates were introduced to the area from the north around 2000 BP (Sealy and Yates, 1994) and with them, knowledge of herding and a pastoralist economy. Smith and Sadr's decades long debate about the spread of pastoralism into southern Africa is summarized in numerous review articles, including Maggs and Whitelaw (1991), Russell and Lander (2015), and Sadr (2013). Smith contends that pastoralism spread as pastoralists did (1998). Hunter-gatherers struggled to adopt the new subsistence practice, at times entering adversarial relationships with their pastoralist neighbours. Pastoralism requires value placed in private property and the adoption of a delayed return economy, two cultural features Smith argues are fundamentally opposed to a mobile, egalitarian hunter-gatherer lifestyle (Smith, 1998). Sadr has a more flexible perspective, suggesting that hunter-gatherers transitioned to hunter-herders by trading for small herds of goats or sheep (2013). His work also focuses on the demic (migration based) diffusion of pastoralism into southern Africa, attempting to model it using zooarchaeological, lithic, and ceramic evidence. He argues that ceramic styles place the migration of pastoralists significantly later, just ahead of the colonial era. Sadr's picture of herding in southern Africa is therefore one where 'true pastoralism' was slow to flourish.

Recent research challenges the assumptions of both Smith and Sadr's models. Russell and Lander (2015a) use ethnographic data of pastoralists around Africa to argue that 'true pastoralism' is an academic construct. Modern and historic pastoralists vary widely in how they use their animals and this translates to variation in social structure and the value they place in their herds. Hunter-gatherers in southern Africa may not exhibit 'traditional' features of pastoralist societies, however they were certainly capable of adopting this new approach and tuning it to existing culture and social values. Russell and Lander (2015b) further suggest that bee-keeping among foragers in southern Africa set a precedent to accept animal domesticates when they arrived. Under this model, the physical movement of pastoralists is not crucial to the spread of herding. Jerardino and colleagues (2014) modelled the spread of herding through southern Africa using spatial and temporal data. They suggest that the practice spread south at a rate of 1.4-3.3 km/yr, too fast to be explained by demic diffusion alone. Primarily cultural transmission of herding practices explains how foragers in southern Africa were able to adopt their own mode of pastoralism. Regardless of the exact mode by which herding reached southern Africa, this body of research suggests the potential for a progressive change in diet starting at 2000 BP. The younger the sample, the more likely it was affected by encroaching pastoralism. Evidence of a flexible foraging subsistence, incorporating at least some animal domesticates, is already present in the protohistoric Karoo sample used in this study (Morris, 1992b). Karoo individuals date between 550 BP and 50 BP. The LSA Cape sample is older, spanning between 5000 BP and 800 BP, however later-dating skeletons could be part of flexible subsistence groups analogous to the Karoo sample. Both regional and temporal variation in diet among foragers in southern Africa is examined in this study.

2.4 ETHNOGRAPHIC COMPARISONS

Linguistic, biological, and archaeological evidence indicate that LSA foragers in the Cape and protohistoric foragers in the Karoo are ancestors of ethnographically documented hunter-gatherers in the Kalahari. Ethnographic accounts of the !Kung in the Kalahari form a rich body of knowledge which may inform hypotheses about forager childhoods in the Cape and Karoo. Infants are quickly initiated into the social fabric of !Kung society, being named a few hours after birth (Howell, 2010). This correlates with Jerardino and colleagues' (2000) interpretation of an infant burial in the Cape. Among the !Kung, colostrum is considered a 'bad' food, however infants take to the breast once the mother produces ‘normal’ milk (Howell, 2010). Supplementation of a !Kung infant’s diet begins around six months, however breast feeding continues until three or four years of age (Lee, 1979). This aligns with Clayton and colleagues’ (2006) isotopic study of Cape children. Weaning foods included pre-masticated meat and sweet vegetables (Konner, 2005; Howell, 2010). The maternal work pattern does not impact weaning behaviour in this group. Children spend the weaning period in close proximity to their mothers. They are carried almost exclusively for the first two years of life before they walk (Lee, 1979), Even after children learn to walk, they are carried by their mothers on gathering trips outside of camp up until the age of four years (Lee, 1979). Education and socialization during childhood are informal. Adults do not formally train children in subsistence tasks, nor do older children normally accompany adults in hunting or gathering and, as a result, they do not contribute much to their own diet. This is consistent with Harrington’s (2010) biomechanical study indicating a delay in the assumption of gendered adult roles.

As with any ethnographic analogy, caution is warranted. Konner’s (2005) cross cultural study of infant and childcare among hunter-gatherers emphasizes their variability, particularly in the realm of weaning practices. Much of this variation is due to ecological differences between groups. Among the Hadza, for example, children are weaned earlier (around 2.5 years of age) and ushered into adult roles sooner (Konner, 2005; Crittenden et al., 2013). Howell (2010) theorizes that the dangers of the Kalahari desert discourage the early independence of children. While the environments of the Karoo and the Kalahari share similarities, there are significant differences between the Cape and the Kalahari which may inspire divergent views on childhood. Juvenile coastal foragers in Melanesia, for example, regularly take part in shellfish collection at a young age (Bird and Bliege Bird, 2000). !Kung ethnography may offer insight into early childhood diets in southern Africa, however the breadth of dietary strategies employed by other foraging groups must also be considered. Temporal, ecological, and cultural factors are all potential sources of variation in early childhood diet, which may in turn manifest in dental wear.

CHAPTER 3 : MATERIALS AND METHODS

3.1 MATERIALS

The individuals selected for study were drawn from southern African foragers curated in four different collections in South Africa: the Albany Museum (ALB), Iziko Museum (SAM), University of Cape Town (UCT), and McGregor Museum (MMK). Selection was based on the preservation of deciduous teeth and the availability of contextual information for the remains. Individuals from the Cape (Table 3.1) are, typically single burials recovered as part of formal or salvage excavations. All individuals are either radiocarbon dated to the LSA, or associated with LSA burial contexts (Mitchell, 2002). The majority of the individuals from the Karoo (Table 3.2) were taken from the Riet River sample, specifically from sites around Koffiefontein (Morris, 1992b). While dated to the protohistoric period, biological and archaeological evidence confirms individuals in this sample are related to LSA Cape foragers (Irish et al., 2014; Morris, 1992b; Stynder et al., 2007). Remaining individuals from the Karoo were excavated from burial contexts consistent with those of the LSA. A total of 47 individuals were selected for study.

Figure 3.1 Map of sites used in this thesis, source Google Maps. Sites from the Cape are coloured red, and those from the Karoo are coloured purple.

Table 3.1 Summary of the Cape sample (n=37). Dates are uncalibrated radiocarbon dates, unless otherwise stated. Undated skeletons are associated with other dated skeletons, or a comparable burial context.

Individual	Site	Date (BP)	Dental Age
ALB51	Plettenberg Bay		9.5
ALB116A	Wilton Large Rock Shelter		4.5
ALB122	Wilton Large Rock Shelter	4721 ±31	5.5
ALB132	Spitzkop	4720 ±70	7.5
ALB133	Spitzkop	4860 ±70	8.5
ALB135	Spitzkop	4900 ±60	1.5
ALB137	Spitzkop	4750 ±60	3.5
ALB138	Spitzkop	4800 ±80	4.5
ALB175	Kleinpoort	360 ±50	5.5
ALB176	Kleinpoort	350 ±50	3.5
ALB181	Kleinpoort	450 ±50	6.5
ALB183	Dunbrody	220 ±50	7.5
ALB193	Kleinpoort	230 ±60	3.5
ALB195B	Melkhoutboom		2.5
ALB205	Middlekop cave	3810 ±70	7.5
ALB236	Mitford Park	2100 ±60	5.5
ALB266	Delamare Farm	580 ±50	6.5
ALB300	St. Francis Bay	805 ±27	2.5
ALB318	Kenton-on-Sea	887 ±27	6.5
ALB322	Klasies River Mouth Cave 5	4340 ±80	0.875
ALB325	Loerie Forest Station	830 ±50	6.5
ALB350	Oyster Bay	2990 ±60	8.5
WSK1Child	Wilton Rock Shelter		1.5
SAM4207	Drury's Cave		7.5
SAM6052	Byneskranskop 3		7.5
SAM6053	Byneskranskop 1		8.5
SAM6054B	Modder River Mouth	2530 ±60	6.5
SAM6054C	Modder River Mouth	ca 2600	2.5
UCT190/217K	Oakhurst Rock Shelter		2.0
UCT190/218	Oakhurst Rock Shelter		1.5
UCT191	Oakhurst Rock Shelter	4100 ±60	6.5
UCT196	Oakhurst Rock Shelter	4830 ±250	3.5

UCT210	Oakhurst Rock Shelter	4995 ±215	7.5
UCT247	Klein Brakrivier	510 ±40	8.5
UCT346	Nelson Bay Cave	2500-3000	2.5
UCT388	Faraoskop	ca 2100	7.5
UCT437	Kasteelberg	1310 ±50	5.5

Table 3.2 Summary of the Karoo sample. Individuals are dated between 550 and 50 BP based on radiocarbon dates from material at the Type R settlements associated with these burials.

Individual	Site	Dental Age
MMK199	Koffiefontein	3.5
MMK200	Koffiefontein	9.5
MMK205	Koffiefontein	2.5
MMK207	Koffiefontein	5.5
MMK214	Koffiefontein	2.5
MMK223	Koffiefontein	3.5
MMK225	Koffiefontein	2.5
MMK230	Koffiefontein	7.5
MMK238	Koffiefontein	3.5
MMK246	Koffiefontein	2.5

3.2 METHODS

3.2.1 AGE ESTIMATION

Dental age estimates were performed using the London Atlas of Human Tooth Development and Eruption developed by AlQahtani and colleagues (2010). Dental development and eruption are under tight genetic control, making dental age estimates among the most accurate indicator of chronological age (Cardoso 2007). Studies of modern populations of known age reveal inter and intra populational variation in the timing of dental development and eruption, however the sequence of eruption rarely varies (Halcrow et al., 2007; Woodroffe et al., 2010; Gaur and Kumar, 2012; Al-Batayneh et al., 2014; Vucic et al., 2014). Individuals sharing the same dental age therefore have comparable developmental maturity, even with slight variations in chronological age. The London Atlas uses dental development and eruption to form an estimate of chronological age. Atlas standards were developed from radiographs of British and Bangladeshi individuals of known age, ranging from 28 weeks in utero to 24 years of age (AlQahtani et al., 2010). The London Atlas was chosen for its accuracy and ease of application. In a recent test of the method (2014) on Portuguese, Dutch, American, Canadian, Bangladeshi, British, and French collections, the London Atlas proved more accurate than the long standing atlases of Schour and Massler (1944) and Ubelaker (1978). Individuals were assigned to the correct age category more frequently and, while all methods underestimated age, the London Atlas was least biased. The atlas utilizes Moorrees, Fanning and Hunt's (MFH) stages (Moorrees et al., 1963a; b) of dental development, meaning MFH data collected prior to the creation of the atlas can still be used. This flexibility was critical to this study, as some age estimates in the sample were generated using Dr. Lesley Harrington's MFH data collected prior to the publication of the London Atlas.

Radiographs were available for 19 individuals in the sample and so the MFH stages for the teeth in these dentitions were determined based on the radiographic images. For the remaining individuals, MFH stages were determined based on macroscopic observations. Age estimates were made primarily using the data for individual teeth published in the tables accompanying the London Atlas, with reference made to the images when necessary to choose between stages. Where it was impossible to assign the individual to one stage, the range for the two applicable stages was recorded and the median used for the purpose of analysis. Inter and intraobserver error was assessed using a quadratic weighted Kappa statistic.

3.2.2 MAKING DENTAL CASTS

Analysis of dental wear was performed on colour-tinted epoxy resin (Epo-Tek 301) dental casts from moulds of the teeth made with vinylpolysiloxane dental impression material

(Coltene President.). The resin was mixed according to manufacturer’s instructions, poured into the moulds, and left overnight to harden. Casts were removed from the moulds and any casts with bubbles on the occlusal surface were recast.

