SIMS oxygen isotope analysis of human dental tissues from Fidler Mounds (EaLf-3), MB: mobility during Manitoba's Middle and Late Woodland periods

BY

Rachel E. ten Bruggencate

A Thesis
Submitted to the Faculty of Graduate Studies
In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF ARTS

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Abstract

Secondary ion mass spectrometry (SIMS) was used to obtain stable oxygen isotope data from the dental tissues of 12 individuals once interred at Fidler Mounds (EaLf-3), a cemetery mound site located in south-central Manitoba, 19 kilometers north of Winnipeg. Fidler Mounds was originally constructed c.1800BP and was utilized as a burial ground by precontact peoples in Manitoba for approximately 1000 years thereafter. The use of SIMS allowed the researcher to obtain several *in situ* $\delta^{18}O$ values from each individual's intact cementum, dentin and enamel. These values show that mobility patterns during Manitoba's middle and late Woodland period were extremely complex and varied. Additionally, intra-tissue $\delta^{18}O$ variability recorded through SIMS analysis indicates that traditional mass spectrometry may not be appropriate for assessing migration patterns within highly mobile populations.

This thesis is dedicated to the men, women and children buried at Fidler Mounds long ago who have had their rest disturbed and who have contributed far more than I to this research.

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Chapter 1: Introduction

The analysis of human dental skeletal tissues is an integral part of understanding the health and lifestyles of past populations. Through morphological, pathological, histological and chemical analyses of preserved archaeological bones and teeth, specialists can generate and support hypotheses regarding mobility, growth and development, diet, warfare, social structure and overall health within the represented people group (Turnbaugh *et al.,* 2001). And the ways in which archaeological human hard tissues can reveal the past to researchers continue to multiply. With almost every new publication in the field, new innovations in human odontological and osteological analysis are allowing archaeologists and physical anthropologists to say more about the way people lived in the past and to support these statements with a greater degree of certainty.

Stable oxygen isotope analysis of human tooth and bone tissue is a relatively recent innovation in archaeology and physical anthropology. Scholars first noticed the correlation between drinking water and body water oxygen isotope levels in mammals during the mid 1980's (Longinelli, 1984; Luz *et al.* 1984). Later, it was established that the hard tissue oxygen isotope ratios of most mammals are in equilibrium with body water oxygen isotope ratios at the time of hard tissue formation (Longinelli, 1984; Luz *et al.* 1984; 1990; Levinson *et al.*, 1987; Luz and Kolodny, 1989). Because of the important role played by climate in determining the oxygen isotope ratio of drinking water resources, oxygen isotope analysis of excavated human and faunal hard tissue quickly became a powerful tool for monitoring ancient climatic fluctuations and mammalian mobility patterns (Luz *et al.* 1990; Fricke *et al.,* 1995; Bowen *et al.*, 2005). The

application of stable oxygen isotope analysis of human hard tissues has been particularly helpful in confirming or rejecting migration hypotheses drawn from archaeological contexts which exhibit non-conclusive, secondary evidence of long-distance human movement (White *et al.,* 1998; 2001; Dupras *et al.*, 2001; Evans *et al.,* 2006; Price *et al.*, 2007).

Several late pre-contact sites in southern Manitoba exhibit this type of artifact-based evidence for human migration (Saylor, 1976; Buchner, 1988). One of the most notable of these is the Lockport site (EaLf-1) located on the Red River several kilometres north of Winnipeg, Manitoba (Buchner, 1988; McKinley, 2001; Flynn, 2002). Some ceramic materials excavated from this site show an undeniable foreign influence during several periods of habitation at Lockport (McKinley, 2001), while the introduction of maize agriculture to the Lockport site c. AD1200 is thought by many to be indicative of an influx of migrants from the south into the northeastern Plains in response to climatic fluctuations (Flynn, 2002). Lockport's associated cemetery site, Fidler Mounds (EaLf-3), also exhibits several features seemingly indicative of migration into the area during its formation. Miniature vessels interred at the site do not resemble local ceramic wares (Saylor, 1976), while the hard tissue chemistry of some of the individuals interred in the mounds indicates that they may have followed a maize agriculturalist lifeway, which leads Garvie (1993) to identify them as potential migrant individuals.

All of this evidence, however, can be produced by social processes other than long-distance human migration. Diffusion and/or long-distance trade networks, for example, can carry goods and ideas across a continent without necessitating the degree of individual mobility detectable by stable oxygen isotope analysis (Adams *et al.*, 1974). It

is possible that similar mechanisms, rather than long-distance human migration, influenced material culture and subsistence pattern changes in the precontact northeastern Plains.

To clarify the potential for long-distance human migration to have played a role in the context of the late precontact period of the northeastern Plains, stable oxygen isotope analysis of 12 individuals excavated from Fidler Mounds was undertaken. The method of analysis utilized by this study, secondary ion mass spectrometry (SIMS), made it possible to conduct several *in situ* analyses of the intact dentin, cementum, and enamel of each individual, allowing changes in lifetime body chemistry to be monitored. As well, comparisons of inter-individual results for each tissue allowed variability in region of origin and lifetime residence to be assessed.

Organisation of the Thesis

This thesis begins with a discussion of the Midwestern Taxonomic System, and its modified application within Manitoban Archaeology. This culture historical approach is the foundation of most migration hypotheses pertaining to the precontact northeastern Plains. This is followed by a review of the history of migration as an explanatory device in archaeological theory worldwide and specifically within Manitoban archaeology. The next chapter presents the rationale behind stable isotope analysis of human remains as a tool to explore various aspects of past lifeways, including mobility and diet. This is followed by a contextualised discussion of the culture history of the late precontact northeastern Plains with a focus on identified mound burial complexes and the notion of

direct and indirect cultural interaction as a culture-shaping process in the area. The next chapter, which outlines the materials and methods utilized to collect data for this thesis, gives the reader a thorough introduction to the temporal, geographical and cultural context of Fidler Mounds and outlines previous studies aimed at interpreting various aspects of this fascinating site. This is followed by a step-by-step discussion of the sample preparation, SIMS analysis and ancillary instrumental techniques required to produce interpretable stable oxygen isotope results from archaeological dental tissue. These results and supporting statistics are presented in graphic format in the next chapter. This is followed by an archaeologically contextualized discussion of the stable oxygen isotope data with emphasis on the degree to which they support previous hypotheses regarding human mobility in the area during the late precontact period. This thesis concludes by synthesizing these interpretations with what is currently understood about human mobility, burial practices and culture change during the late precontact period on the Northern plains. The potential for further research and refinement of techniques in this study area will also be discussed.

Chapter 2: Literature Review

Technological change and intricate inter-group relationships characterize the Middle to Late Woodland period in the northeastern plains and peripheral parkland and boreal forest zones (Syms, 1977). The archaeological record from this era is incredibly complex and paints a picture of changing subsistence patterns, long-distance trade, ideological exchange and stylistic fluctuation, all of which are potentially indicative of cross cultural contact (Syms, 1977, Johnson and Johnson, 1998; Meyer and Hamilton, 1994).

Archaeologists studying Precontact North America have employed numerous theoretical paradigms in an attempt to interpret the complexity and subtlety of this period's archaeological record. In southern Manitoba, the earliest archaeological interpretations with solid theoretical underpinnings were framed within the classificatory-descriptive Culture History paradigm (Syms, 1978). This paradigm maintains that the archaeological record can only be understood by breaking it down into geographically and stratigraphically contextualized assemblages of specific material culture forms which occur together consistently (Childe, 1929). These assemblages are taken to represent the activities of a single people or culture group, which is assigned a name for future reference. The archaeological record is thus divided into a series of temporally and geographically distinct "cultures" based on material remains.

The Midwestern Taxonomic System (MTS) is a slightly modified approach to Culture History that was often applied in early North American archaeology. It consists of a hierarchically organised system of classifications of varying specificity. These

classifications are applied to excavated archaeological materials to clarify relationships between people groups in the past. The MTS has been revised numerous times since its introduction by McKern (1939) in the early part of the last century. Terminological definitions vary across time and from author to author, even within the relatively specialized field of Manitoba archaeology. An in depth discussion of these revisions is beyond the scope of this thesis. However, to understand the multiple formulations of Manitoba culture history, a brief discussion of some of the terminology to be used in the following section is required For the sake of simplicity, the classificatory system devised by Syms (1977), which varies only semantically from McKern's (1939) original formulation of the MTS and is currently preferred by many archaeologists in Manitoba, will be followed.

The most basic and specific level of cultural classification within Syms' (1977) archaeological taxonomy is the *component*. This term is applied to the material culture left at a specific site by a group of people over a single occupation. Assigning individual artefacts from a site to a specific component can be quite difficult, if not impossible, especially at multi-component surface sites, or sites with collapsed stratigraphy. In such cases, assigning artefacts to a specific component often depends upon comparisons to material from known, single component sites or sites with identifiable cultural horizons. To complicate matters, components left by nomadic hunter-gatherers, such as those who occupied Manitoba for much of the precontact era, often represent the remains of seasonal or resource specific behaviours, which have different material culture signatures (Syms, 1977). Thus, the activities of one people group over a relatively short period of time may be represented by multiple components.

The next highest level of classification within the MTS accounts for this potential diversity. A *complex* is made up of all of the components left by a single people over their entire geographic range within a short enough time-span to preclude major shifts in culture or technology (Syms, 1977). In early Manitoba archaeological literature, complexes are most commonly defined within rigid geographical and temporal boundaries. Scholars now acknowledge the gradient nature of relationships between complexes over time and space (Syms, 1977). Geographically or temporally adjacent complexes or complexes with shared cultural affiliations may be different from one another in some important aspects, but may also share many similarities.

In some cases, such closely related complexes may be assigned to a single *composite*. This designation has been encumbered with a plethora of names throughout the development of Manitoba archaeological literature and may be, depending on the researcher, referred to as either a "culture", "phase" or "variant" (MacNeish, 1958; Krause, 1969; Stoltman, 1973; Syms, 1977). Composites in early Manitoba archaeology were at one time defined with much the same rigidity as complexes, especially in terms of possible multi-composite geographic overlap (Syms, 1977). Any variation in material culture within a bounded geographic area was traditionally identified as the result of intracomposite changes over time (Syms, 1977). The possibility of multicomposite utilization of a single region was not considered. With the introduction of the co-influence sphere model by Syms (1977), however, the idea was introduced that multiple groups likely co-existed in many areas of Manitoba. The application of the co-influence sphere model, in which the effects of culture contact and overlap are considered, finds considerable support in the ethnography of Aboriginal groups in Manitoba, which

suggests that some areas of the province may have been utilized – to varying degrees – by more than a dozen people groups over relatively short periods of time. According to Syms (1977), there is no reason to suspect that this was not also the case in precontact Manitoba.