3.2.3 MEASUREMENTS OF DENTAL WEAR

Measurements for dental wear were made using an adaptation of Clement’s (2007) method of quantifying dental wear from wear facet areal measurements. The dental casts were examined under a Keyence VHX-2000 digital microscope using a VH-Z00R/W/T lens at the lowest magnification (5x). Each tooth was examined for the presence of dental wear facets. The occlusal surface was coloured using a marker to visually demarcate the border of the wear facet depression from the surrounding occlusal plane. Functionally, this means that only wear facets that had progressed through the enamel to expose dentine were measured. Plasticine was used to position the casts so the occlusal surface was parallel to the lens of the microscope. The occlusal surface of each tooth was outlined on the digital image by the author and the area of the traced polygon was calculated by the microscope’s measurement software (Figure 3.2A). The software was then used to differentiate between the enamel surface and the exposed dentine based on the difference in colour, and the area of the enamel surface was measured (Figure 3.2B).

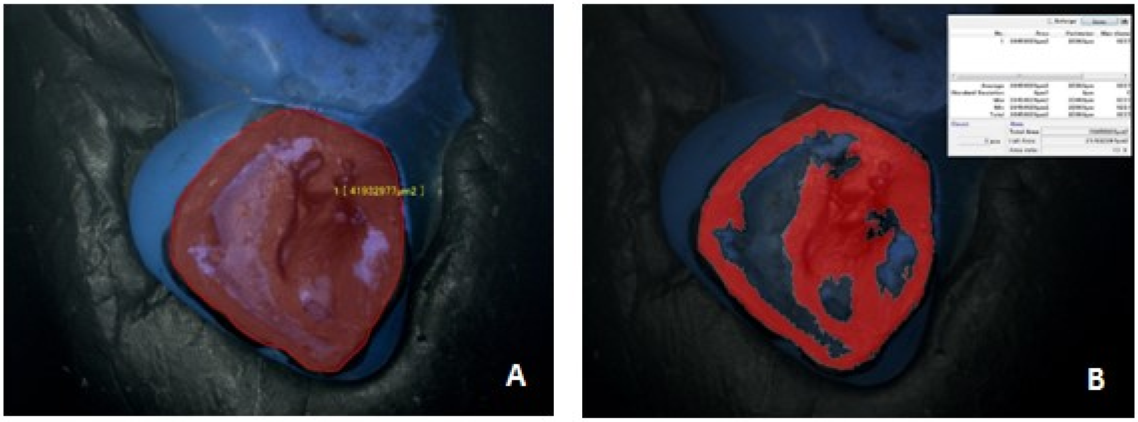

Figure 3.2 An example of measurements made on the occlusal surface. A) Measurement of the total occlusal area and B) measurement of the dyed enamel surface.

The area of exposed dentine was determined by subtracting the area of enamel from the total area of the occlusal surface. Following Clement (2007), ratios of wear were determined by dividing the area of exposed dentine by the area of the occlusal surface. In order to evaluate whether the pattern of wear for each individual followed a ‘normal’ pattern (i.e. followed the eruption pattern), an adjusted wear ratio was calculated. The following eruption sequence was assumed: first incisor, second incisor, third premolar, first canine, and fourth premolar (Table 3). Using the preserved teeth in each dentition, the wear ratio of the earliest erupting tooth was compared to each subsequently erupting tooth using the following formula:

adjusted wear ratio = wear ratio of tooth wear ÷ ratio of earliest erupting tooth

The adjusted wear ratio was only used to determine if individuals followed a ‘normal’ pattern of wear. All subsequent analysis was performed using the original wear ratios for each tooth. A Mann Whitney U test was performed to test the presence of left-right asymmetry in wear ratios and, finding none, left and right sides were combined for analysis. In cases where left and right antimeres were present, the average of the two wear ratios was used in analysis. After combining left and right antimeres, preservation scores, out of ten, were assigned to each individual based on the number of teeth preserved in the mandible and maxilla. A Mann Whitney U test was performed to compare preservation in the Cape and Karoo. No significant difference in preservation was observed between the regions.

Table 3.3 Sequence and median age of eruption for deciduous teeth, taken from AlQahtani et al. (2010).

Maxilla			**Mandible**		
Tooth	Alveolar Eruption	Full Eruption	Tooth	Alveolar Eruption	Full Eruption
i^1	4.5 months	10.5 months	i_1	4.5 months	10.5 months
i^2	7.5 months	1.5 years	i_2	7.5 months	1.5 years
c^1	10.5 months	2.5 years	c_1	10.5 months	2.5 years
p^3	10.5 months	1.5 years	p_3	10.5 months	1.5 years
p^4	1.5 years	2.5 years	p_4	1.5 years	2.5 years

Table 3.4 Sequence and age of exfoliation of deciduous teeth. Minimum and maximum age of exfoliation are taken from AlQahtani et al. (2010).

Maxilla			**Mandible**		
Tooth	Minimum age of exfoliation	Maximum age of exfoliation	Tooth	Minimum age of exfoliation	Maximum age of exfoliation
i^1	6.5 years	6.5 years	i_1	6.5 years	7.5 years
i^2	7.5 years	8.5 years	i_2	6.5 years	8.5 years
c^1	9.5 years	11.5 years	c_1	9.5 years	11.5 years
p^3	10.5 years	11.5 years	p_3	10.5 years	11.5 years
p^4	10.5 years	12.5 years	p_4	10.5 years	12.5 years

3.2.4 STATISTICAL METHODS

All wear measurements were exported as .csv files and compiled with age estimates and contextual data in Excel. The dataset was imported into R Studio and all statistical tests and graphics were run using this program. Non-parametric statistics were chosen for all measures of correlation and significance. This sample, as with all archaeological samples, does not have a normal distribution due both to the osteological paradox (Wood et al., 1992) and the inherent sampling constraints affecting what enters the archaeological record, what is preserved, and what is ultimately excavated.

Dental age, region, and date were examined as covariates most likely to affect wear. Dental age, determined by the development and eruption of teeth, should correlate with wear because it reflects the length of time the teeth have been in occlusion . The region and date of the burial are most likely variables to reflect relative abrasiveness of diet, as regional ecology influences available foods, and there is a body of research suggesting a change in diet through time in southern Africa. Correlations between dental age and wear, region and wear, and date and wear were tested using Spearman's rank correlation. Spearman's rank correlation was chosen because it is both non-parametric and can be applied to ordinal and categorical data. Before the correlations were performed, the 'Region' variable was converted into a binary dummy variable, with 0 representing the Cape, and 1 representing the Karoo. The "Date" variable was converted into a 10 level ordinal scale by dividing the range into 500 year increments. Dental age, region, and date were used as independent variables in a multiple linear regression analysis to examine the degree to which each contributed to wear. These models were evaluated based on the reported significance (t-value) for each of the independent variables as well as the r-squared value and p-value of the overall model. The relationship between dental age and wear was further explored, running Spearman's rank correlation separately for the Cape and Karoo. Linear and polynomial regressions were run for each tooth type. As with the correlations, the models were run three times, for the Cape, Karoo, and combined regions. Models were evaluated based on the r-squared value and the p-value.

CHAPTER 4 : RESULTS

4.1 AGE ESTIMATES

Dental age estimates for each individual are summarized in the materials tables (Tables 3.1 and 3. 2). The distribution of the ages, both for the total sample and divided by region, are summarized by Figures 4.1 and 4.2, respectively. The results of the Kappa statistic to test intra and inter-observer error are summarized in Table 4.1.

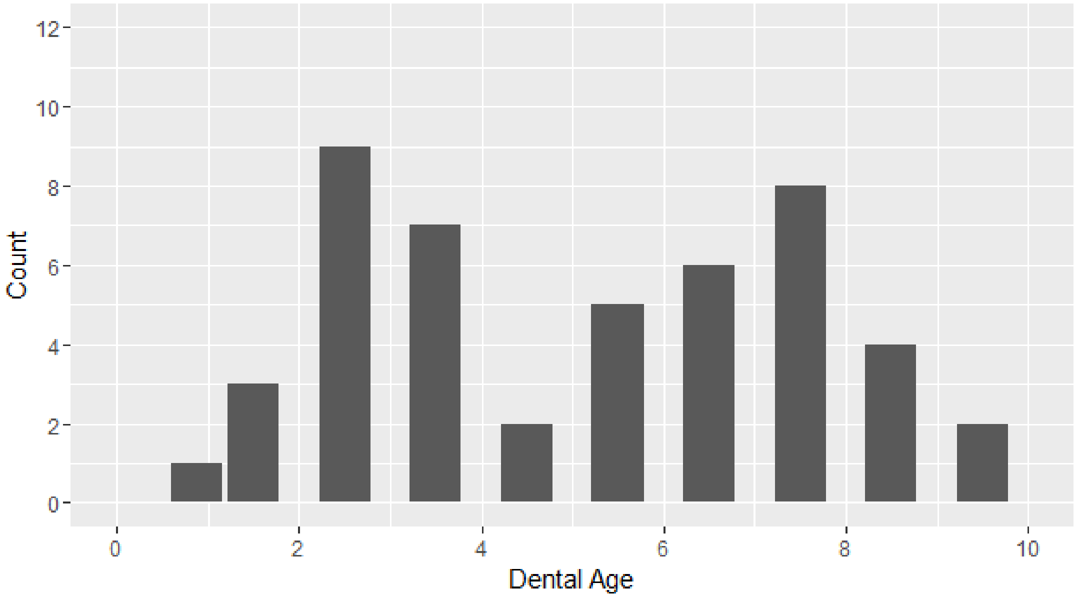

Figure 4.1 Dental age distribution for the sample.

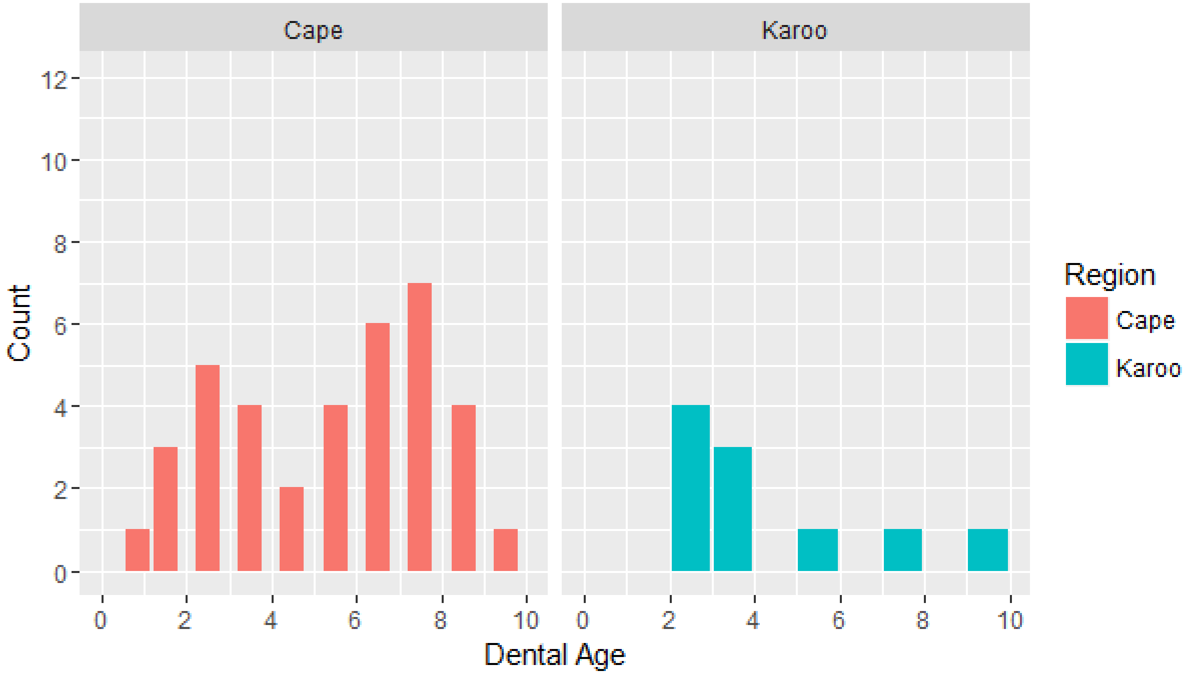

Figure 4.2 Dental age distribution for the sample, divided by region.

Table 4.1 Kappa statistic summarizing inter and intra-observer error for the sample.