The next highest level of classification is the *configuration*, which is the term applied to composites which are similar enough to each other to suggest either a distant, shared ancestry or convergence due to co-habitation or similar resource pursuit strategies, but too dissimilar to be assigned to a single composite. As an example, Syms (1977) identifies the Blackfoot confederacy, which was an example of fission and parallel development on the part of the Blackfoot, Piegan and Blood peoples, and convergence on the part of the Sarsi.

The final, highest level of classification is the *pattern*, which refers to any geographically and/or evolutionarily related group of composites which shares material culture evidencing similarities in broad cultural characteristics such as food procurement or settlement pattern. For example, Syms (1977) points to the northern plains nomadic hunting pattern.

Migration Theory and Manitoba Archaeology

Migration is defined as the movement of an individual or group of people from one location to another (Anthony, 1990). Anthropologists studying human movement have defined several types of migration. Migrations can be short or long distance, one-way or two-way, individual or group; they can proceed in a leapfrog fashion with mobile groups

moving in the same direction alternately overtaking one another, or they can proceed in a steady migration stream (Anthony, 1990). In some cases, migrations will combine elements of more than one of these categories. Most of what is known about the causes and effects of migrations is derived almost exclusively from modern studies of current population movements (Anthony, 1990). The effect of different kinds of migration on the archaeological record, to say nothing of migrations which blend characteristics of more than one type, has been hotly debated in recent literature (Anthony, 1990). The degree to which migration had any sort of impact on the archaeological record at all has been debated since the very first applications of formal archaeological theory in the early twentieth century (Trigger, 2006). Different theoretical camps have alternately championed and decried migration's status as an important factor in the formation of the archaeological record. As domination of the major vehicles of archaeological discourse have fluctuated between paradigmatic viewpoints, so too has the importance of migration to prevalent interpretations of material culture ebbed and flowed (Trigger, 2006).

The earliest applications of Culture History and the Midwestern Taxonomic System to archaeological interpretation were heavily coloured by prevailing anthropological sentiments regarding migration during the mid to late nineteenth and early twentieth centuries. During this period, similarities in practices and material culture between people groups were viewed, with very few exceptions, as the result of culture contact through migration or diffusion (Childe, 1927; 1929; Trigger, 2006). V. Gordon Childe (1927; 1929), the main proponent and credited source of the Culture History paradigm, viewed every similarity between archaeologically recovered material culture from different areas of Europe, Asia and Africa as the result of population movement and

diffusion over huge geographical distances. Unless excavated material culture was utterly unique, the possibility of convergence and independent invention was not considered (Childe, 1927; Trigger, 2006). In North America, this anthropological fixation with mobility as the root of shared material culture was often mingled with dominant, anti-Aboriginal discourses in its application to the archaeological record (Mann, 2003). Anything which seemed to the archaeologists of the time too complex to be attributed to precontact Aboriginals was interpreted as the work of migrants from haunts as exotic as Wales, Israel or the lost continent of Atlantis (Mann, 2003; Syms, 1978; Trigger, 2006).

The application of migration theory to material culture in Manitoba and surrounding areas has an inconsistent and convoluted history. Although some nineteenth and early twentieth century authors, such as Bryce (1904) interpreted certain aspects of the province's archaeological record through the lens of now-discredited theories such as that of the "mound builders", Manitoba archaeology escaped the worst of this early, racist migrationism, as it was still very much in its infancy during this period (Syms, 1978). Formal archaeological excavations in the province at the time were few and far between. When they did occur, excavations were characterized by poor stratigraphic control and very poor documentation; subsequent interpretations were speculative at best (Syms, 1978). Field notes were rare, artefacts were often distributed among private collectors and materials that did make it into museum collections were often inadequately or confusingly labelled (Syms, 1978). Informal and possibly unintentional excavations, however, seem to have flourished during this poorly regulated era. Many sites, especially the highly visible cemetery mounds of Southern Manitoba, appear to have been

extensively disturbed by looting and construction prior to formal investigation in the later half of the twentieth century (Syms, 1978).

While the scarcity of formal, recorded investigations into Manitoba archaeology during this era of dominant racist theoretical paradigms was likely beneficial to following local academic discourse in some ways, the corresponding paucity of formal data from early excavations is frustrating to the modern scholar. Put simply, there is a shortage of useful data from excavations conducted in Manitoba prior to the 1940s. Archaeologists excavating sites with research histories dating back to this period are faced with piecing together the past using highly disturbed, incomplete assemblages.

Changes in archaeological theory that originated in the intellectual centres of both Europe and North America during the late forties through the sixties were the result of a growing post-war dissatisfaction with Culture History's strictly descriptive, particularist nature (Trigger, 2006). While Culture History had revolutionized the manner in which archaeologists thought about material remains, it did not advocate for much beyond the careful recording of artefact proveniences, identification of consistently juxtaposed material culture and the application of blanket migration/diffusion interpretations to the archaeological record (Childe, 1927; 1929; Trigger, 2006). The schools of Cultural Ecology and Processual Archaeology both rose up out of the desire to discover the *in situ*, universal social and environmental laws that govern the composition of the archaeological record (Binford, 1968; Sahlins and Service, 1960; Trigger, 2006). In the push away from Culture History that characterized most archaeological theory from the 1940's onward, migration as a cultural process, which was perceived at the time as a strictly Culture Historical interpretive tool, was all but abandoned by mainstream scholars

(Anthony, 1990; Trigger, 2006). This was especially the case in North American Processual archaeology (Anthony, 1990).

This is not to say that Culture History was completely purged from archaeological discourse after the 1940's. Many of its major theoretical tenets, such as the importance of geographically and temporally contextualizing material culture, survive in current theory. The Culture Historical paradigm itself continued to be applied in one form or another at the fringes of academia for much of the twentieth century (Syms, 1978). In Manitoba, where theoretical debate chronically lags twenty years behind dominant discourse, papers and books describing and debating the composition, geographical limits and temporal boundaries of past cultures within the province and surrounding areas make up the bulk of archaeological publications from the mid to late twentieth century. To be fair, this is largely due to the paucity of the sort of well-recorded archaeological data at the time that would make higher level interpretation of social processes feasible. Migration theory was still applied generously to interpretations of the province's archaeological record to explain general similarities between Manitoba material culture and that from more distant locales (Pettipas, 1996; Syms, 1977). However, many of the more outrageous migration theories applied to Aboriginal material culture in the early twentieth century had been widely discredited before the widespread emergence of Culture History in Manitoba and thus were not seriously considered in the context of this paradigm.

Culture history, because its application depends so strongly on the identification of consistently juxtaposed material culture, demands careful proveniencing of excavated archaeological materials. Thus, the emergence of the Culture History paradigm in

Manitoba archaeology was accompanied by a dramatic increase in formal archaeological documentation. For example, Vickers' (1945; 1946; 1947; 1951) investigations into precontact Manitoba Culture History, conducted during the 40's, represent the first systematic, rigorously recorded excavations in the province. Vickers (1945; 1946) did not always interpret the results of these excavations within a Culture Historical framework derived from the area in which he was working (Syms, 1977). Instead, he often attempted to fit excavated materials into regional chronologies from other areas, such as Minnesota. In some regions, such as southwestern Manitoba, this led to the relegation of almost two thousand years of Precontact material culture into a single composite (Syms, 1977).

Richard "Scotty" MacNeish (1958; MacNeish and Capes, 1958), through his work for the Geological Survey of Canada, also conducted excavations at a number of sites throughout central and southern Manitoba during this period. Due to the exigencies of time, these excavations were often rudimentary, though data was collected diligently (MacNeish, 1958; Syms, 1977). MacNeish's (1958; MacNeish and Capes, 1958) interpretations of the data he collected were made without the aid of radiometric dating and sometimes stretched the applicatory utility of chronometric and palaeoenvironmental techniques (Syms, 1977). However, his work came to define the most widely accepted Precontact culture history sequence in Manitoba for a number of years. Scholars working in peripheral areas, such as Reeves (1970a; 1970b) and Johnson (1969, 1973) also made contributions to the archaeology of Manitoba as their definitions of composites and complexes were often applied to sites within the province.

The application of migration theory to archaeological interpretation during this period is not as overt as during the previous incarnation of Culture history in Europe and other areas of North America. However, the application of regional chronologies from geographically distant areas to the archaeological record of Manitoba seems to hint at implicit assumptions of culture contact between groups in these areas.

A push began in the late 1960's and early 1970's within Manitoba archaeology to reconcile Culture Ecology, Processual Archaeology and Culture History into a single interpretive framework (Syms, 1977; 1978). This took the form of selective application of different tenets of each paradigm in conjunction with one another to gain a more nuanced view of the archaeological record. The Culture Historical approach, in the form of a modified version of the Midwestern Taxonomic System, was still applied to the archaeological record to define relationships between people groups within the Province and surrounding areas using material culture. Additionally, the importance of migration as an influence on material culture was acknowledged (Pettipas, 1996; Syms, 1977). Culture Ecology, or the view of culture in which social processes are viewed as a result of interaction between peoples and the natural environment, was often applied to explain hypothesized past migrations, for example, the influx of peoples onto the northern plains during the warm, dry Pacific period (Syms, 1977). Interpretive methods with their origins in the Processualist movement are also applied in this blend of theories. This is especially true of ethnographic analogy, in which historic records of related groups and modern ethnographies of groups with similar behaviour patterns to those responsible for creating the archaeological record are used to infer past behaviours from material culture. Many Processualists are comfortable with the application of cross-cultural analogies, in

which the archaeological record is interpreted using ethnographic data collected from groups which are totally unrelated to and geographically distant from those represented by excavated materials (Binford, 1969). However, because of the particularist influences of Culture History on Manitoba archaeology, most ethnographic analogies were drawn either from groups that were known to be directly related to archaeologically represented peoples or groups occupying similar ecological niches (Syms, 1977).

This blended theoretical approach to Manitoba archaeology is perhaps best represented by E. L. Syms' (1977) application of the co-influence sphere model to ceramic era material culture from southwestern Manitoba. Syms (1977) utilizes the traditional Culture Historical approach to define a series of geographically and temporally contextualized complexes. These complexes are described in terms of their material culture – particularly ceramics, mobility, subsistence and settlement patterns. The latter three of these cultural qualities are, in some cases, inferred through reference to ethnographic literature written on groups known to be directly related to those represented by the archaeological record (Syms, 1977). In cases where this is not possible, analogies to groups pursuing what are assumed to be similar lifeways in the same type of environment are drawn upon to clarify ancient behaviour patterns (Syms, 1977).