Error	**Developmental Score**			**Age Estimate**		
	Number of teeth (N)	Kappa	p-value	Number of individuals (N)	Kappa	p-value
Intra-observer	141	0.989	0	18	0.938	6.14e-05
Inter-observer	118	0.890	0	18	0.913	8.88e-05

4.2 WEAR RATIOS

4.2.1 LEFT/RIGHT ASYMMETRY TEST

Wear ratios for the left and right antimeres of each tooth type were tested for left/right asymmetry using a Mann Whitney U test. Based on a significance level of 0.05, the p-values for each test indicated no significant difference between the left and right sides (Table A.1, Appendix). Left and right teeth were therefore combined for analysis. Where left and right antimeres of the same tooth type were present in an individual, the average of the two wear ratios was used for analysis.

4.2.2 WEAR RATIOS AND THE ERUPTION SEQUENCE

Wear ratios for each tooth in the sample are shown in Table A.2 (see Appendix). In each individual, wear ratios were compared across the dentition to determine if they followed the pattern expected based on the sequence of eruption using an adjusted wear ratio (Table A.3, Appendix). Of the 47 individuals in the sample, 22 followed the eruption sequence and 25 did not. The canine was most aberrant, displaying higher than expected wear in 19 of the 25 deviating individuals. For the 22 individuals with normal patterns of wear, 12 did not have canines preserved. Region did not affect deviation.

4.3 SPEARMAN'S RANK CORRELATIONS

Spearman’s rank correlation was used to examine the relationship between wear ratios and dental age, wear ratios and region, and wear ratios and date for each tooth type (Table 4.2). Significant correlations were only found between wear ratios and dental age. Region and date were not significantly correlated with wear for any tooth type. In addition, rho values for the region and date correlations were low compared to those for dental age. Rho values may fall between -1.0 and 1.0, with values approaching zero signaling the weakest correlation. Negative values indicate a negative relationship between the variables and positive rho values indicate a positive one. All rho values for the correlations between wear and dental age were above 0.5, whereas most for the wear and region and wear and date correlations hovered around zero (Table 4.2).

Spearman’s rank correlation verified that dental age (ie biological maturity) was significantly correlated with wear in the sample. The results of the Spearman’s rank correlations testing the relationship between dental age and wear are summarized in Table 4.3. Values for the

Cape and Karoo are displayed, despite a lack of statistical distinction between regions. Most of the correlations show a statistically significant relationship at the 95% confidence level between dental age and wear. The anterior teeth, maxillary and mandibular, in the Karoo do not show a statistically significant relationship. However, this could be a product of small sample size. There are 10 individuals in the Karoo sample, however, due to missing teeth, the sample size ranges between 4 and 9 teeth in each tooth category. All other tooth types display statistically significant correlations between dental age and wear. The correlation between dental age and wear in the canines is significant because canines exhibit higher than expected wear in this sample. Correlation between dental age and wear in the canines indicates that the high wear is produced by a factor present consistently through time. For the tooth types with statistically significant relationships, all the rho values are between 0.506 and 0.892, indicating relatively strong correlation between dental age and wear.

Table 4.2 Summary of Spearman's rank correlation comparing wear with dental age, region, and date.

Tooth Type	**Dental Age**		**Region**		**Date**	
	N	rho	N	rho	N	Rho
i^1	22	0.8142[c]	22	-0.3176	21	0.1697
i_1	21	0.8141[c]	21	0.008951	18	0.02081
i^2	23	0.7381[c]	23	-0.2309	21	0.01156
i_2	27	0.7802[c]	27	-0.2612	21	0.2095
p^3	38	0.8326[c]	38	-0.2258	32	0.1125
p_3	38	0.7818[c]	38	-0.1447	32	-0.02763
c^1	26	0.7648[c]	26	-0.06695	24	-0.1534
c_1	30	0.6650[c]	30	-0.1852	24	-0.1469
p^4	37	0.8145[c]	37	-0.06863	31	-0.4496
p_4	37	0.7402[c]	37	-0.06531	30	0.009524

[c] *$p<0.001$*

Table 4.3 Summary of Spearman's rank correlations examining dental age and wear.

Tooth Type	**Cape**		**Karoo**		**Combined**	
	N	rho	N	rho	N	rho
i^1	18	0.7369[c]	4	0.7746	22	0.8142[c]
i_1	15	0.8223[c]	6	0.2928	21	0.8141[c]
i^2	17	0.7726[c]	6	0.43994	23	0.7381[c]
i_2	20	0.7980[c]	7	0	27	0.7802[c]
p^3	29	0.8442[c]	9	0.6993[a]	38	0.8326[c]
p_3	31	0.7563[c]	7	0.9608[c]	38	0.7818[c]
c^1	19	0.8231[c]	7	0.6594	26	0.7648[c]
c_1	24	0.6508[c]	6	0.6928	30	0.6650[c]
p^4	29	0.7884[c]	8	0.8924[b]	37	0.8145[c]
p_4	29	0.6842[c]	8	0.8316[a]	37	0.7402[c]

[a] $p<0.05$ [b] $p<0.01$ [c] $p<0.001$

4.4 REGRESSIONS

Multiple linear regressions were run for each tooth type to evaluate the contribution of dental age, region, and date to models of dental wear in this sample (Table 4.5). All the models were significant however, region and date did not significantly contribute to variation in wear. This corresponds with the results of the Spearman's rank correlations (Table 4.2). In one tooth type, the lower fourth premolar, region significantly affected the model. However, this pattern did not carry across all tooth types. The impact of region and date on wear was not investigated further.

The relationship between dental age and wear was further explored using linear (Table 4.5) and polynomial (quadratic) regression (Table 4.6). Regressions were run for each tooth type, both for the overall sample and the separate regions. In both the Cape and combined regions, all the linear regression models were statistically significant. With the exception of the upper canine, none of the models for the anterior teeth in the Karoo were significant. This is likely an artifact of small sample size. R^2 values for the significant models indicate that linear regression models of wear based on dental age account for 34-70% of the variation in wear.

Polynomial regressions models for the Cape and combined regions were significant in the upper third premolar, upper fourth premolar, and lower fourth premolar. In the Karoo, only the polynomial models for the upper and lower fourth premolar were significant. R^2 values for the significant models indicate that polynomial regression models of wear based on dental age account for 50-99% of the variation in wear. For tooth types where both linear and polynomial regression models were significant, the polynomial model consistently performed better. For each tooth type, models of best fit were selected and plotted to describe wear for age (Figures 4.3-4.12).

Table 4.4 Summary of multiple linear regressions examining the effect of dental age region, and date on wear for each tooth type.

Tooth Type	**R^2**	**F**	**B**				**Standard Error B**			
			Constant	Dental Age	Region	Date	Constant	Dental Age	Region	Date
i^1	0.5769	7.727 ^{b}	-0.06926	0.08440 ^{c}	-0.04948	0.003613	0.1322	0.01989	0.1239	0.01265
i_1	0.6368	8.182 ^{b}	-0.1529	0.1127 ^{c}	0.05161	-0.002516	0.1483	0.02304	0.1269	0.015233
i^2	0.5400	6.653 ^{b}	-0.1305	0.1147 ^{c}	-0.009303	-0.01142	0.1736	0.02832	0.1390	0.01505
i_2	0.7097	13.86 ^{c}	-0.1157	0.09498 ^{c}	-0.05495	-0.01161	0.1118	0.01629	0.09396	0.01146
p^3	0.4622	8.021 ^{c}	-0.2344 ^{a}	0.06033 ^{c}	0.09539	0.003132	0.08148	0.01259	0.06334	0.007438
p_3	0.5037	9.474 ^{c}	-0.1467 ^{a}	0.04719 ^{c}	0.04802	-0.001551	0.06172	0.008951	0.05283	0.005556
c^1	0.5991	9.962 ^{c}	-0.1900	0.07855 ^{c}	0.07286	-0.005446	0.09987	0.01448	0.08333	0.01000
c_1	0.3991	4.427 ^{a}	-0.09900	0.06594 ^{b}	0.01348	-0.009390	0.1327	0.01895	0.1154	0.01257
p^4	0.5612	11.51 ^{c}	-0.1839 ^{a}	0.04230 ^{c}	0.1231	-0.001857	0.05527	0.007597	0.04463	0.005173
p_4	0.5927	12.61 ^{c}	-0.2394 ^{c}	0.04854 ^{c}	0.1479 ^{b}	0.001528	0.05741	0.008420	0.04576	0.005223

^{a} $p<0.05$ ^{b} $p<0.01$ ^{c} $p<0.001$

Table 4.5 Summary of linear regressions of the relationship between dental age and wear for each tooth type.

Tooth Type	R^2	F	B		Standard Error B	
			Constant	Dental Age	Constant	Dental Age
Cape						
i^1	0.5350	18.41 [c]	-0.06585	0.08697 [c]	0.09756	0.02027
i_1	0.7018	30.60 [c]	-0.1634	0.1052 [c]	0.08946	0.01901
i^2	0.5557	18.76 [c]	-0.1902	0.1091 [c]	0.1297	0.02518
i_2	0.5645	23.34 [c]	-0.1404	0.08323 [c]	0.08932	0.01723
p^3	0.5105	28.16 [c]	-0.2682 [a]	0.07834 [c]	0.08846	0.01476
p_3	0.4011	19.42 [c]	-0.1006	0.03716 [c]	0.04930	0.008430
c^1	0.5638	21.98 [c]	-0.1730 [a]	0.06598 [c]	0.07428	0.01407
c_1	0.4044	14.94 [c]	-0.1233	0.06104 [c]	0.09030	0.01579
p^4	0.4445	21.60 [c]	-0.1192	0.03256 [c]	0.04317	0.007005
p_4	0.3736	15.51 [c]	-0.1422 [b]	0.03607 [c]	0.05701	0.009158
Karoo						
i^1	0.7821	7.181	-0.4270	0.19780	0.2055	0.07382
i_1	0.01525	0.06196	0.01276	0.03559	0.4348	0.1430
i^2	0.1660	0.7962	-0.2895	0.1635	0.5264	0.1833
i_2	0.005315	0.02672	0.1446	-0.01662	0.3020	0.1017
p^3	0.5666	9.152 [a]	-0.2020	0.07810 [a]	0.1048	0.02582
p_3	0.9515	98.10 [c]	-0.2000 [b]	0.07564 [c]	0.03008	0.007528
c^1	0.5951	7.350 [a]	-0.1961	0.09956 [a]	0.1427	0.03672
c_1	0.3041	1.748	-0.5146	0.2058	0.4736	0.1557
p^4	0.8822	44.95 [c]	-0.2228 [b]	0.07997 [c]	0.05904	0.01193
p_4	0.9215	70.39 [c]	-0.2630	0.08807 [c]	0.05275	0.01050
Combined						
i^1	0.5753	27.10 [c]	-0.09422	0.09143 [c]	0.07927	0.01756
i_1	0.6146	30.31 [c]	-0.1172	0.09918 [c]	0.07742	0.01802
i^2	0.5256	23.27 [c]	-0.1557	0.1043 [c]	0.1008	0.02162
i_2	0.5544	31.10 [c]	-0.1387	0.08236 [c]	0.06957	0.01477
p^3	0.5167	38.49 [c]	-0.2282 [b]	0.07358 [c]	0.06636	0.01186
p_3	0.4483	29.25 [c]	-0.1028	0.03982 [c]	0.03997	0.007197
c^1	0.5055	24.54 [c]	-0.1486 [b]	0.06621 [c]	0.06605	0.01337
c_1	0.3784	17.05 [c]	-0.1064	0.05930 [c]	0.07601	0.01436
p^4	0.4543	29.14 [c]	-0.1390 [b]	0.04009 [c]	0.04397	0.007425
p_4	0.4300	25.65 [c]	-0.1670 [b]	0.04479 [c]	0.05288	0.008844

[a] $p<0.05$ [b] $p<0.01$ [c] $p<0.001$

Table 4.6 Summary of polynomial regressions for the relationships between dental age and wear for each tooth type.

Tooth Type	**R^2**	**F**	**B**			**Standard Error B**		
			Constant	Dental Age	Dental Age 2	Constant	Dental Age	Dental Age 2
Cape								
i^1	0.5538	9.308 [b]	-0.2036	0.1653	-0.008770	0.1995	0.1007	0.01104
i_1	0.7514	18.14 [c]	-0.3913 [a]	0.2484 [a]	-0.01639	0.1701	0.09435	0.01059
i^2	0.5626	9.002 [b]	-0.2991	0.1677	-0.005422	0.2673	0.1275	0.01367
i_2	0.5965	12.56 [c]	-0.3338	0.1916	-0.01164	0.1888	0.09502	0.01003
p^3	0.6539	24.56 [c]	0.3065	-0.1656 [a]	0.02206 [c]	0.1908	0.07540	0.006722
p_3	0.4803	12.94 [c]	0.06857	-0.04752	0.008462	0.09430	0.04178	0.004097
c^1	0.6391	14.16 [c]	0.05154	-0.04969	0.01202	0.1413	0.06470	0.006581
c_1	0.4046	7.136 [b]	-0.1401	0.06946	-0.0008432	0.1927	0.08630	0.008482
p^4	0.5917	18.84 [c]	0.1416 [a]	-0.07766 [b]	0.009896 [c]	0.09317	0.03652	0.003232
p_4	0.6058	19.21 [c]	0.2763 [c]	-0.1332 [c]	0.01494 [c]	0.1184	0.04473	0.003894
Karoo								
i^1	0.7821	7.181	-0.4270	0.1978	N/A	0.2055	0.07382	N/A
i_1	0.01525	0.06196	0.1276	0.03559	N/A	0.4348	0.1430	N/A
i^2	0.1660	0.7962	-0.2895	0.1635	N/A	0.5264	0.1833	N/A
i_2	0.005315	0.02672	0.1446	-0.01662	N/A	0.3020	0.1017	N/A
p^3	0.6617	5.868 [a]	0.2476	-0.1448	0.02307	0.3604	0.1734	0.0177
p_3	0.9652	55.55 [b]	-0.04501	-0.0006239	0.007451	0.1265	0.06021	0.005925
c^1	0.6532	3.786	-0.7750	0.3906	-0.02910	0.7224	0.3575	0.03554
c_1	0.3041	1.784	-0.5146	0.2058	N/A	0.4736	0.1557	N/A
p^4	0.9771	106.7 [c]	0.2376	-0.1364 [a]	0.01875 [b]	0.1051	0.04789	0.004119
p_4	0.9969	808.2 [c]	0.1815 [b]	-0.1127 [b]	0.01719 [c]	0.04179	0.01830	0.001554
Combined								
i^1	0.5918	13.77 [c]	-0.2332	0.1690	-0.008649	0.1777	0.0904	0.009884
i_1	0.6673	18.05 [c]	-0.3623 [a]	0.2416 [a]	-0.01606	0.1630	0.08614	0.009517
i^2	0.5340	11.46 [c]	-0.2861	0.1737	-0.007575	0.2411	0.1181	0.01268
i_2	0.5704	15.93 [c]	-0.2858	0.1615	-0.008415	0.1704	0.08499	0.008895
p^3	0.6477	32.17 [c]	0.2828	-0.1533 [b]	0.02106 [c]	0.1529	0.06373	0.005838
p_3	0.5138	18.49 [c]	0.06543	-0.04444	0.008301 [a]	0.08630	0.03900	0.003823
c^1	0.5441	13.73 [c]	0.04435	-0.03255	0.01020	0.1527	0.07199	0.007309
c_1	0.3815	8.328 [b]	-0.1675	0.08966	-0.003031	0.1827	0.08344	0.008205
p^4	0.6619	33.28 [c]	0.2358 [b]	-0.1243 [c]	0.01485 [c]	0.08924	0.03647	0.003249
p_4	0.6934	37.31 [c]	0.3375 [c]	-0.1679 [c]	0.02933 [c]	0.1026	0.04049	0.003558

[a] $p<0.05$ [b] $p<0.01$ [c] $p<0.001$

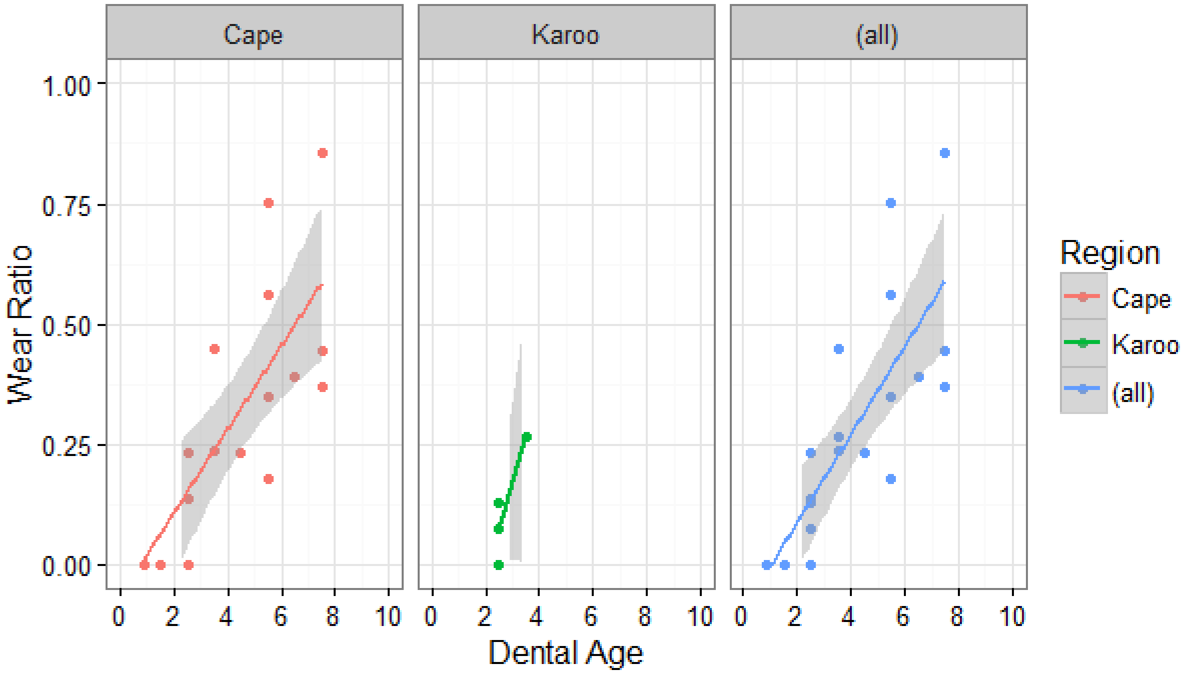

Figure 4.3 Plot of the linear regression model of dental wear for age in the upper first incisors.

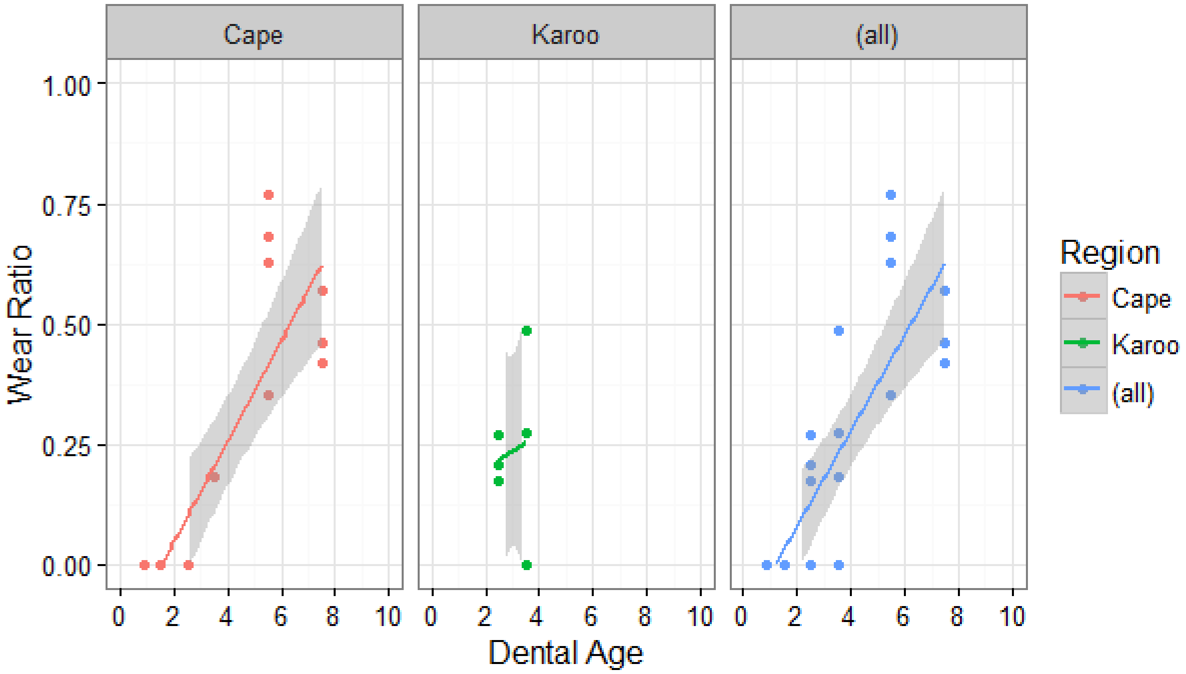

Figure 4.4 Plot of the linear regression model of dental wear for age in the lower first incisors.

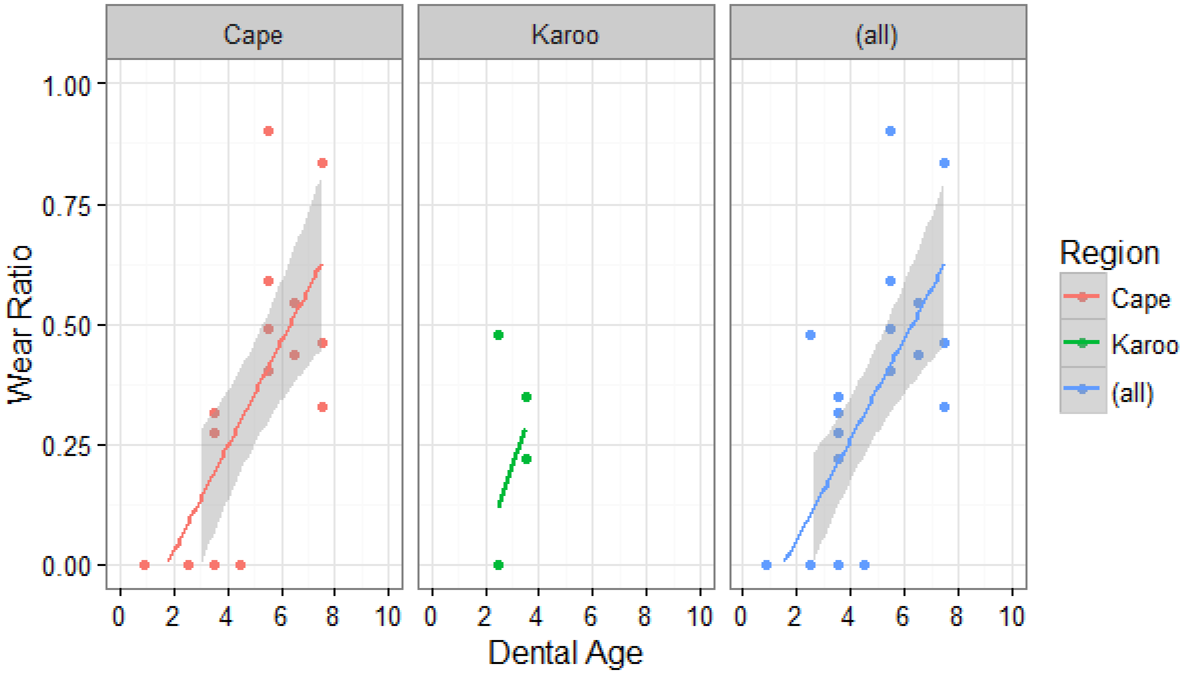

Figure 4.5 Plot of the linear regression model of dental wear for age in the upper second incisors.