Having defined these groups using a culture historical approach, Syms (1977) estimates the total distribution of each composite by mapping artefact distributions. The frequency and permanence of sites assigned to each complex within different areas is used to divide their total ranges into primary, secondary and tertiary territories. A primary territory can be thought of as the homeland of the people represented by a single

composite (Syms, 1977). A group's secondary territory is made up of the regions visited on a regular basis, while its tertiary territory comprises locations only visited irregularly for special purposes (Syms, 1977). In Precontact North American contexts, these territories can be quite large (>1000km), and the territories of multiple people groups often overlap (Syms, 1977)

These variable land use patterns are closely tied to resource procurement strategies, especially those related to subsistence (Syms, 1977). Plant and animal food resources utilized by Aboriginal groups in southern Manitoba and surrounding areas have highly seasonal schedules of availability which can be altered by even minor shifts in climate. In light of this close relationship between the environment and food resources, and therefore, between the environment and mobility, Syms (1977) views human ecology as playing a fundamental role in shaping Precontact Manitoba material culture and driving migration in the area. In light of the land use overlap between groups predicted by Syms (1977) and supported by the ethnographic record of early contact southern Manitoba, one of the fundamental postulates of the co-influence sphere model is that multiple people groups were brought into contact with one another through territorial overlap. This contact will result in either positive, beneficial interaction or negative, harmful interactions. The nature of these interactions, according to Syms (1977), determines, to a large extent, the behaviour patterns of people groups involved with them. The co-influence sphere model was introduced largely because previous regional chronologies provided no means for identifying culture contact, cultural interactions and thus, explaining the results of these processes (Syms, 1977). Behaviours which may be

affected by both positive and negative cross-cultural interactions include mobility and migration patterns (Syms, 1977).

Using this multi-faceted theoretical approach, Syms (1977) reconstructs the cultural landscape of southwestern Manitoba from the advent of ceramic technologies in the area up to the early Postcontact period. The history produced is not one of culture change through constant diffusion and migration, to the exclusion of independent invention. Nor is it an environmentally deterministic laundry list of rigidly defined stacked chronologies in which people groups develop in total isolation from one another. Rather, it is a story of regional culture change resulting from migration, material and cognitive exchange between people groups and adaptation to a shifting environment.

Migration theory is currently enjoying a renaissance in dominant archaeological discourse. This has less to do with the current theoretical atmosphere than it has to do with recent methodological advances. The original culture historians, by necessity, tracked population movements using only material culture analysis and some spurious craniometric methods (Childe, 1927; 1928; Trigger, 2006). Improvements in stable isotope analysis of teeth and bones – which will be discussed more thoroughly below – now allow archaeologists to directly test hypotheses of population movement using preserved human remains (Evans *et al..*, 2006; White *et al..*, 1998; 2000; 2001; 2004). The results of these analyses are beginning to show that the relationship between human migration and culture change is far more varied and complex than the either/or view advocated by the Culture History and Processual paradigms. For example, using oxygen stable isotope analysis, scholars are beginning to uncover cases of nearly identical material culture shared between past populations with almost no identifiable geographic

contact (White *et al.*., 2001). In modern archaeological practice, migration is once again seen as a feasible explanation for some kinds of material culture variability. However, before they are widely accepted, migration hypotheses should be supported, whenever possible, by chemical analyses of associated human remains.

To the best of the author's knowledge, migration hypotheses derived from Manitoba archaeological materials have not yet been tested using stable isotope analysis of human bone. Consequently, all hypothesized Precontact population movements in the province have been derived from a combination of material culture analysis and oral history. In most cases, these lines of evidence are preferable to the destructive analysis of human remains. However, there are some situations in which they are not sufficient to support population movement hypotheses. Material culture analyses may be problematic because of the numerous social processes, such as long distance trade or simple convergence, which can produce archaeological signatures similar to migration (Anthony, 1990). Additionally, relevant oral histories, which often prove superior to archaeological analysis in reconstructing past movements (Mann, 2003), may not exist for the temporal and geographic context under study. When this is the case, and where associated human remains exist and all ethical guidelines pertaining to destructive analysis have been met, stable isotope analysis may be useful in clarifying Precontact population movement in Manitoba.

Isotopic Analysis of Human Remains in Archaeology

Isotopic analysis of archaeologically recovered human bones and teeth is rapidly becoming a standard method for directly inferring aspects of past human lifeways

including dietary and migration patterns. The almost ubiquitous nature of isotopic analysis in archaeological literature makes it extremely important for every archaeologist to have at least a basic understanding of the theory behind this technique and the costs and benefits of its application. To this point, the following will be a discussion of the biological premises which make stable isotope analysis relevant to reconstruction of past human ecology, what different isotope ratios can tell us with regards to human migration and subsistence, and the practical application of these methods to the archaeological record.

The nature of archaeological analysis, in which analytical methods are borrowed from many and diverse fields of study, makes it difficult for any single archaeologist to completely understand the theory behind every analytical technique that might be applied to material they have excavated. According to Sillen and colleagues (1989), the main compromising factor in the field of archaeological stable isotope analysis is the misapplication of this technique due to lack of specialized knowledge on the part of archaeologists. They argue that, until geochemists and biochemists become motivated to apply their expertise to archaeological analysis – or until archaeologists begin to specialize in the fields of bio- and geochemistry, the results of stable isotope analysis will be open to misinterpretation (Sillen *et al.* 1989). Fortunately for archaeology, both have occurred in the decades following Sillen and colleagues' (1989) publication; interdisciplinary partnerships flourish in many academic environments and many archaeologists are beginning to supplement classic method and theory training with education in the fields of geology, biology and chemistry (Schoeninger and Moore 1992).

An isotope is an atomic configuration of an element in which one or more neutrons is added to the nucleus relative to its standard arrangement (Schoeninger and Moore 1992). Because neutrons, unlike protons or electrons, do not carry any charge, this alteration does not affect the general behaviour of the atom. However, the addition of a neutron does affect the element's atomic mass, which may affect its behaviour in certain metabolic pathways.

Some isotopes are unstable, or radioactive, and quickly decay into stable isotopes. This decay occurs at a constant rate and, in the case of radioactive isotopes such as Carbon-14, is the foundation of some absolute dating techniques. Other isotopes are stable, meaning that they do not decay and thus, once incorporated into biological tissues, remain in their *in vivo* ratios in tissues preserved after death (Schoeninger and Moore 1992).

Stable isotope analysis of human tissue is predicated on the premise that "you are what you eat, plus or minus 5 permil" (Schoeninger and Moore 1992). In other words, dietary stable isotopic ratios are metabolized in relatively unchanged proportions into human tissues, including bone and tooth collagen and apatite. Dietary isotopic ratios fluctuate according to the type of foods included in the diet – as is the case for isotopes of carbon and nitrogen – or according to the climate or geology of the area from which dietary elements are obtained – as with strontium and oxygen (Schoeninger and Moore 1992; Wright and Schwarcz 1998; Price *et al.* 2002; Evans *et al.* 2006).

Stable isotopes may pass through various metabolic pathways at each trophic level before incorporation into human bone tissue (Schoeninger and Moore 1992). Because of the difference in weight of various stable isotopes – which, in lighter elements, may equal

a large proportion of overall atomic mass – different isotopes may or may not be differentially treated by various metabolic pathways (Schoeninger and Moore 1992). If this occurs, it can lead to a difference between original environmental isotopic ratios and those observed in living tissues (Schoeninger and Moore 1992). This alteration of isotopic ratios due to metabolism is known as "fractionation", and may or may not create a problem in isotopic analyses. In some cases, which will be discussed in detail below, fractionation rates at different trophic levels are actually the foundation of meaningful stable isotope analysis (Schoeninger and Moore 1992; Wright and Schwarcz 1998; Price *et al.* 2002).

It is important to note that isotopic ratios in human tissues are a reflection of dietary isotopic ratios at the time of tissue *formation* (Evans *et al.* 2006). Bone tissue, for example, is replaced – or "turns over" – at varying rates averaging around 7-10 years (Evans *et al.* 2006). Bone with different levels of vascularisation turns over at different rates; spongy bone, with many associated blood vessels, turns over more quickly than less vascularised compact, lamellar bone (Cox and Sealy 1997). Therefore, bone stable isotope ratios are assumed to be a summation of dietary ratios over the last seven to ten years of life, depending on which type of bone was sampled (Cox and Sealy 1997). Dental tissue presents a slightly more complex picture of individual isotopic history. Enamel, unlike bone, is not modified at all after its initial mineralization in childhood, and thus reflects dietary isotopic composition at the time of its formation (Schoeninger and Moore 1992; Evans *et al.* 2006). Cementum is, strictly speaking, not remodeled either. However, this tissue, which coats the external surface of tooth roots, accumulates in annual layers. The isotopic composition of each layer of cementum, therefore, is

indicative of dietary isotopic composition over roughly one year of life. Bulk sampling of cementum would, thus, present one with an average value of tissue isotope levels spanning the time from tooth formation until death. Dentin is the well vascularised hard tissue which surrounds the pulp cavity of each tooth and forms its internal structure. It is usually not remodeled after childhood, however, in some cases, especially where injury to the tooth has occurred, redeposition of dentin can take place. Comparing the isotopic ratios between tissues formed at different life stages allows for the identification of dietary isotopic changes between early childhood and the period before death in adult individuals (Evans *et al.* 2006).

As in all archaeological analysis, diagenetic processes are a factor in stable isotope analysis and must be identified and hopefully mitigated before meaningful results can be produced (Sillen *et al.* 1989; Schoeninger and Moore 1992). Between interment and excavation, human skeletal material is exposed to a multitude of biological and geological contaminants, each with their own different stable isotopic signature (Schoeninger and Moore 1992). The original isotopic composition of a skeleton can be altered through the actions of saprophytic organisms such as bacteria or fungi, or the percolation of ground water through porous hard tissues. Storage and laboratory handling can also introduce foreign materials with different isotopic compositions to the surface of bone specimens. Thus, almost any presentation of stable isotopic analysis will contain a description of the cleansing process to which specimens of tooth and bone are subjected before finally being submitted for analysis (Lynott *et al.* 1986; Price *et al.* 1994; Ambrose *et al.* 1997; Cox and Sealy 1997; Richards and Hedges, 1998; Richards *et al.* 2000; Dupras *et al.* 2001; Privat *et al.* 2002; Bentley *et al.* 2003).. Aside from

contamination, the general preservation of a specimen's chemical composition must also be assessed before analysis. For example, the decaying process can strip bone of its organic components. This process would result in bone isotopic levels that are not representative of *in vivo* values. Most studies of human bone carbon and nitrogen isotope ratios require isolation of bone collagen for analysis (Schoeninger and Moore 1992). The carbon to nitrogen (C:N) ratio of collagen is unique and not duplicated by any other known protein or potential non-biological contaminant (Schoeninger and Moore 1992). Therefore, the C:N ratio of any collagen sample can be tested to assess its purity and level of preservation (Schoeninger and Moore 1992). Acceptable collagen samples should have a C:N ratio of 2.7-3.6; any samples with ratios outside this range have either been contaminated by non-collagen material or are too poorly preserved for meaningful analysis (Schoeninger and Moore 1992). In studies where apatite is isolated for analysis, such as those which involve strontium or oxygen isotopic rations, Fourier-transform infrared (FTIR) spectrographic measurements of crystallinity index (CI) are frequently employed to asses the chemical integrity of samples (Stuart-Williams *et al.,* 1996).

It should be noted that different hard tissues are subject to different levels of diagenetic alteration. Tooth enamel, because of its relatively tight crystal structure, is to a large degree immune to contamination by ground water infiltration (Cox and Sealy 1997). Dentin, on the other hand, is more porous, while the mineral component of cementum has a less tightly assembled crystal structure than enamel, making both of these tissues more vulnerable to contamination by diagenetic fluids (Cox and Sealy 1997). Bone is more easily contaminated than enamel. Dense, compact bone, however, is much less prone to isotopic alteration than spongy, trabecular bone (Cox and Sealy

1997). No matter what tissue type is submitted for analysis, however, it is important to use precautionary methods to lessen the effects of exposure to field and laboratory contaminants and to ensure the chemical integrity of one's sample through the appropriate tests.

Carbon stable isotope analysis

Carbon exists in three isotopes – ^{13}C, ^{14}C, and ^{12}C. Only two of these, ^{13}C and ^{12}C are stable (Schoeninger and Moore 1992). Carbon isotope ratios, like all isotopic ratios, are expressed as delta (δ) values in parts permil (‰). These values are calculated though comparison of bone ratios to the ratio of a universally accepted standard. In the case of $^{13}C/^{12}C$, this standard is Pee Dee Belemnite, a Cretaceous fossil from the Pee Dee formation in South Carolina (Schoeninger and Moore 1992). The formula for calculating $\delta^{13}C$ is:

$$\delta^{13}C = \{[(^{13}C/^{12}C_{sample})/(^{13}C/^{12}C_{PDBstandard})]-1\} \times 1000$$

Along with atmospheric $\delta^{13}C$ values, the photosynthetic pathway utilized by specific plants determines their $\delta^{13}C$ value (Schoeninger and Moore 1992). Three photosynthetic pathways are known to exist, C_3, C_4 and CAM, each of which lead to different plant $\delta^{13}C$ isotope ratios (Smith and Epstein 1971; Schoeninger and Moore 1992). C_3 and C_4 pathways are so named because the product of the first photosynthetic step in each contains three and four carbon atoms respectively. C_3 plants tend to grow in

more temperate latitudes and have relatively low $\delta^{13}C$ values ranging from – 20 to – 30‰ (Smith and Epstein 1971; Schoeninger and Moore 1992). C_4 plants, on the other hand, are generally found in warmer areas and have $\delta^{13}C$ values ranging between –9 and –16‰. The most archaeologically important C_4 plants are food crops such as maize, sorghum and millet (Smith and Epstein 1971; Schoeninger and Moore 1992). Crassulacean acid metabolism (CAM) plants utilize both pathways and therefore have $\delta^{13}C$ values that fall between C_3 and C_4; these plants include succulents such as cacti and aloes and are generally found in hot, dry environments (Schoeninger and Moore 1992).

When these plants are consumed, their respective $\delta^{13}C$ values are incorporated into animal tissues, including bone. Therefore, $\delta^{13}C$ values obtained from bone collagen can be used to detect shifts in dietary plant use between C_4 and C_3 species.

Carbon stable isotope analysis has been used in multiple contexts to test hypotheses regarding dietary shifts in the past. The most well-known of these is represented by the literature dedicated to tracing the introduction of domestic maize, a C_4 plant, into the previously C_3-dominated diets of precontact Aboriginal populations of North, South and Central America (Garvie, 1993).

Nitrogen stable isotope analysis

Like carbon, nitrogen is found naturally in two stable isotopes, ^{15}N and ^{14}N (Schoeninger and Moore 1992). Naturally occurring nitrogen is made up of roughly 99.64% ^{14}N and 0.36% ^{15}N (Schoeninger and Moore 1992). $\delta^{15}N$ values are calculated

using AIR (ambient inhalable reservoir) as a standard with a formula almost identical to that used for $\delta^{13}C$

$$\delta^{15}N = \{[(^{15}N/^{14}N_{sample})/(^{15}N/^{14}N_{standard})] - 1) \times 1000$$

Atmospheric and oceanic N_2 (which make up 99% of the earth's nitrogen) can enter biological systems in one of two ways. Nitrogen is fixed by blue-green algae in marine systems or by buds on plant roots in terrestrial systems (Schoeninger and Moore 1992). The $\delta^{15}N$ values of nitrogen-fixing plants and algae are very similar to surrounding atmospheric or oceanic $\delta^{15}N$ values (Schoeninger and Moore 1992). However, with each rise in trophic level, $\delta^{15}N$ values become enriched by about 3-4‰ (Schoeninger and Moore 1992). This trophic level effect does not vary over geographic areas. Therefore, stable isotope analysis of human bone can be used to differentiate between humans whose diet consisted primarily of plants, herbivorous animals or carnivores (Richards *et al.* 1998, 2000; Privat *et al.* 2002). Additionally, because oceanic food chains are very complex, containing more trophic levels than terrestrial food chains, marine food resources are relatively ^{15}N enriched over terrestrial levels; therefore, $\delta^{15}N$ values can also be used to differentiate between populations utilizing terrestrial versus marine resources (Schoeninger and Moore 1992).

Strontium isotope analysis

Strontium exists in four stable isotopes: ^{88}Sr, ^{87}Sr, ^{86}Sr and ^{84}Sr (Hodell *et al.* 2004). Most naturally occurring strontium (82.53%) is made up of ^{88}Sr, while other isotopes occur in much lower concentrations (Hodell *et al.* 2004). For the purposes of tracking human migration using strontium isotope ratios, hard tissue ratios of ^{87}Sr to ^{86}Sr, which reflects the chemical composition of local geology, is considered (Price *et al.* 2002; Hodell *et al.* 2004). Within rocks, ^{87}Sr is added over time through the radioactive decay of Rubidium-87, while original levels of ^{86}Sr do not change over time (Hodell *et al.* 2004). Therefore, the ratio of ^{87}Sr to ^{86}Sr within a rock formation is determined by its initial $^{87}Sr/^{86}Sr$ content and its age (Hodell *et al.* 2004). The $^{87}Sr/^{86}Sr$ value of an area's bedrock is directly reflected by the $^{87}Sr/^{86}Sr$ ratios overlying soils (Price *et al.* 2002; Hodell, 2004; Evans *et al.* 2006). Strontium enters biological systems through soil nutrient uptake by plants. Because strontium is a much heavier element than oxygen, carbon or nitrogen, the gain or loss of one neutron does not significantly alter relative isotopic weights. Therefore, strontium does not undergo any appreciable fractionation in biological systems (Hodell *et al.* 2004). Because of this, $^{87}Sr/^{86}Sr$ ratios values of soil are directly reflected by plant $^{87}Sr/^{86}Sr$ ratios and so on for each trophic level (Price *et al.* 2002; Hodell *et al.* 2004). One might think, therefore, that human tooth and bone $^{87}Sr/^{86}Sr$ ratios could be directly compared to soil $^{87}Sr/^{86}Sr$ ratios in different areas to directly determine human geographic origins and migration routes (Hodell *et al.* 2004). However, the situation is hardly that simple.

$^{87}Sr/^{86}Sr$ ratios of bedrock, and therefore of soil, vary not only between geologic formations, but are also subject to micro-scale variations *within* geologic formations (Price *et al.* 2002). This means that the strontium isotopes incorporated into mobile

organisms are actually a summary of $^{87}Sr/^{86}Sr$ ratios over the region from which they obtain food resources (Price *et al.* 2002). This regional summary of $^{87}Sr/^{86}Sr$ ratios is known as the area's "bioavailability" strontium isotope ratio, and also incorporates minor atmospheric contributions to biological $^{87}Sr/^{86}Sr$ ratios (Price *et al.* 2002). Studies which characterize regional $^{87}Sr/^{86}Sr$ ratios using lithic samples alone do not accurately reflect the $^{87}Sr/^{86}Sr$ ratios of living organisms – including humans – from those regions (Price *et al.* 2002; Hodell *et al.* 2004). Even studies that incorporate a few plant samples may not be able to recreate the geographic $^{87}Sr/^{86}Sr$ ratio distributions of mobile species (such as humans), which may incorporate plants from a large area into their diet (Price *et al.* 2002). Price *et al.* (2002) addressed this shortcoming by creating a regional $^{87}Sr/^{86}Sr$ ratio distribution map based on isotope ratios from faunal samples collected over a broad geographic area. Snails were chosen as test subjects in this analysis, not only because they are small and easy to catch, but also because they are not subject to the range uncertainty of larger animals (Price *et al.* 2002).

Oxygen stable isotope analysis

Oxygen exists naturally in three stable isotopes: ^{18}O, ^{17}O and ^{16}O. Most studies of oxygen stable isotopes deal with the ratio of ^{18}O to ^{16}O. Atmospheric levels of these isotopes vary geographically according to a number of environmental factors: altitude, latitude, longitude, temperature and distance from large bodies of water (Wright and Schwarcz 1998; Evans *et al.* 2006).

Recently, $\delta^{18}O$ analyses of human tooth and bone have been used to reconstruct individual migration events and, more broadly, patterns of population movement at certain points during the distant past (Evans *et al.* 2006). This is possible because human bone $\delta^{18}O$ values have a direct relationship with $\delta^{18}O$ values in ingested drinking water. Drinking water $\delta^{18}O$ values are, in turn, related to those of meteoric precipitation, which vary according to the above mentioned environmental factors (Wright and Schwarcz 1998). Therefore, a change in $\delta^{18}O$ values between hard tissues formed in childhood and those formed during adulthood would indicate a movement between environmentally and climatically distinct zones (Evans *et al.* 2006).