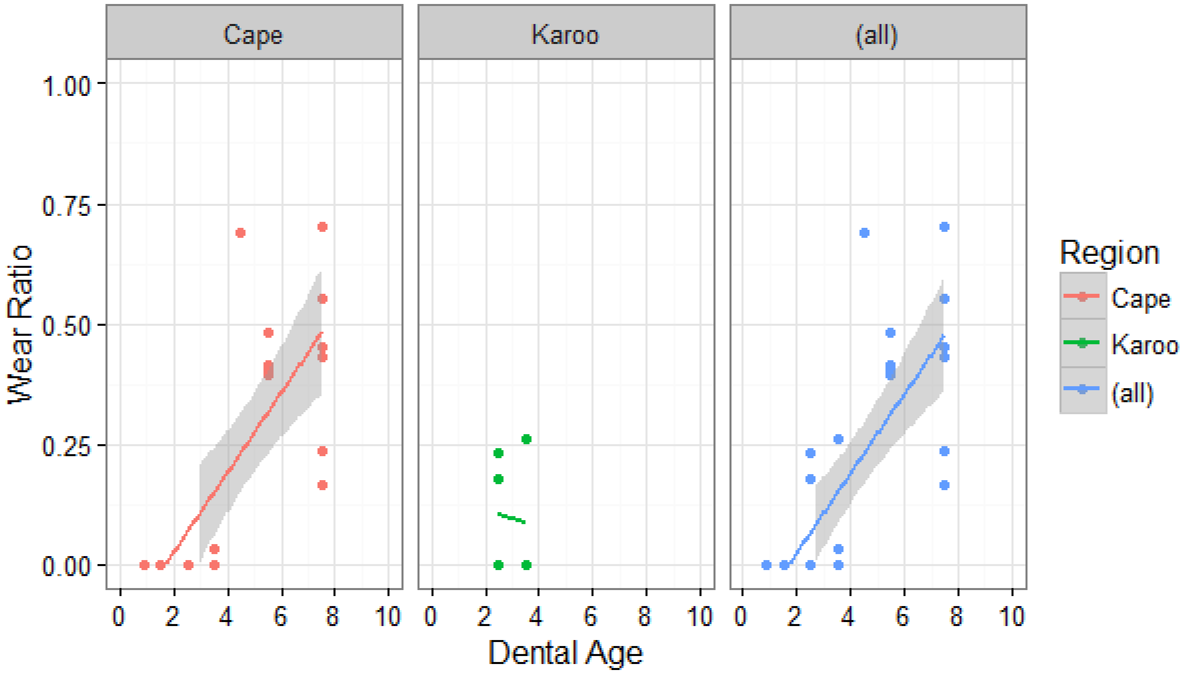

Figure 4.6 Plot of the linear regression model of dental wear for age in the lower second incisors.

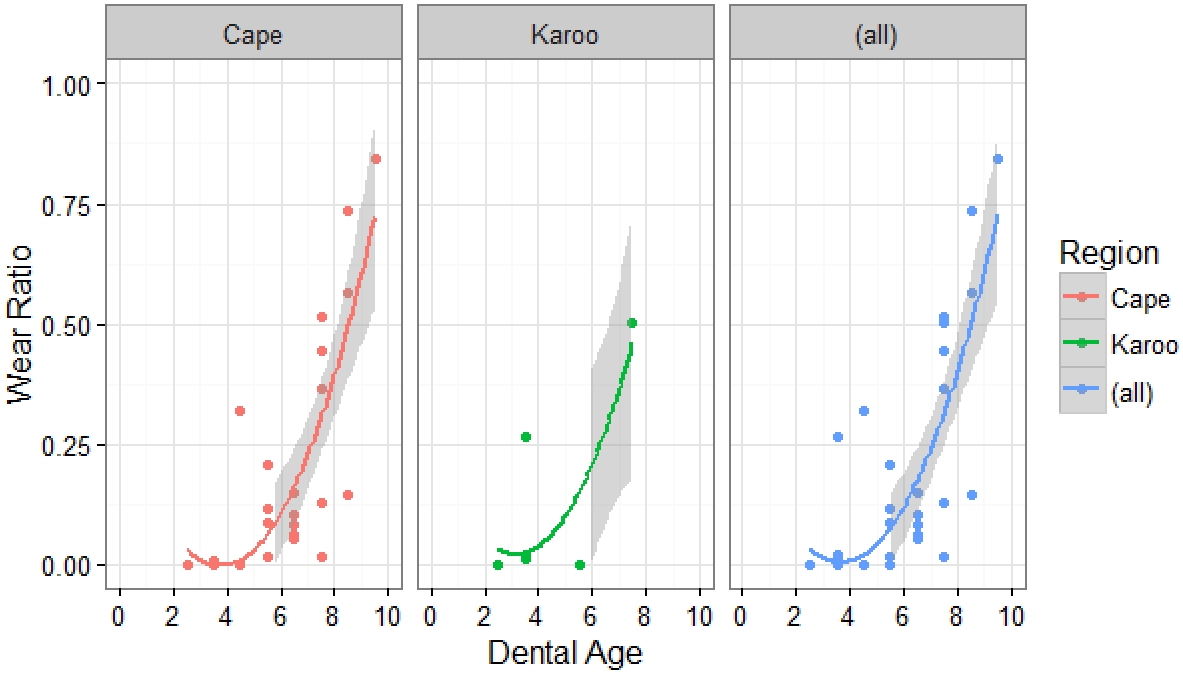

Figure 4.7 Plot of the polynomial regression model of dental wear for age in the upper third premolars.

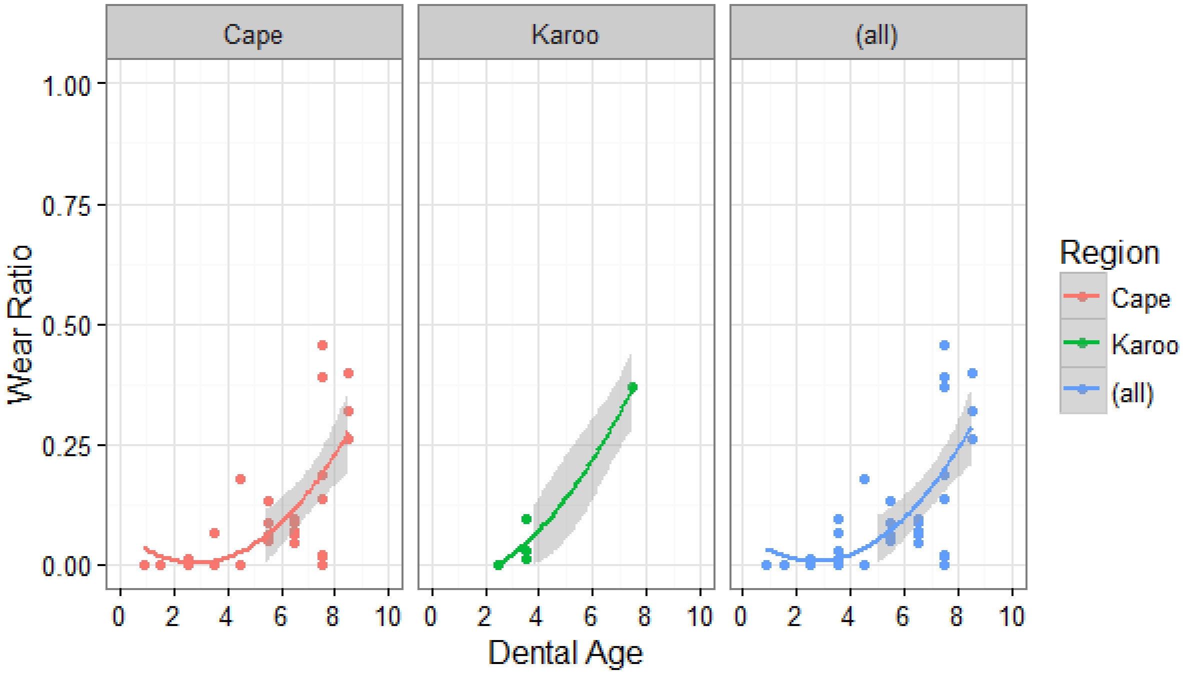

Figure 4.8 Plot of the polynomial regression model of dental wear for age in the lower third premolars.

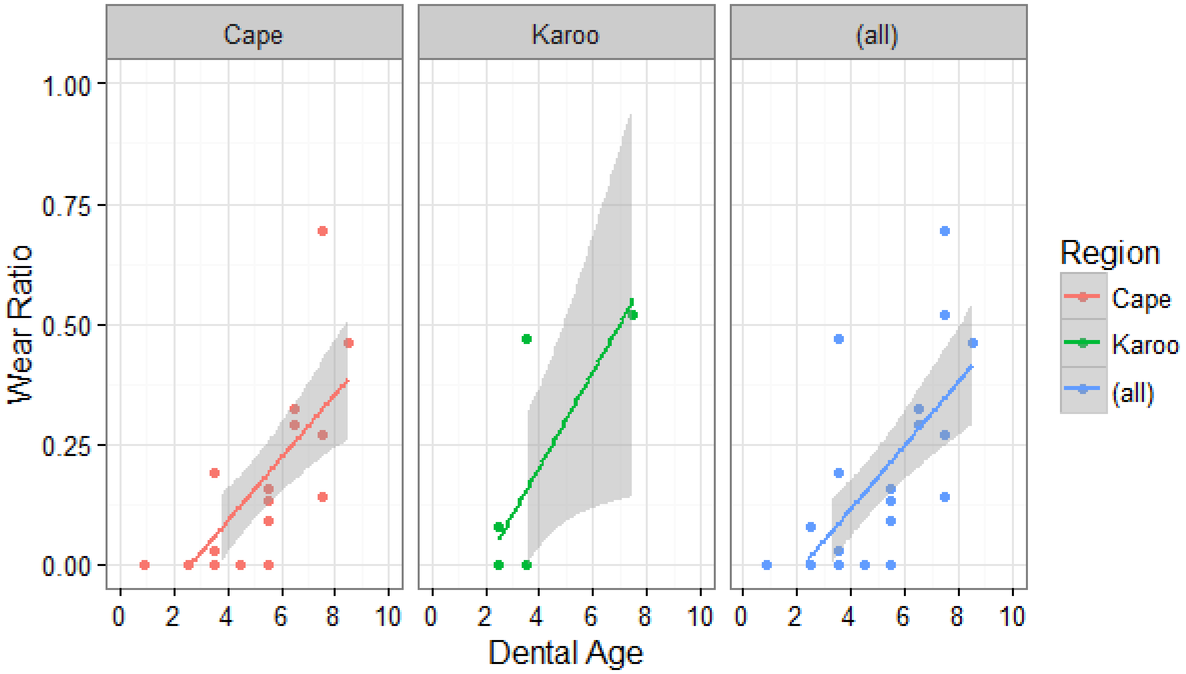

Figure 4.9 Plot of the linear regression model of dental wear for age in the upper first canines.

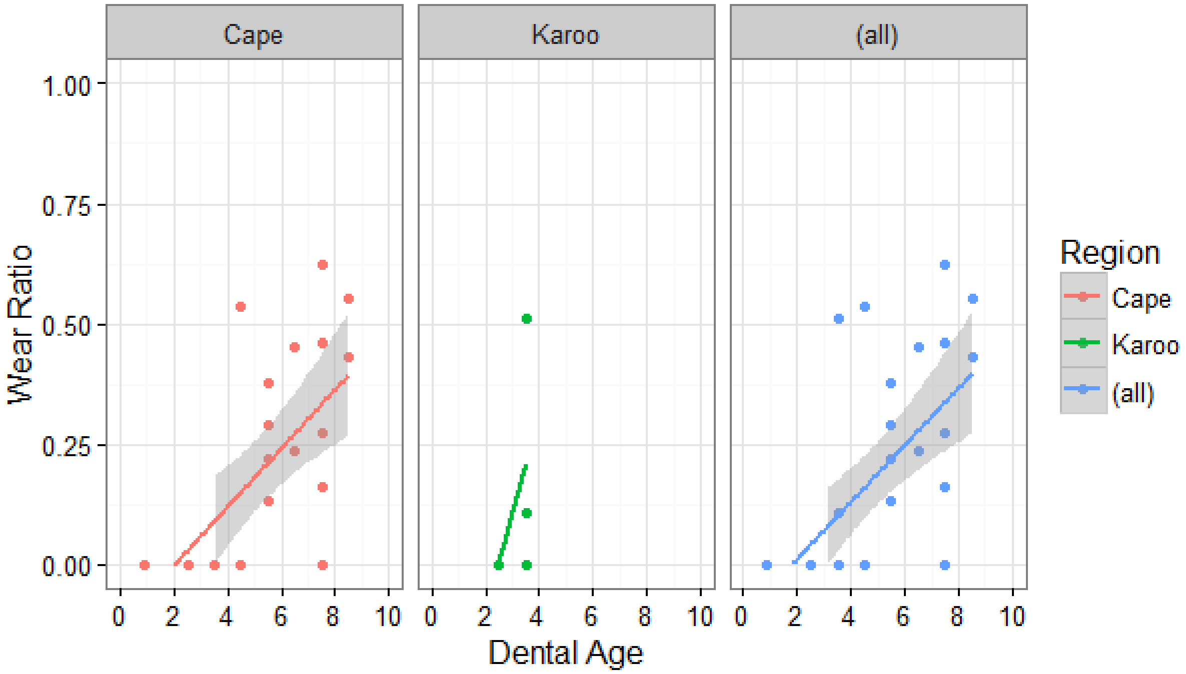

Figure 4.10 Plot of the linear regression model of dental wear for age in the lower first canines.