Differential metabolic fractionation of ^{18}O and ^{16}O was poorly understood at first, however; several formulae have been developed to convert bone and tooth enamel $\delta^{18}O$ values into associated drinking water values (Longinelli, 1984; Luz *et al.,* 1984; 1990). These formulae, though, when applied to the same sample value, will often produce different results, leading to some confusion (Evans *et al.* 2006). To circumvent the problem of unknown fractionation rates, Evans *et al.* (2006) directly compared the childhood $\delta^{18}O$ values of several individuals from burial sites in Wiltshire, southern England to those of individuals from "known sites and historical times". This was done to determine the geographical origins of the Wiltshire individuals by matching their childhood isotopic ratios to those of an adult population. This method, while creative, must be applied carefully. Firstly, when comparing the $\delta^{18}O$ values of a population of unknown origins to those of individuals excavated from other areas, it is important to ensure that members of the "known" sample did not undergo a migration event during adulthood, which could lead to bone $\delta^{18}O$ levels that do not reflect those of local drinking

water. It could be argued that a large sample of skeletons from a specific geographic area, all with similar $\delta^{18}O$ values, would present a strong argument for that value being the result of local drinking water values (Evans *et al.* 2006). However, not all archaeologists have the opportunity to build such a sample, either due to restrictions on destructive skeletal analysis, or simply due to the paucity of excavated human remains in a given area or both. Therefore, it is important to test absolute environmental $\delta^{18}O$ values and their variation over time in different climatic zones wherever hard tissue $\delta^{18}O$ values are used to connect an individual or group to a specific geographic location. Evans and colleagues (2006) do compare their $\delta^{18}O$ data to absolute drinking water values within Great Britain, however, they do not make it clear whether these values represent modern drinking water $\delta^{18}O$ values, or those from the time at which the individuals being analyzed were alive – or even whether there might be a difference between the two. Because drinking water $\delta^{18}O$ values vary according to climate and environment, and both may fluctuate over time, it is essential to ensure that environmental $\delta^{18}O$ values for comparison to skeletal samples are comparable to regional $\delta^{18}O$ values from the pertinent time period. Similarly, when comparing individuals of unknown origin to samples of known origin to determine the geographic origins of the former, it is important to ensure that the two populations are at least somewhat contemporary. Otherwise, the same climatic shifts which may cause drinking water $\delta^{18}O$ values to fluctuate over time may also cause populations from the same geographic area, but different time periods, to have dissimilar $\delta^{18}O$ values.

Trophic level effects must be taken into consideration in some oxygen stable isotope studies. In most cases, body $\delta^{18}O$ values are derived from drinking water,

however, in breastfeeding children, $\delta^{18}O$ values are a reflection of breast milk $\delta^{18}O$ values. Human body $\delta^{18}O$ values, including breast milk $\delta^{18}O$ values in nursing mothers, tend to be enriched in ^{18}O. These maternal $\delta^{18}O$ values are taken up by breastfeeding infants and fractionated further through conversion to infant body $\delta^{18}O$ values. Thus, breastfeeding children tend to have slightly higher $\delta^{18}O$ values than other, non-breastfeeding members of a given population (Wright and Schwarcz, 1998). This needs to be accounted for when oxygen stable isotope analysis is applied to hard tissues with formation times spanning the age of weaning (Wright and Schwarcz, 1998)

This thesis applies stable isotopic analysis of human bone to the interpretation of mobility and migration patterns at the Fidler Mounds (EaLf-3) site in south central Manitoba. The material culture assemblage from this site indicates some form of contact with multiple adjacent and distant people groups over its >1000 years of use (Saylor, 1976; Hewitt, 2004). However, the exact nature of this contact and the extent to which migration played a role in the formation of this site remains unknown. As of yet, no oral histories pertaining directly to population movements in the area during the period of mound use have been uncovered and material culture analyses, while thorough, have failed to adequately assess the nature of culture contact and its impact on culture change at this site.

To understand these results, the cultural context of the individuals being analysed must also be understood. The following section will discuss the culture history of southern Manitoba, with specific attention paid to the cultural chronology of Lockport (EaLf-1), a habitation site near Fidler Mounds.

Precontact Culture History and Cultural Interactions in Southern Manitoba

The Culture History of Manitoba has been the subject of numerous publications since the emergence of a formal archaeological discipline in the province during the 1940's (Vickers, 1945; 1946; 1951; MacNeish, 1958; Meyer and Hamilton, 1994; Johnson and Johnson, 1998, Greg, 1994; Syms, 1977; 1978). Early workers in the field of Manitoba archaeology tended to follow the regional chronologies laid out by Vickers (1945; 1946; 1951) and MacNeish (1958) in interpreting excavated material culture. However, as more and more scholars became involved in the excavation and publication of sites in Manitoba, interpretations of the province's archaeological record diversified proportionately. Some authors, such as Reeves (1970a; 1970b), tend to lump components and complexes into a few geographically and stylistically broad composites, while other authors, such as Syms (1977; 1978), are more likely to divide material culture assemblages into a large number of very specific complexes. As interpretations diversified, so to did the terminology used to discuss them. For each archaeological taxon, several terms developed, while names for composites, complexes and components, as well as their definitions, varied widely from scholar to scholar. For the sake of simplicity, these variations will not be explored in depth. Instead, the middle and late Woodland Culture History of southern Manitoba will be discussed in very broad terms.

The geographic ranges of composites defined by many workers in the field of precontact southern Manitoba archaeology often conform to the boundaries of the three major ecological zones within the study area. These are the Northeastern Plains, the Aspen Parkland, and the Boreal Forest. The Northeastern Plains in Manitoba consists of

two general vegetation zones, the shortgrass and tallgrass/mixed prairie. The first of these, shortgrass prairie, is composed mainly of blue grama (*Bouteloua gracilis)*, buffalo (*Buchloe dactyloides*), needle-and-thread (*Stipa comata*), Western wheat (*Agropyron smithii*) and green needle (*Stipa viridula)* grasses (Buchner, 1980). Within the present study area, this zone is restricted to the southwestern corner of the province. The second zone, the tallgrass/mixed prairie is, as one might expect, dominated by taller species of grasses, including big bluestem (*Andropogan gerardi*), little bluestem (*A. scoparius*), sand bluestem (*A. halii*), *Agropyron smithii*, switchgrass (*Panicum virgatum*), needlegrass (*Stipa spartea*), *S. comata*, side-oats grama (*B. gracilis*) and Indian grass (*Sorghastrum mutans).* River valleys within this area are characterized by deciduous arboreal species such as cottonwood (*Populus deltoides)* elm (*Ulmus americanus)* and willow (*Salix nigra*). Tallgrass/mixed prairie is also restricted to the southwestern part of the province (Buchner, 1980). The Aspen Parkland, the third vegetational zone to be considered here, arcs north of the prairies from northwestern Minnesota, across southern Manitoba and central Saskatchewan before finally terminating in southwestern Alberta (Buchner, 1980). This belt of vegetation is characterized by a predominance of deciduous arboreal species such as trembling aspen (*Populus tremuloides)*, burr oak (*Quercus macrocarpa*) and balsam poplar (*Populus balsamifera*); white elm (*Ulmus americana*), *Populus deltoides,* and Manitoba maple (*Acer negundo*) may be found in riparian environments (Buchner, 1980). Directly to the north of the Aspen Parkland can be found the Boreal Forest, the largest arboreal community in Canada (Buchner, 1980). The Boreal Forest is dominated by white and black spruce (*Picea glauca* and *P. mariana,* respectively), although jack pine (*Pinus banksiana*), tamarack (*Larix laricina*) and

balsam fir (*Abies balsamea*) may also be encountered depending on soil type and drainage (Buchner, 1980). The boreal forest mixes with the Aspen Parkland at its southern edge and deciduous species typical of the latter may be interspersed with coniferous flora in this region (Buchner, 1980). The Boreal forest is truly massive in extent, stretching from Newfoundland in the east to Alaska in the west and encountered as far north as the Yukon as far south as New England. Within Manitoba, it covers the eastern, northern and much of the central portions of the province (Buchner, 1980)

The beginning of the Middle Woodland period in Manitoba is generally placed at around AD100 (Johnson and Johnson, 1998). On the Northeastern Plains, the start of this period is marked by the appearance of ceramics in components attributed to the Besant complex (Johnson and Johnson, 1998). Besant assemblages are normally defined by the presence of broad, side notched Besant or Samantha projectile points, ceramics with vertical, horizontal or diagonal cord impressions, extensive use of Knife River flint as a lithic raw material and bifaces with moderate hafting elements (Reeves, 1970b). Faunal and material culture analyses of Besant components indicate that the people represented by this composite engaged in communal bison hunting as a subsistence strategy (Johnson and Johnson, 1998; Reeves, 1970b). There are also strong indications that Besant and other Middle Woodland peoples were strongly influenced by social and technological developments occurring to the southeast, specifically, the influx of trade goods and ideological influences associated with the rise of the Hopewell Interaction Sphere (Reeves, 1970; Syms, 1977; 1978).

Specific mortuary assemblages, in addition to habitation and subsistence-oriented components, have been attributed to the Besant composite. Mounds identified as

"Sonota" are dated to c. AD0-600 and have been associated with Besant peoples by a number of authors (Johnson and Johnson, 1998; Reeves, 1970b) – although there is some debate regarding this association (Syms, 1977). Sonota mounds tend to be dome shaped and built over a roughly rectangular subfloor pit (Reeves, 1970b; Neuman, 1975). Pits may be lined with vegetal matting and are often log-covered (Reeves, 1970; Neuman, 1975). Most burials consist of secondary interments accompanied, in many cases, by a variety of exotic and local grave goods. These include: tubular bone beads, antler pins, flakers, mauls, bone awls, worked beaver and canine teeth and jaws, bear tooth pendants, side-notched blades, ovoid knives, triangular and triangular-side-notched points, bi-pointed stone drills, atlatl weights, worked and unworked obsidian, catlinite artifacts, *olivella* conch and *dentalium* beads and ornaments, partial or whole bison, worked human palates, and, rarely, thick walled, cord-paddled ceramics (Johnson and Johnson, 1998; Reeves, 1970b; Neuman, 1975). Several of these mounds have been recorded in Manitoba. The majority of these are located in the Pembina River Valley in the southwestern part of the province (Syms, 1978).

Middle Woodland assemblages from the Aspen Parkland and Boreal Forest of southeastern Manitoba are dominated by components attributed to the Laurel complex (Johnson and Johnson, 1998; Meyer and Hamilton, 1994; Syms, 1977; 1978). Laurel components in Manitoba share a basic core of traits, including: large, thick-walled conical ceramics which may be decorated with punctates or pseudoscallop, stab and drag or linear stamping applied to the upper third of the vessel, toggle head harpoons, and a variety of small projectile point forms, including Laurel Triangular (Reeves, 1970; Syms, 1977). There are indications that Laurel subsistence patterns were much more diverse

than those of Besant peoples to the west (Meyer and Hamilton, 1994). Laurel seasonal mobility in southern Manitoba seems to have followed a pattern in which groups aggregated in the summer to focus on the utilisation of a diverse set of resources, including fish and other riparian species, and then fissioned into smaller hunting groups in the late fall to exploit mammalian taxa (Meyer and Hamilton, 1994).