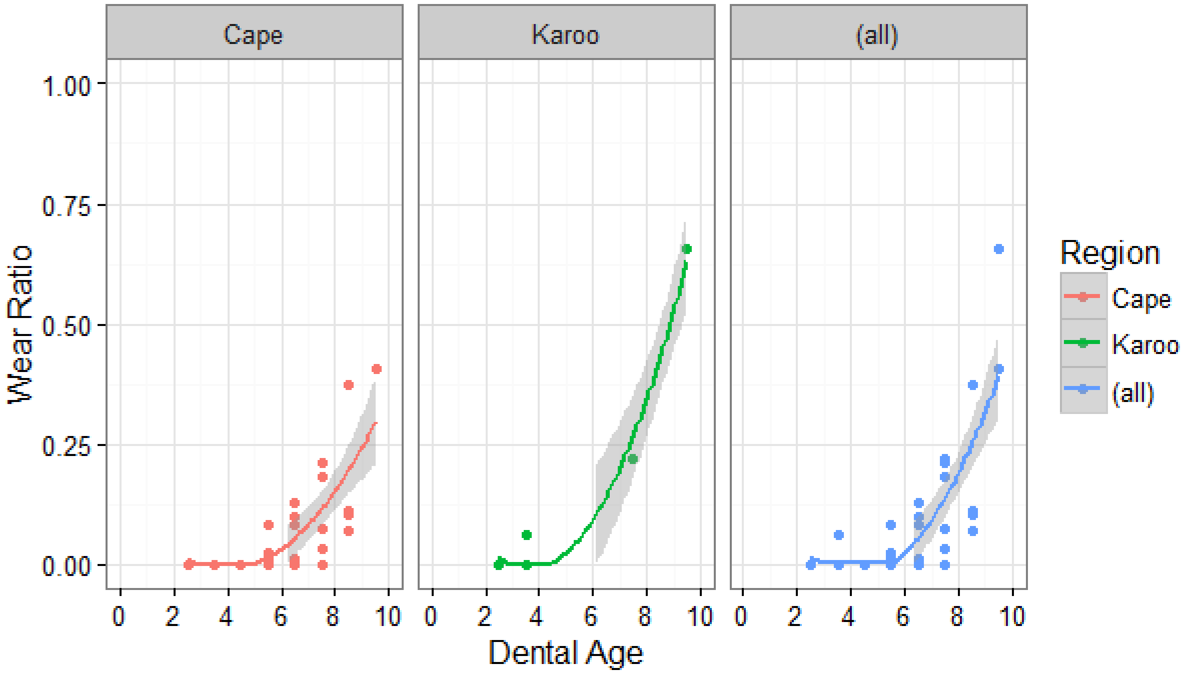

Figure 4.11 Plot of the polynomial regression model of dental wear for age in the upper fourth premolars.

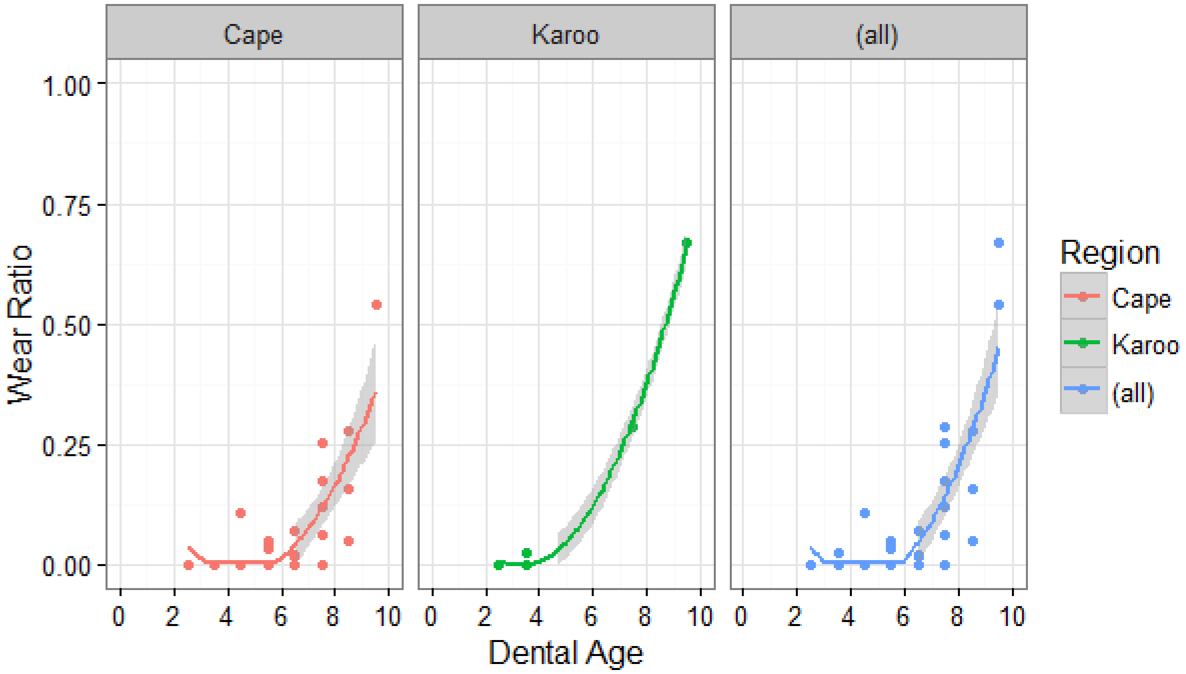

Figure 4.12 Plot of the polynomial regression model of dental wear for age in the lower fourth premolars.

4.5 ONSET OF WEAR

Onset of wear in each tooth type was determined by identifying the earliest age at which dentine was exposed. The onset of wear in each tooth type is summarized in Table 4.7.

Table 4.7 Dental age at onset of wear for each tooth category for the Cape, Karoo, and combined regions.

Tooth Type	**Dental Age at Onset of Wear**		
	Cape	Karoo	Combined
i^1	2.5 (n=2)	2.5 (n=2)	2.5 (n=4)
i_1	3.5 (n=1)	2.5 (n=3)	2.5 (n=3)
i^2	3.5 (n=2)	2.5 (n=1)	2.5 (n=1)
i_2	3.5 (n=1)	2.5 (n=2)	2.5 (n=2)
p^3	3.5 (n=1)	3.5 (n=2)	3.5 (n=3)
p_3	2.5 (n=1)	3.5 (n=3)	2.5 (n=1)
c^1	3.5 (n=2)	2.5 (n=1)	2.5 (n=1)
c_1	4.5 (n=1)	3.5 (n=2)	3.5 (n=2)
p^4	5.5 (n=2)	3.5 (n=1)	3.5 (n=1)
p_4	4.5 (n=1)	3.5 (n=1)	3.5 (n=1)

CHAPTER 5 : DISCUSSION AND CONCLUSIONS

5.1 DISCUSSION

5.1.1 METHODOLOGICAL LIMITATIONS

Clement's (2007) method of measuring dental wear is not suitable to determine the onset of wear and, by extension, weaning. Under the present method, wear is only recorded once dentine is exposed and therefore the appearance of wear is delayed from its actual onset. Wear on the first deciduous incisors, the earliest erupting teeth, begins in this sample around 2.5 years of age. Supplementation of the diet would be required long before 2.5 years. The 'appearance' of wear at 2.5 years, however, is an indication that solid foods are being consumed at least by this age. This is not to say that dental wear cannot capture the onset of wear and, therefore, the implied onset of weaning. Prowse and colleagues (2008) were able to identify the onset of weaning using a qualitative method. True onset of wear may be determined by examining the enamel wear facet; the area of polished enamel on the occlusal surface prior to dentine exposure. However, it is difficult to objectively measure this facet using quantitative methods. Quantifying deciduous dental wear using crown height bypasses this difficulty entirely. Mays and Pett (2014) have proven the viability of such a method in quantifying deciduous dental wear. However, there are two caveats to consider. First, the method is comparatively time consuming. Crown height is measured from photographs by taking multiple transects on the buccal surface of the crown. This process is not automated, so it must be manually performed for each transect on each tooth. The number of transects and their position must be adapted for each tooth type, depending on its morphology. Second, Mays and Pett (2014) only measured wear in the third and fourth deciduous premolars and Mays (2015) on first deciduous incisors The method would have to be expanded to determine the appropriate number and position of transects for the canines based on their unique morphology. Measuring wear from dentine exposure therefore remains attractive due to the relative ease and speed of the method.

Future studies using dentine exposure to quantify deciduous dental wear may benefit from incorporating qualitative data. One could convert the wear ratios to an ordinal scale and add categories for wear prior to dentine exposure. However, this approach suffers from the two limitations as other qualitative methods: difficulty comparing across populations and limited statistical testing. A more suitable alternative would be to add a single qualitative category to the wear ratios describing the presence or absence of an enamel wear facet. Presence/absence data is sufficient to identify onset of wear in each tooth type and, therefore, the onset of weaning. The presence/absence data could be integrated into the existing framework of the method with a slight adjustment. Individuals without enamel or dentine wear facets would still be assigned a value of zero. Those with evidence of enamel wear would advance to one. Wear calculated based on exposed dentine would be counted in addition. An individual in this sample with a wear ratio of 0.506, for example, would have a ratio of 1.506 under the new method. Condensing all descriptions of the enamel wear facet to a single number (one) may seem like an oversight. However, until normal patterns of deciduous wear are established, an further division would only create false categories and introduce subjectivity to the method. Limiting observations of enamel wear to a single value (one) balances concerns about subjectivity with the interpretive value of data on the onset of wear.

5.1.2 ERUPTION SEQUENCE: INTERPRETING THE CANINES

Wear on all tooth types followed the eruption sequence, with the exception of the deciduous canines. Canines displayed higher than expected wear in 19 of the 47 individuals in the sample. Despite the deviation, dental age was significantly correlated with wear in all teeth, including the canines (Tables 4.2 and 4.3). If the factor producing high wear on canines was inconsistent or transitory, it would have impacted the relationship between dental age and wear in this tooth type. Possible explanations for higher than expected wear in deciduous canines in this sample must therefore focus on factors exerting a prolonged or consistent effect. There are four possible candidates. First, the unique biomechanics of chewing in a developing child's mouth. Second, a difference in enamel thickness in deciduous canines compared to deciduous third premolars. Third, a cultural practice that produces non-nutritive wear. Fourth, a population level proclivity for the early eruption of deciduous canines in the mouth, out of sequence. The first three warrant consideration whereas the fourth is easily dismissed. The sequence of deciduous tooth eruption rarely varies and, when it does, does not vary consistently within a population (Woodroffe et al 2010).

Biomechanical differences in chewing between juveniles and adults narrow through time as juveniles gain morphological and behavioural maturity (for a review, Le Révérend et al 2014). However, research into the development of 'mature chewing' is sparse and only just emerging. Changes in juvenile mastication appear to begin rapidly after birth. The hard and soft tissue morphology of the mandible changes more in the first year of life than it does between the end of the first year and puberty (Le Révérend et al 2014). Early chewing displays mandibular movement overshoot; jaw movement in early life is more vigorous than required to masticate food (Wilson and Green, 2009). Between 9 and 18 months, this overshoot decreases dramatically, indicating the development of mature motor skills capable of adjusting speed and force for efficient mastication. Adult muscle coordination and rotary mastication appear to develop within the first two years (Le Révérend et al 2014). Deciduous canines begin eruption around 1.5 years of age, so they would only be affected by these changes for a six month period. In any case, none of these dramatic changes are easily linked to disproportionate wear on deciduous canines because of a paucity of bite force data. Measurements of bite force along the deciduous tooth row at various ages would provide the best data to link biomechanical changes in the jaw to wear. However, none have been completed to date. Mountain, Wood, and Toumba's (2010) study of bite force in children only compared values for deciduous incisors and premolars on a restricted age group, 3-6 years. The pattern of biomechanical development in the developing jaw is likely comparable between populations, however its interaction with food textures in early life render it an intriguing variable for further investigation in the field of deciduous dental wear.

Mahoney's (2013) study of enamel thickness found that in deciduous teeth, as with their permanent counterparts, average enamel thickness increases distally along the tooth row. Since enamel thickness increases distally rather than with the eruption sequence, deciduous canines have thinner enamel than third premolars despite the fact they erupt later. Mahoney's measurements revealed a large jump in thickness between the canine and third premolar compared to the second incisor and canine. Higher wear on deciduous canines, compared to third premolars, therefore aligns with patterns of enamel thickness within the deciduous dentition. The method used in this study to quantify dental wear only measures wear once the enamel is exfoliated and dentine is exposed. Thicker enamel slows the exposure of dentine, so teeth with thicker enamel appear to have less wear compared to those with thinner enamel under this method. Thicker enamel in the third and fourth deciduous premolars may explain why they are better represented by polynomial (quadratic) regression models. Wear appears non-existent as the enamel erodes, but once dentine is exposed wear increases dramatically through time. Mahoney's (2013) study was performed on a modern British sample and, to date, comparable research on average enamel thickness has not been published. Measuring enamel thickness along the tooth row in this southern African sample would be useful not only to test the above theory, but also to add to the body of research on patterns of enamel thickness in deciduous teeth.

Both hypotheses discussed above relate to the biological realities of the juvenile mouth. If correct, one would expect consistently high wear in deciduous canines across all populations. A number of modern studies have identified severe wear in deciduous canines compared to the rest of the tooth row (Kreulen et al 2010, Millward et al 1994). However, all of these studies use subjective wear-stage data which is difficult to compare to the present study. Clement and Freyne's (2012) study of deciduous dental wear in a Nubian population (present day Sudan) offers a comparable quantitative approach. They observed higher than expected wear in the second incisors and canines. Additional cross-cultural data collected using quantitative methods would be useful, however it is probable that the high wear observed in primary canines in southern Africa has a biological origin. The third possible explanation for high wear in the deciduous canines, cultural practices producing non-nutritive wear, has less merit. High anterior tooth wear in the Nubian sample was interpreted as non-nutritive wear caused by teething implements (Clement and Freyne 2012). This was plausible, given the high wear observed across all anterior teeth. However, higher than expected wear ratios in the present study are only observed in the canines. Wear could be explained by something gripped in the side of the mouth.

A survey of the ethnographic record in southern Africa, as well as historic and modern reports of deciduous dental wear fail to provide a potential cultural cause for high wear solely on deciduous canines.

5.1.3 FACTORS INFLUENCING WEAR

Contrary to expectations, region and date do not contribute to variation in dental wear among juvenile foragers in southern Africa. Ecological differences between the South African Cape and Karoo do not appear to impact early childhood diet in a manner that systematically influences dental wear. Similarly, dietary variation in this sample is not linked to change through time. Despite the body of research on the introduction of pastoralism to the region, and therefore an implied change in diet, the date of the burial did not significantly contribute to models predicting wear. Wear was significantly correlated with dental age, accounting for an average of 55% of the variation in wear in the sample. The remaining variation in wear warrants discussion. Dental age only captures the proportion of wear attributable to the length of time the teeth have been in occlusion. Most of the remaining variation in wear should be captured by dietary characteristics, however the variables investigated in this study do not appear to characterize change in diet. There are a number of possible scenarios to explain the lack of trends as well as the remaining variation in wear not explained by this study.

5.1.3.1 Unexpected Regional Uniformity

A lack of regional patterning in wear does not necessarily indicate a lack of regional distinction in diet. It is possible that cultural constraints on weaning practices and early childhood diet among LSA foragers in southern Africa were loose, resulting in varied diets with no clear patterning. Without tight cultural constraints, caregivers and children (through self-provisioning) could exercise individual agency to exploit a wide variety of resources. Ethnographic analogy suggests that self-provisioning may not be a significant factor in this group, as self-provisioning among !Kung children was not observed by ethnographers (Lee, 1979). However, ethnographic analogy should always be treated with caution. Konner (2005) emphasizes the variability of childcare practices among cultural groups and other hunter-gatherer groups encourage children to forage quite young. Among the Hadza in Tanzania, for example, self-provisioning begins as soon as the child is weaned, between two and three years of age (Crittenden et al, 2013). Howell (2010) suggests that permission to self-provision is determined by the environment. She asserts that the dangers of the Kalahari desert discourage early independence. If Howell's theory is true, applying the !Kung timeline for self-provisioning to foragers in the Cape and Karoo is unadvisable. The agency of both adults and children over food choice in this population should therefore be considered. Significant dietary variation would be possible regardless of the degree of child versus adult control of diet in early childhood. Even with ecological differences between the Cape and Karoo, consuming a wide variety of flora and fauna in each region would drown out unique regional signatures in the resultant ‘noise’. Markedly different regional diets could produce similar patterns of wear. For example, wear due to the regular exploitation of fibrous geophytes in the Karoo could be ‘matched’ by sand introduced to the diet in the Cape due to the heavy consumption of shellfish. 'Noise' generated by exploiting diverse flora and fauna in both regions may also explain the remaining 45% of variation in dental wear unaccounted for by dental age. One isotopic study of diet in the Karoo found significant dietary variation between biomes and settlements (Lee-thorp et al., 1993). Perhaps such variation was prevalent in the Cape as well. Dental wear only picks up dietary differences when there are distinct differences in the abrasiveness of regularly consumed foods. A diet with a variety of textures would be difficult to characterize with dental wear data alone.

Conversely, a lack of distinction in wear between the Cape and Karoo could be due to tight cultural constraints on early childhood diet. Early childhood diets often follow cultural prescriptions of 'healthy foods', highlighting cultural similarities. If foragers in the Cape and Karoo were both part of the same cultural group with a strictly prescribed diet in early life, then they may have selected similar foods despite ecological differences. This theory holds weight because of previous success detecting regional differences in diet among foragers using dental wear (Lieverse et al., 2013; Littleton et al., 2013; Molnar et al. 1989). Dental wear data has proven to be capable of distinguishing regional diets and so the absence of regional patterning between the Cape and Karoo suggests dietary uniformity between regions. This scenario does not explain the remaining 45% of variation in wear not captured by dental age, it only addresses the lack of regional patterning.

Dental wear data alone cannot determine whether the lack of regional patterning is a result of loose or tight cultural constraints on early childhood diet. However, both theories could be tested with the isotopic analysis of dentine. If isotopic signature of both the Cape and Karoo samples are regionally distinct, the former hypothesis would be supported. If the signatures were indistinguishable, the latter. An isotopic study would also expand the sample, particularly in the Karoo. The juvenile sample from the Karoo in this study was small and adult remains are more frequently recovered in the archaeological record. Permanent teeth can be used in isotopic studies to examine childhood diet because they represent tissue formed in early life. Only one isotopic study has been conducted on LSA foragers in the Karoo, focusing solely on adult diet. Additional dietary research on juvenile diets in the LSA is required, in the Karoo in particular.

5.1.3.2 Unexpected Temporal Uniformity

This study did not yield conclusive evidence supporting of any one of the theories on the introduction of herding to southern Africa and corresponding dietary change. A lack of change in wear through time, however, lends credence to two perspectives on this debate. The first is that pastoralism was difficult to adopt and therefore its introduction to the area had minimal impact on the diet of existing foraging groups. This supports Smith's (1998) view of the spread of pastoralism in southern Africa. Second, the data support the theory that pastoralism in southern Africa was not adopted in the 'classic' sense where foraging is assumed to be usurped by a pastoral lifeway. If herding was adopted on a small scale, without full conversion to a traditional pastoralist economy, then the new practice may have had minimal effect on diet and dental wear, as Sadr (2013) and Russell and Lander (2015) suggest. Similarly, if animal domesticates were not regularly exploited for meat, but instead for milk, labour, or other resources, it is possible that the adoption of herding would have little to no effect on wear or diet.

5.1.3.3 Biomechanical Considerations

Variation in wear in this sample may be shaped by additional factors, beyond dietary variation. The biomechanical development of chewing in early life warrants attention. As described above, marked changes occur in jaw morphology, muscle coordination, and motor skills in the first two years of life. Further dynamism is added by the staggered eruption of deciduous and permanent teeth in early life. Forces exerted on teeth adjust during mastication as the composition of the mouth changes. These biological changes affect all individuals and should have a relatively uniform effect on wear across populations. However, with the exception of the eruption schedule, there is evidence that the development of adult mastication is impacted by food choices during early diet. Le Révérend and colleagues' (2014) review of the literature on the development of adult mastication suggests that the introduction of foods of varying textures in early diet impacts orofacial development. Differences in food type and preparation determine dietary texture and abrasiveness, which directly impacts wear. However, dietary choice may magnify the existing effects of biomechanical variables where cultural rules influence the variety of textures given to children in early life. This theory is difficult to test, particularly if food preparation and not choice is the primary predictor of food texture in a given group. An isotopic study would not shed light on food texture in this case. Studies of bite force across the tooth row through time would help establish how biomechanical changes impact wear throughout development. However, it is difficult to artificially control childhood diet in an experimental setting.

5.1.4 INCLUSION OF THE KAROO (KOFFIEFONTEIN) SUBSAMPLE

Few studies exist comparing foragers in the Cape and Karoo, making it difficult to determine if the populations should be considered together. This study suggests that the comparison of the Karoo individuals from Koffiefontein with LSA individuals from the Cape is appropriate. Craniometric (Morris, 1992b; Stynder et al., 2007), dental morphological (Irish et al, 2014) and archaeological (Morris, 1992b) studies have already suggested similarities between the Cape sample and individuals from Koffiefontein. The regional uniformity in dental wear presented in this thesis may indicate a cultural connection, at least regarding food choice in early childhood. The lack of regional distinction, as discussed above, suggests either shared dietary choices or a mirrored exploitation of a wide variety of resources in both regions. The Koffiefontein material represents some of the youngest material analyzed in this study, dating between 550 and 50 BP. Its date, combined with the presence of animal domesticates at the site (Morris, 1992b), makes the subsample the most likely to be affected by the introduction of pastoralism and its progressive spread through southern Africa. However, regional and temporal differences between the Cape and Karoo are absent. After the introduction of pastoralism to the Karoo, this group maintained hunter-gatherer diets comparable to those on the coast.

Could the lack of regional and temporal distinction in early childhood diet indicate a shared cultural identity between the Koffiefontein sample (Karoo) and the Cape? As of yet, this is unclear. The present study is one of two directly comparing Cape and Karoo populations. The present study indicates homogeny in diet, however, Cameron's (2013) thesis analyzing activity patterns between the Cape and Karoo found differences of either an ecological or cultural origin. Dental wear data does not support regional differences, however an average of 45% of the variation in dental wear in this sample remains unaccounted for. If this variation has a cultural origin, it suggests that culture in southern Africa during the Holocene was not defined along ecological lines. The lack of temporal patterning in this study shows that the Koffiefontein sample follows a diet indistinguishable from Cape hunter-gatherers, to the extent that it can be characterized using deciduous dental wear. Considering the Koffiefontein (Karoo) individuals alongside those in the Cape is not only warranted, it is vital. Until evidence emerges to divide these two groups, the interrogation of how they retain similarities across space and time remains a pressing question. A more comprehensive study of Karoo populations is warranted to explore the connections among foragers occupying the diverse landscapes of southern Africa.

5.2 CONCLUSIONS AND FUTURE DIRECTIONS

Weaning practices among foragers in southern Africa were not elucidated by the dental wear data in this study. Neither the onset nor duration of weaning were discernible because the method did not capture wear prior to dentine exposure. The limitations of the present method should not incite a disregard for dental wear research. Dental wear studies, for all their faults, remain worthwhile to the study of diet because of their wide applicability; they are non - destructive, easy to implement, and inexpensive. Modifying Clement's (2007) method of measuring dental wear using dentine exposure would allow the onset of food supplementation to be determined. Wear prior to dentine exposure could be subsumed under the value 'one' and subsequent wear measured by dentine exposure added to this value. Such a modification would allow the 'true' onset of wear to be determined while preserving the advantages of a quantitative method.