The Laurel complex in Manitoba is also associated with burial mounds. Laurel mounds tend to be small, interments are usually bundle burials and grave goods are normally local (Syms, 1977). The latter usually consist of projectile points, native copper artifacts, bone-hafted beaver incisor gouges, awls, beads and chisels (Syms, 1977). When exotic artefacts are encountered in Laurel mounds, they most commonly consist of obsidian objects or monitor pipes from the south (Syms, 1977). Laurel mounds in Manitoba are most common along the southern border of the Boreal Forest where it meets the Aspen Parkland (Syms, 1977; 1978). While Laurel mounds to the south in the Rainy River region of Minnesota and Ontario contain Laurel-style ceramics, these are not found in any mounds in Manitoba (Syms, 1977).

Syms (1977) hypothesizes that the Middle Woodland Laurel complex in Manitoba represents the immigration of a people group displaced from the south into the Boreal Forest due to a "domino effect" triggered by the expansion of Hopewell groups in the southeast. There is insufficient evidence in the archaeological record to conclusively state whether this was the case; however, this hypothesis would explain the seemingly sudden appearance of well-crafted ceramic technologies in southern Manitoba at the beginning of the Middle Woodland (Syms, 1977).

There is evidence for extensive interaction between Laurel, Besant and more distant groups during the Middle Woodland (Greg, 1994; Johnson and Johnson, 1998; Meyer and Hamilton, 1994; Syms, 1977; 1978). For instance, ceramics attributed to Besant and western Plains complexes, such as Avonlea, sometimes appear in Laurel components and vise versa (Greg, 1994; Meyer and Hamilton, 1994). As well, the presence of exotic materials as grave goods, especially in Sonota mounds, indicates the existence of continent-wide trade networks during this period. The *dentalium* used to make the beads found in some Sonota mounds, for example, have their origins on the west coast, while the conch shells also found in these mounds originate in the Gulf of Mexico (Syms, 1978). The obsidian sometimes included in Laurel mounds is most likely from present-day Wyoming, while the native copper has been provenienced to the Great Lakes region (Syms, 1977).

Changes in subsistence and mobility patterns associated with the rise of Mississippian centres to the south in conjunction with the warming, drying climatic trend of the Neo-pacific resulted in a major cultural shift in southern Manitoba and surrounding areas c. AD700-800 (Syms, 1977; MDCAHR, 1983). These changes mark the shift from the Middle Woodland to the Late Woodland in this region.

Although the Laurel complex persisted into the Late Woodland period in the northern and eastern regions of the study area, the most common early to middle Late Woodland complex in Southern Manitoba is Blackduck (which is also referred to as the Manitoba Focus in some early literature [MacNeish, 1958]) (MacNeish and Capes, 1958; Johnson and Johnson, 1998; Greg, 1994). Blackduck assemblages are usually identified by the presence of distinct, globular, flared-rim pottery decorated with cord-wrapped

stick impressions. Indeed, like most Late Woodland composites, Blackduck is defined almost exclusively by pottery style. Some other, non-ceramic traits have also been assigned to Blackduck. These include the presence of tubular pipes, end and side scrapers, small notched and un-notched triangular projectile points, socketed and unilateral harpoon bone projectile points, fleshers, copper artefacts – including beads and awls – and bone-hafted beaver tooth gouges (Syms, 1977; Wilford, 1955).

The subsistence of Blackduck peoples in Manitoba appears to have been bison-focused (MDCAHR, 1983). However, it is likely that these groups also supplemented their diet with small mammals, waterfowl and wild rice consumption (MDCAHR, 1983). Additionally, there is evidence for trade between bison-hunting groups in Manitoba and agriculturalists to the south. It is likely that preserved bison meat and skins were traded for agricultural produce such as maize (Syms, 1977; MDCAHR, 1983). Furthermore, there is strong evidence for the pursuit of a Plains Village lifeway through the practice of maize hoe-agriculture by Blackduck peoples in southern Manitoba. The presence of storage pits, bison-scapula hoes and maize plant remains dated to a 200 year time period between AD1200 and AD1400 at the Lockport site, which is very near to Fidler Mounds, all indicate horticultural practice in addition to trade with agricultural groups to the south (Buchner, 1988).

The origin of Blackduck groups and their relationship to historic Aboriginal groups has been a matter of debate in Manitoba archaeology for many years. Some authors maintain that Blackduck represents a migration of populations from the eastern Great Lakes region of Ontario into Manitoba in the wake of northward-expanding Mississippian agricultural communities (Syms, 1977). Others maintain that Blackduck

developed *in situ* in southern Manitoba before expanding into Minnesota, western Ontario and northern and eastern Manitoba (Meyer and Hamilton, 1994). This debate has not yet, to the author's knowledge, been settled to the satisfaction of all parties.

The relationship between Blackduck and ethnographically documented cultures has also been debated for a number of years. MacNeish (1958) originally identified Blackduck peoples as the ancestors of the Assiniboine on the basis of stratigraphy and the supposed affiliation between a later composite, Selkirk, and the Cree. Evans (1961), on the other hand suggests that Blackduck represented the ancestors, not of the Assiniboine, but of an Algonquian group, likely the Cree, based on similarities between Algonquian and Blackduck geographic distributions and differences between Blackduck and Assiniboine mortuary practices as reconstructed from the archaeological record and early historic documents respectively. Wright (1965) and Dawson (1974), on the other hand, attribute Blackduck assemblages to the precontact ancestors of the Anishnabe (or Ojibwa) based on territorial distributions and supposed cultural continuity between these two groups. There is no evidence, however, to support the continuity of the Blackduck composite into the Postcontact era, though most authors are comfortable with associating Blackduck generally with Algonquian groups (Syms, 1977).

Several other people groups appear in Manitoba during the Late Woodland. The first of these is represented in the archaeological record by a ceramic type known as Selkirk ware. This pottery was originally identified by MacNeish (1958) as Winnipeg River Fabric-Impressed ware and appears to have originated in the Boreal Forest of Northern Manitoba c. AD1250 before spreading to central and southern Manitoba shortly thereafter (Meyer and Hamilton, 1994). Selkirk ware has high, vertical rims and is most

commonly fabric impressed, coiled and decorated with punctates. Artefacts associated with Selkirk pottery include small side-notched and triangular projectile points (Syms, 1977) Most scholars today agree that Selkirk ware most likely represents the ceramic industry of precontact Cree peoples (Meyer and Hamilton, 1994; Syms, 1977).

The Duck Bay ceramic complex was also developing in central Manitoba during the late Woodland, while in the Boundary Waters area to the south, Sandy Lake ware begins to appear. Traits shared between Sandy Lake and Selkirk pottery seem to indicate a certain level of culture contact between these groups (Meyer and Hamilton, 1994). These peoples likely followed lifeways very similar to those recorded for Algonquian groups in the area at contact. Subsistence patterns were probably diffuse, in keeping with the patchy distribution of food resources within Boreal Forest and Parkland settings (Cleland, 1976).

The relationship between Late Woodland groups and burial mounds utilized during this period are less obvious. Traditionally, three major mortuary complexes have been assigned to the late Middle and Late Woodland period in southern Manitoba. These are the Devil's Lake Sourisford (DLS) Complex (Syms, 1979), Blackduck mound component and the Arvilla Complex (Johnson, 1973).

Blackduck mounds are normally identified by the presence of cord-wrapped stick-impressed Blackduck ceramics and other artefacts associated with habitation sites assigned to this complex (Syms, 1978). These mounds normally contain flexed, sitting burials and are primarily found in the Rainy River area of Ontario and Minnesota, however, the Stott Mound in southern Manitoba has been identified as a Blackduck mound (Syms, 1978).

The Devil's Lake Sourisford complex has its distribution primarily in southwestern Manitoba, North and South Dakota and eastern Saskatchewan. This land use area roughly follows the path of the Missouri Coteau and seems to be linked to seasonal pursuit of bison migrating between the Plains and Aspen Parkland (Syms, 1978; 1979). This mortuary complex has been dated to c. AD900-1400. Due to poor excavation technique applied to early investigations of the mounds it is defined by material culture alone. Artefacts found in DLS mound fill and as grave goods include: conch shell gorgets with and without a "weeping eye" motif, conch collumella pendants, short collumella beads, flat, incised tablets, catlinite tubular pipes, wristlets and anklets of incised bone, trapezoidal, notched shell pendants, washer shaped shell beads and copper bands and beads (Syms, 1979). Additionally, some DLS mounds contain small, round, smooth-walled mortuary vessels. These often feature incised designs, which may be of Thunderbirds, salamanders, spirals and/or broken arrows (Syms, 1979). The rim of these pots is usually flared and may be round or may have pinched, squared corners (Syms, 1977). Ethnographic accounts detailing the use of such pots by shamans in healing rituals in the area support a ceremonial interpretation of these vessels (Syms, 1979).

The Arvilla complex is the other major Middle to Late Woodland mortuary complex encountered in Manitoba (Johnson, 1973). Arvilla mounds are mostly confined to the banks of the Red River in Minnesota. However, a few scattered mounds in the Dakotas and Manitoba have been assigned by some authors to this complex (Johnson, 1973; Syms, 1978). Arvilla mounds may be either circular or linear in form. Burial pits are often multiple and are normally found underneath circular mounds (Johnson, 1973). Interments occurring after original mound construction may also intrude into the sides of

the mounds themselves (Johnson, 1973). Burials may be secondary, bundle or extended, flexed or disarticulated primary. Artefacts most commonly included as grave goods and mound inclusions in Arvilla mounds are: shell gorgets, collumella beads, washer-shaped shell beads, copper ornaments, bone beads and bracelets, bone harpoons, clay elbow-pipes, Middle to Late Woodland fabric-impressed pottery, antler-hafted beaver-tooth gouges and, in some cases, miniature mortuary vessels (Johnson, 1973). In Minnesota, this complex developed c. CE500-600 and disappeared by AD900. However, Syms (1982) argues that it lasted until c. AD1400 in southern Manitoba.

The utility of these latter two mound complexes as cognitive devices in the interpretation of Manitoba precontact lifeways is somewhat questionable. While the above paragraphs present a seemingly long list of diagnostic features by which DLS and Arvilla mounds might be identified, it should be kept in mind that none of the diagnostic traits for either given complex is present at *every* DLS or Arvilla site. Some are found at no more than two or three sites and many are found at only one (Johnston, 1973; Syms, 1982). Additionally, the reader will note that several artefact types listed as diagnostic by Syms (1979) and Johnston (1973) are shared between Arvilla and DLS. Furthermore, radiocarbon dating has shown that some mounds assigned to either the Arvilla or DLS complex have histories of use longer than the temporal span of the either complex (Hewitt, 2004). Such mounds actually represent accumulations of cultural material which may span up to 1000 years in some cases and could potentially reflect long-term changes in adaptation, external cultural influences and ideology (Hewitt, 2004). While these sites may prove frustrating for the archaeological taxonomist, they give scholars an unprecedented chance to observe long-term trends in Precontact Manitoba lifeways.