Only one trend was evident in the dental wear data presented in this study: higher than expected wear in the deciduous canines. The degree of dental wear on the deciduous canines departed from the eruption sequence in 40% of individuals in the sample. There are a number of possible explanations for this trend, however the most plausible is the variation in enamel thickness along the deciduous tooth row. Enamel thickness does not pattern along the eruption sequence, rather, it increases distally along the tooth row. Deciduous canines therefore have significantly thicker enamel compared to the tooth erupting before them, the deciduous third premolar. Despite this knowledge, a pattern of high wear in the deciduous canines has not been observed in other studies. There is a scarcity of data on deciduous dental wear in the literature. The difficulty in explaining this trend highlights the need to study the pattern of wear in deciduous teeth. Without an understanding of the breadth of variation in deciduous dental wear, it is difficult to isolate cultural and biological influences. A cultural explanation for high wear in the deciduous canines is possible, however the literature lacks a plausible scenario to produce this pattern of wear in juvenile foragers.

Variation in dental wear in this sample did not follow the expected regional and temporal patterning. A lack of regional patterning between the distinct ecological regions of the Cape and Karoo suggests dietary uniformity. However, the strength of that interpretation is limited by the nature of dental wear data. It is difficult to determine whether similar dental wear signatures reflect similar diets in the sample. A lack of regional patterning in dental wear could be an artefact of dental wear data if it is the result of a wide exploitation of resources (of varying textures) in both the Cape and Karoo. Such loose cultural constraints over early childhood diet have implications for early self-provisioning, something that contradicts prevailing ethnographic analogy with the !Kung. Regional similarities in diet could just as easily be the result of tight constraints on early childhood diet in the Cape and Karoo by a shared cultural group. Temporal patterning bears on the literature surrounding the introduction and spread of pastoralism to southern Africa. A lack of temporal trends may be due to the rejection of pastoralism by foraging groups in southern Africa or its non-traditional adoption. Either way, this study suggests that the introduction of pastoralism to the region did not significantly impact diet in this region. If it did, it did not change what foragers chose to feed their children in early childhood. Interpretations concerning childhood diet in this sample, given the lack of regional and temporal trends, must be confirmed by additional data. An isotopic study could verify any of the hypotheses suggested in this thesis and expand the sample size. This is particularly important in the Karoo, where the limited number of juveniles recovered in region restricted the sample size in the present study.

Around 45% of the variation in dental wear in this sample remains unaccounted for. The variation could be explained by the dynamic changes in the juvenile mouth in early life. Our understanding of how the development of adult mastication patterns impacts dental wear through time is limited, however it is influenced by the textures of food introduced to the diet. This makes it relevant to a discussion of diet. In order to determine the influence of the changing juvenile mouth on dental wear, comparable studies of deciduous dental wear are necessary in addition to biomechanical studies of bite force across the deciduous tooth row at different stages of development. Currently, it is unclear whether all studies of wear on deciduous teeth suffer from the same issue. Namely, unexplained variation and difficulty isolating dietary variables influencing dental wear.

What can this study say about childhood in foraging groups in southern Africa? It can comment on regional similarities and the treatment of Cape and Karoo populations. Few studies have compared Cape and Karoo foragers and, as a result, it is unclear how to treat Karoo samples in relation to those on the Cape. The Karoo sample in this study, drawn from sites around Koffiefontein, is both regionally and temporally distinct from the Cape sample. However, dental wear data in this study suggests that childhood diet was not distinctive between groups. Further studies are necessary to determine if this homogeny extends to other cultural facets. If populations in the Cape and Karoo maintained similarity across space and time, further investigation into potential cultural links between the two are warranted.

The dental wear data presented in this study offers limited conclusions. At the onset of the study, three variables were predicted to influence dental wear in this sample: ecological differences between the Cape and Karoo, progressive temporal changes in diet due to the introduction of pastoralism, and the length of time teeth had been in occlusion (dental age). Of the three, only dental age was significantly correlated with wear. This could suggest the utility of dental wear as an age estimation technique. However, estimation of age based on degree of dental wear was not possible in this sample, given that only an average of 55% of variation in wear was accounted for by dental age alone. Inferences regarding early childhood diet in this sample are marginally better, however most are interpretations based on the lack of trends rather than any clear patterning. This study should be viewed as a springboard for two newly developing areas of study. First, it emphasizes the need for future studies of childhood and childhood diet among foragers in southern Africa, particularly in the Karoo. Isotopic studies would help clarify the lack of regional and temporal variation observed in this project. They would also clarify the timing and duration of weaning in this region. Second, it adds to the small body of data on deciduous dental wear. Few studies have examined deciduous dental wear and fewer still have attempted interpretations using a quantitative method. As this body of research grows, the breadth of variation in wear in early life will become clear. Quantitative data will allow for cross-populational comparison as well as an examination of how deciduous dental wear patterns differ from their permanent counterparts.

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APPENDIX

Table A.1 Results of Mann Whitney U (Wilcox Rank Sum) test checking left/right asymmetry in wear ratios.

Tooth Type	W	p-value
i^1	160	0.7479
i^2	118	0.3568
c^1	250.5	0.6193
p^3	687	0.3702
p^4	625	0.9856
i_1	121	0.4150
i_2	267	0.7298
c_1	326	0.8308
p_3	779	0.5464
p_4	672.5	0.8959

Table A.2 Wear ratios for each individual in the sample.

Individual	**i^1**	**i^2**	**c^1**	**p^3**	**p^4**	**i_1**	**i_2**	**c_1**	**p_3**	**p_4**
ALB 51				0.843	0.405					0.539
ALB 116A				0.321	0.000		0.689	0.535	0.177	0.105
ALB 122	0.750	0.588	0.000	0.207	0.083	0.766	0.395	0.291	0.130	0.047
ALB 132				0.128	0.032	0.567	0.552	0.459	0.185	0.174
ALB 133				0.562	0.102			0.432	0.317	0.158
ALB 135	0.000					0.000				
ALB 137	0.237	0.274	0.026	0.000	0.000		0.032	0.000	0.000	0.000
ALB 138	0.234	0.000	0.000	0.000	0.000			0.000	0.000	0.000
ALB 175	0.560	0.490	0.158	0.085	0.012	0.625	0.415	0.379	0.049	0.041
ALB 176				0.007	0.000				0.000	0.000
ALB 181		0.437	0.290	0.101	0.009			0.454	0.068	0.017
ALB 183				0.443	0.209				0.389	0.118
ALB 193	0.446	0.317	0.190	0.000					0.064	0.000
ALB 195B				0.000	0.000	0.000	0.000	0.000		
ALB 205	0.856	0.833	0.693	0.514	0.181		0.703	0.624	0.455	0.254
ALB 236	0.347	0.903	0.130	0.114	0.022	0.681	0.483	0.218	0.086	0.030
ALB 266				0.062	0.000				0.061	0.000
ALB 300	0.137	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.012	0.000
ALB 318				0.150	0.127					
ALB 322	0.000	0.000	0.000			0.000	0.000	0.000	0.000	
ALB 325				0.053	0.098				0.094	0.070
ALB 350			0.459	0.145	0.068					
MMK 199	0.265	0.218	0.471	0.263	0.059	0.484	0.259	0.511	0.093	0.023
MMK 200					0.656					0.670
MMK 205	0.127	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000
MMK 207				0.000						
MMK 214	0.000	0.000	0.000	0.000	0.000	0.173	0.000	0.000	0.000	0.000
MMK 223		0.347	0.000	0.012		0.272	0.000	0.106	0.026	0.000
MMK 225	0.075	0.000	0.000	0.000	0.000	0.205	0.179	0.000	0.000	0.000
MMK 230			0.517	0.504	0.220				0.369	0.284
MMK 238				0.018	0.000	0.000	0.000	0.000	0.011	0.000
MMK 246		0.477	0.078	0.000	0.000	0.270	0.232			
WSK1 Child						0.000	0.000		0.000	
SAM-AP 4207		0.462	0.138	0.363	0.071		0.165	0.162	0.137	0.062
SAM-AP 6052						0.417	0.431	0.274	0.015	0.000
SAM-AP 6053				0.737	0.374			0.551	0.261	0.278
SAM-AP 6054B	0.388	0.546	0.324	0.080	0.082			0.238	0.086	0.020
SAM-AP 6054C	0.230		0.000	0.000	0.000	0.000	0.000	0.000	0.000	
UCT 190/217K	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000
UCT 190218										0.836
UCT 191									0.043	0.000
UCT 196	0.446	0.000	0.000	0.000	0.000	0.183	0.000	0.000	0.000	0.000
UCT 210	0.446	0.328	0.270	0.013	0.000	0.460	0.234	0.000	0.021	0.000
UCT 247					0.112				0.398	0.049
UCT 346	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
UCT 388	0.370						0.452	0.000	0.000	
UCT 437	0.179	0.403	0.090	0.015	0.000	0.351	0.406	0.130	0.061	0.000

Table A.3 Adjusted wear ratios for each individual in the sample.

Individual	i^1	i^2	c^1	p^3	p^4	i_1	i_2	c_1	p_3	p_4
ALB 51				1.000	0.480					0.639
ALB 108	1.000							0.000		
ALB 116A				0.466	0.000		1.000	0.776	0.256	0.153
ALB 122	0.989	0.775	0.000	0.273	0.109	1.010	0.521	0.384	0.171	0.063
ALB 132				0.226	0.057	1.000	0.973	0.809	0.326	0.307
ALB 133				1.278	0.231			0.982	0.721	0.359
ALB 135										
ALB 137	1.000	1.156	0.113	0.000	0.000		0.138	0.000	0.000	0.000
ALB 138	1.000	0.000	0.000	0.000	0.000			0.000	0.000	0.000
ALB 175	0.945	0.827	0.266	0.143	0.021	1.054	0.700	0.639	0.083	0.069
ALB 176				2.000	0.000				0.000	0.000
ALB 181		1.000	0.662	0.231	0.022			1.036	0.155	0.040
ALB 182		1.000	0.412	0.266	0.031				0.106	0.103
ALB 183				1.065	0.504				0.934	0.283
ALB 193	1.000	0.709	0.426	0.000					0.144	0.000
ALB 195B										
ALB 205	1.000	0.973	0.809	0.601	0.212		0.822	0.729	0.531	0.296
ALB 236	0.675	1.756	0.254	0.221	0.043	1.324	0.939	0.425	0.168	0.059
ALB 266										
ALB 300	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.188	
ALB 318				1.000	0.850					
ALB 322										
ALB 325				0.695	1.297				1.239	0.921
ALB 350			3.166	1.000	0.472					
MMK 199	0.708	0.583	1.257	0.704	0.158	1.291	0.691	1.364	0.250	0.062
MMK 200										
MMK 205	1.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000
MMK 207										
MMK 214										
MMK 223		1.274	0.000	0.044		1.000	0.000	0.390	0.097	0.000
MMK 225	0.536	0.000	0.000	0.000	0.000	1.463	1.279	0.000	0.000	0.000
MMK 230			1.166	1.137	0.498				0.833	0.640
MMK 238										
MMK 246		1.766	0.289	0.000	0.000	1.000	0.859			
WSK1 Child										
SAM-AP 4207		1.471	0.442	1.157	0.229		0.528	0.516	0.438	0.229
SAM-AP 6052						1.000	1.034	0.657	0.037	0.000
SAM-AP 6053				1.475	0.749			1.104	0.524	0.557
SAM-AP 6054B	1.000	1.406	0.835	0.208	0.212			0.613	0.223	0.052
SAM-AP 6054C										
UCT 190/217K										
UCT 190/218										
UCT 191										
UCT 196										
UCT 210	0.984	0.725	0.596	0.030	0.000	1.015	0.517	0.000	0.046	0.000
UCT 247					0.282				1.000	0.124
UCT 346										
UCT 388	1.000						1.220	0.000	0.000	
UCT 437	0.675	1.521	0.343	0.057	0.000	1.324	1.534	0.491	0.232	0.000