However, the exact nature of these trends will remain elusive until archaeologists come to a better understanding of the people groups represented by the multiple components making up these fascinating sites. One step towards this goal lies in the correlation of mortuary materials to habitation sites and thus, to better understood archaeological composites. This approach has been sorely underemployed in the Precontact mortuary archaeology of some areas, such as Minnesota, where the Arvilla complex has yet to be strongly associated with any non-mortuary material culture. However, some other mortuary complexes, such as Sonota and DLS, have been tied to non-mortuary taxa – Besant and the precontact Sioux, respectively (Neuman, 1975; Syms, 1979).

Fidler Mounds, the site to be considered by this thesis, is most commonly associated with Middle to Late Woodland occupations at the Lockport site, which is located a very short distance from the mounds (Saylor, 1976). Therefore, to properly understand the components making up the Fidler Mounds assemblage, it is essential to understand the archaeology of this habitation site

Occupation at Lockport began with the appearance of the archaic Larter culture c. 1350BC. (Buchner, 1988). Mound burial is not a known trait of archaic peoples, nor does any of the material included in the Fidler Mounds suggest an affiliation with this group, so they shall not be considered to any great depth here (Saylor, 1976; Syms, 1977). By c. 360BC, the Larter component had disappeared from Lockport assemblages to be replaced at c. 200BC by the first appearance of Laurel complex materials at this site. At this point, ceramics begin appearing in assemblages from Lockport and resource exploitation at the site seems to have diversified (Buchner, 1988). It is also during this stage of occupation that the initial construction of Fidler Mounds likely took place

(Buchner, 1988; Fiske, 1964; Hewitt, 2004; Saylor, 1976). The Laurel component at Lockport persisted until c. AD832; well into the Middle Woodland period. At this point, it appears that Laurel peoples either transitioned into the Blackduck lifeway or were replaced by an influx of Blackduck peoples (Syms, 1977; Buchner, 1988). It is during the Blackduck phase at Lockport that the site reached its greatest fluorescence in terms of size and population (Buchner, 1988). Buchner (1988) points out that Blackduck horizons at Lockport are by far the site's richest, and attributes this to the shift in subsistence towards maize hoe-agriculture which occurred at Lockport c. AD1200. Bell-shaped, bark-lined storage pits, a large number (21) of bison-scapula hoes, and burnt maize kernels found in Blackduck horizons at Lockport all indicate that this people group was involved not only in trading for maize with nearby agricultural groups, but were also involved in maize production (Buchner, 1988; Syms, 1977). The Blackduck composite, as well as material culture associated with hoe-agriculture both vanish from the Lockport site c. AD1500 (Buchner, 1988). Simultaneously, material culture attributed to the Selkirk composite appears at this site. A radiocarbon date of c. AD1650 associated with Selkirk materials suggests that Lockport was inhabited into the early historic period, however, the absence of any European goods associated with Selkirk materials seems to indicate that the site was abandoned before widespread European settlement in the area (Buchner, 1988).

The contribution of migration to the archaeological record at Lockport has been the subject of a number of at least two graduate theses at the University of Manitoba during the past decade (McKinley, 2001; Flynn, 2002). Specifically, the sudden appearance of material culture indicating the pursuit of a semi-sedentary, horticultural or hoe-

agricultural lifeway at this site has been interpreted by researchers to be the result of a long distance migration of southern agriculturalists into the area (McKinley, 2001; Flynn, 2002). Flynn (2002) attributes this migration to a number of factors. The most important of these was the shift in the climate which took place in North America at around AD800 which led to what is known as the Medieval Warm Period. During this warm, dry climatic stage, which lasted until roughly AD1400, drought and high temperatures would have made previously fertile areas of the continent, such as those supporting some Mississippian groups, poor for farming (Flynn, 2002). The archaeological record indicates that this was a time of dramatic food shortages and growing inter-group tensions in areas south of Manitoba, especially after AD1150 (Flynn, 2002). In southern Manitoba, however, the warming and drying associated with the Medieval Warm Period would have increased the annual growing season long enough to easily allow the pursuit of maize horticulture in the area (Flynn, 2002). This, coupled with milder winters and the abundant fish and game resources available for exploitation, would have made some areas of southern Manitoba, including Lockport, extremely appealing to horticultural or agricultural groups pushed from their homeland by conflict and seeking a new place to practice their traditional subsistence strategy (Flynn, 2002). The new AMS dates obtained for the site (Hewitt and Hoppa 2003; Hewitt 2004) from individuals interred at Fidler Mounds fall within time span of both Laurel and Blackduck occupations at Lockport. The total span of mound use also encompasses the period of immigration into the area supported by the work of McKinley (2001) and Flynn (2002). This is the context in which interpretations of isotopic data obtained from individuals interred at the Fidler Mounds will be made.

Fidler Mounds: The Site

Fidler Mounds (EaLf-3) is a mid to late Woodland period cemetery site located approximately 19km north of the city of Winnipeg, Manitoba, near the town of Lockport. The original layout of the mounds once present at the site is unknown. Farming in the area likely altered the landscape many years before it was first surveyed by archaeologists. Early accounts of the form of the mounds at this site seem to indicate that they were a composite linear mound group, which consisted of a long, barely visible linear mound with a taller, rounded mound at each end (Syms, 1978). Several excavations have occurred at this site since the mid-nineteenth century and have ranged from professional digs to plundering and undocumented destruction. The first of these occurred in 1866 when a local farmer attempted hollow a root cellar out of the side of one of the mounds (Saylor, 1976). Periodic excavations of a dilettantish, antiquarian nature occurred at Fidler Mounds over the rest of the eighteenth century (Saylor, 1976; Syms, 1978). Recorded digs were undertaken by Charles N. Bell of the University of Winnipeg in 1885, A. McCharles in 1887 and later by the Rev. George Bryce (Saylor, 1976). There is only a very poor record of these excavations; the nature, and in many cases the location, of the artefacts and human remains "recovered" by these excavators is unknown and the individuals and materials, themselves, are not currently available for study (Saylor, 1976). The only archaeological excavation at Fidler Mounds for which a known collection with strong documentation exists was conducted in 1963 by Timothy Fiske of the University of Manitoba (Fiske, 1964). This excavation occurred to collect and

document what remained of the artefacts and individuals still interred in the mounds before the site was almost totally destroyed by the construction of the Winnipeg Floodway. In total, sixty-three individuals were recovered from 20 discrete burials and the mound fill of Mound 1, along with 1685 unidentifiable human bone fragments. Four individuals were recovered from one burial and the mound fill of Mound 2, along with 40 unidentifiable bone fragments (Fiske, 1964; Saylor, 1976; Hewitt, 2004). Material culture diagnostic of the Laurel, Blackduck and Selkirk complexes, including ceramics and projectile points, was recovered from the mounds (Saylor, 1976). Other artefacts, such as marine shell pendants, Mississippian potsherds and clay pipes reminiscent of Minnesotan finds indicate cultural influences from beyond southern Manitoba (Saylor, 1976). Today, due to the efforts of amateur collectors, the work of the University of Manitoba 1963 salvage crew and the construction of the Winnipeg Floodway, all that remains of Fidler Mounds is half of the smaller of the two original cemetery mounds.

The first thorough, academic study of the Fidler Mounds site was conducted by Saylor (1976), and consisted of an assessment of metric and qualitative traits of the individuals and an in-depth analysis of the lithic, ceramic and faunal materials excavated in 1963. In her conclusions, Saylor (1976) noted the various attempts of other authors to "shoehorn" the Fidler Mounds into one of several cultural complexes, including both Arvilla (Johnson, 1973) and, later, Devil's Lake Sourisford (Syms, 1978). However, she refrained from assigning any specific cultural identity to the builders of the Fidler Mounds (Saylor, 1976). Instead, she cautiously concluded that these mounds were built by a well-organised group of hunter-gatherers prior to European contact (Saylor, 1976). This conclusion was based on the subsistence pattern indicated by the artefacts included

in the mounds, the amount of effort and organisation required to construct two burial mounds, as well as the lack of any European trade goods in the Fidler Mounds assemblage. She also rejected the carbon date of AD 1570 obtained by Fiske (1963) from charcoal found on the floor of the central burial pit in mound 1 on the basis of possible contamination (Saylor, 1976). Instead, she tentatively concluded that the mounds could only be said to have been built during the Middle to Late Woodland period (AD 1-1600) based on stylistic comparisons to other mounds (Saylor, 1976).

The second major study of the Fidler Mounds materials and individuals was conducted by Garvie (1993). This study consisted of stable carbon and nitrogen isotope analysis of 28 human bone samples and a large number of faunal samples taken from the Fidler Mounds and Lockport archaeological assemblages (Garvie, 1993). The objective of the Garvie (1993) study was to determine whether maize constituted a significant part of the Middle to Late Woodland peoples' diet on the northeastern Plains (Garvie, 1993). The results of Garvie's (1993) work indicate that previous interpretations of the Fidler mounds as representative of the burial practices of a single cultural group may not be tenable. She found that the $\delta^{13}C$ values of the Fidler Mounds individuals showed a greater range than one would expect if the sample had been drawn from a single, homogeneous population (Garvie, 1993). Adult females, on average, have high $\delta^{13}C$ values when compared to other individuals, possibly indicating that these females preferentially consumed ^{13}C-enriched plants, such as maize. Garvie (1993) proposes several hypotheses to account for this variation. These include temporal variability in mound use, the use of the Fidler Mounds by multiple contemporaneous but culturally different groups, use of the mounds by a single group with intrapopulation dietary

variation, and intermarriage between the mound group and a nearby group with a different subsistence pattern (Garvie, 1993). Of these four hypotheses, Garvie (1993) decided that the latter was best supported by archaeological and isotopic data.

The most recent major study of the individuals from the Fidler Mounds was by Hewitt (2004). This study consisted of a pathological analysis as well as trace element and carbon and nitrogen stable isotopic analyses and carbon dating of several individuals exhumed during the 1963 excavation (Hewitt, 2004). The carbon dates, in particular, underscore the population variability suggested by the $\delta^{13}C$ values obtained by Garvie (1993). While the single carbon date obtained by Fiske (1963) places the construction of the Fidler Mounds at AD 1570 in the Late Woodland period, the multiple carbon dates from eight individuals from this site places the minimum date for the initial construction of the mounds at c. AD 260, with mound use continuing until c. AD 1390, and a gap in interment occurring between c. AD 640 and AD 1000 (Hewitt and Hoppa 2003; Hewitt, 2004). This means that Fidler Mounds are quite possibly the earliest excavated mound group in the province and exhibit a considerable temporal depth of use. It stands to reason that the study of the human remains and cultural materials from Fidler Mounds is of the utmost importance to Canadian mortuary archaeology. The present study is aimed at more fully understanding the contribution of migration to the diversity of the people and artefacts from Fidler Mounds.

Chapter 3: Materials and Methods

Sample preparation

The sample set for this study consisted of 12 teeth in total. Eight teeth were originally prepared as LA-ICP-MS thick-sectioned samples by Hewitt (2004). Four teeth were prepared by the researcher as thin-sections especially for this study. In both cases, canines which were still situated in alveolar bone after excavation and storage were extracted manually. Some teeth, which had been glued into their sockets by previous researchers as a well-intentioned conservation measure, had to be extracted through gentle loosening and the application of small amounts of water (Hewitt, 2004). Two teeth (11LLC and 21ULC) were broken during the extraction process, while the others were removed without any damage. The teeth prepared by Hewitt (2004) were embedded in epoxy-resin surrounded by a ring of plastic tubing and sectioned using a Buhler IsoMet diamond-edge saw. The thin-sectioned samples were prepared in much the same way, however, after embedding and cutting, the samples were glued to a glass slide, ground into thin-sections and polished to eliminate saw-lines. Slides were then cut to fit the SIMS sample chamber. The dentin of the eight thick-sectioned teeth was analysed by Hewitt (2004) using the LA-ICP-MS, which left a macroscopically visible burn line approximating the longitudinal axis of each tooth. The results of these analyses can be found in Hewitt (2004). After Hewitt's analysis, the thick-sections were placed in storage in the University of Manitoba department of Anthropology for roughly three years.

Samples containing enamel, cementum and dentin were required for the purposes of the current research project. Hewitt (2004) selected her samples based on the presence of a complete CEJ. This was thought to be an accurate proxy of overall tooth preservation. This selection protocol also serendipitously ensured the presence of all three dental hard tissues – cementum, dentin and enamel – on each of Hewitt's samples. Due to the lengthy amount of time these samples spent in storage, it was thought prudent by the researcher to re-examine them to assess their condition both microscopically and macroscopically before testing. Upon examination, it was found that the resin in which the teeth were originally set had degraded during storage and, in some areas, had completely pulled away from the external tooth surface, creating gaps between the tooth and the resin. The cause of this phenomenon is uncertain; it may be related to the environmental conditions in which the teeth were stored. *In situ* oxygen isotopic analyses obtained by secondary ion mass spectrometer (SIMS) next to gaps in sample surfaces are unreliable due to surface charge effects (John and Odom, 1997). In most cases, gaps and rough surfaces can be avoided by carefully selecting analysis areas. However, four of the samples exhibited shrinkage and large gaps between tissues were observed. These samples were excluded from the present study.

Most SIMS sample chambers are designed to hold samples only up to 2.5 cm in diameter. Larger samples, such as teeth and bones, must be trimmed to fit inside the sample chamber. Additionally, if one wishes to test the chemical composition of internal tissues, such as dentin or unexposed trabecular bone, appropriately sized thick or thin sections must be prepared. Either of these procedures will ultimately result in the destruction of larger samples, so extensive photography, measurement and

documentation should be undertaken before subjecting archaeological material or human remains to SIMS testing.

Microscopic examination of the samples showed that the level of polish of the thick-sections was insufficient for SIMS analysis. Therefore, samples were polished using Buhler 0.05-micron aluminium paste, distilled water and a buffing mat until no scratches were apparent on the teeth.

The thick-sectioned samples were subjected to a slightly modified version of the standard cleaning process for SIMS mineral samples. This consisted of a series of sonic baths in water and cleanser (10 minutes), distilled water (10 minutes) and ethanol (15 minutes). The thin-sectioned samples only required swabbing with 95% ethanol. After cleaning, samples were handled using latex gloves, wrapped in soft tissue and stored in individual snap-lid plastic containers. One enamel and one cementum test site were chosen per tooth. Each site was photographed and marked with permanent ink to facilitate its identification once inside the SIMS.

A ~200 Å thick Au coat was sputter-deposited on the sample mount surface prior to ion microprobe (SIMS) analysis using an Ernest F. Fullham No. 18930 Effacoater. The mounts were placed in steel sample holders where surface conductivity was approximately 5-10 ohms/cm. The entire assembly was then placed in the SIMS sample lock and held at high vacuum prior to the start of analysis.

Secondary Ion Mass Spectrometer analysis

The analytical protocol for O-isotope measurements using the CAMECA ims 7f secondary ion mass spectrometer at the University of Manitoba is similar to that described by Hervig *et al.* (1992). Oxygen isotope ratios ($^{18}O/^{16}O$) from dentin, enamel, and cementum were measured using a Cs^+ primary beam and monitoring O- secondary ions with extreme energy filtering of 300 eV. A normal incidence flood gun was employed to neutralize potential sample charging. The ~3 nA primary ion beam was focused to a 15 x 30 μm spot using a 100 μm aperture in the primary column. Secondary oxygen ions were detected sequentially by switching the magnetic field. The detection system consisted of a Balzers electron multiplier coupled with an ion counting system with an overall dead time of 15 ns. A typical analysis lasted ~12 minutes, comprising 85 analysis cycles. Whenever possible, at least four analyses were obtained from each tissue type for all samples.

During the isotope measurement process by ion microprobe, an intrinsic mass dependent bias is introduced and is referred to as instrumental mass fractionation (IMF). A variety of processes combine to produce the observed IMF. These include secondary atom extraction (sputtering) and ionization, (e.g., Williams, 1979, Yu and Lang, 1986), secondary ion transmission (Shimizu and Hart, 1982), and detection (Valley and Graham, 1991, Lyon *et al.*, 1994). The greatest contributors to the IMF are sputtering and ionization, which depend most strongly upon sample characteristics (i.e., chemical composition). This is referred to as compositionally dependent fractionations or "matrix effects" (e.g., Eiler *et al.*, 1997). Therefore, in ion microprobe analyses, IMF are usually

corrected for by comparing measurements of a chemically and isotopically homogenous mineral standard that is chemically similar to the unknown. SIMS results for the standard are compared to its accepted isotopic composition to compute a correction factor that is applied to the unknowns measured during the same analysis session (e.g., Leshin *et al.*, 1998). However, in this study oxygen isotopic standards for teeth are not available. Therefore, one tooth (Fill B) was chosen as an internal standard and analysed daily along with samples. Data are reported relative to tooth Fill B.

The overall precision and accuracy for each isotope analysis include errors arising from counting statistics of each individual analysis, calibration to a known standard, and uncertainty in deadtime corrections arising from variable count rates. In general, the overall internal precision for an individual spot is ±1.0‰ (1σ).

Analyses were positioned parallel to the growth axes of tissue to sample the entire growth history of the tissue. In this way, the average $\delta^{18}O$ value would more closely approximate bulk oxygen isotopic analyses. However, in practice, this was not always possible. In most cases, it was possible to use enamel striations to approximate the axis of growth in this tissue to ensure sampling from all stages of enamel formation. However, in the case of cementum and dentin, it was not always possible to sample from the entire period of tissue growth. As mentioned earlier, tissue in close proximity to resin gaps was not sampled. Such gaps seemed to occur adjacent to cementum with much greater frequency than dentin or enamel. Cementum layers are added to the exterior of the root surface roughly every year. Therefore, the exterior portions of cementum, which represent annulations formed in later years of life, could not be sampled in many cases. The presence of a pulp cavity in some of the samples precluded the testing of interior

dentin in these teeth. Instead, dentin was sampled from areas directly medial to enamel and cementum test sites. Sampling tissue next to cracks was avoided whenever possible. However, in certain cases this could not be avoided and analyses that were obtained adjacent to a crack in the tissue were noted and removed from the data set.

Sampling of the teeth was conducted over a 6 day period in July (2 days) and October (4 days) of 2007. After analyses, the sections were placed in storage in Wallace 419. In all, the oxygen isotope ratios of twelve thin and thick sectioned teeth were measured using the SIMS. Each section contained all three dental hard tissues, and each tissue was sampled four times if possible. Hand-drawn diagrams indicating the approximate location of each tissue test area were maintained throughout analysis. Whenever the exigencies of archaeological dental histology led to non-standard placement of test sites, diagrams were marked to reflect this (See Appendix A).

The bulk nature of SIMS analysis has implications for the comparability of SIMS data to data obtained through gas source mass spectrometry. Because there is a greater potential for IMF to contribute to dental $^{18}O/^{16}O$ values obtained through SIMS, as opposed to those generated through gas source mass spectrometry, it is not feasible to compare results obtained using these two methods. Therefore, the $\delta^{18}O$ values discussed in the following chapter cannot be directly compared to values generated through traditional methods, nor can they be correlated to any natural drinking water reservoirs.

Laboratory conditions, such as temperature and humidity, are almost always subject to minor daily fluctuations. These changes can have an impact on the performance of the SIMS. To monitor these variations, standard dentin was analyzed four times at the beginning of every laboratory day. $\delta^{18}O$ values obtained during a single day were

calibrated relative to the standard dentin values obtained at the beginning of the analytical session. Preliminary analyses had shown the dentin of Fill B to be relatively isotopically homogeneous. Thus, calculating the standard deviation of the results obtained during the four daily analyses of this tissue allowed the researcher to gauge the precision of the SIMS, which could also be subject to daily fluctuation. These standard deviations remained relatively small throughout the six days of analysis, which means that intra- and inter-tissue variation recorded by the SIMS likely reflects actual tissue values, rather than instrumental variation. Therefore, 2σ errors are reported for all data, which takes into consideration both the internal precision for each spot and the spot-to-spot reproducibility of the standard Fill B.

Scanning Electron Microscope analysis

Three teeth were selected for imaging using a scanning electron microscope (SEM). The gold-coat was removed from sample surfaces by polishing with Buhler 1 micron diamond paste and distilled water on a 1500 grit mat. After polishing, any remaining gold was removed by swabbing with ethanol. A thin, conductive carbon coat was sputter-deposited onto the sample surface prior to SEM analysis and double-sided carbon tape was wrapped around the edges of each sample to aid in diffusion of the charge generated by electron bombardment and to adhere the sample to the microscope stage.

In SEM, electrons are thermoionically emitted from a tungsten filament, focused into a beam and accelerated towards surface of the sample to be imaged using paired

electromagnetic coils (Goldstein *et al.*, 1992). The many different ways in which samples interact with the SEM electron beam are the foundation of a variety of topographical and chemical imaging techniques. Secondary emission (SE) analysis, the most commonly utilized SEM technique, is based on detection of the low-energy secondary electrons generated by a sample when it is struck by the high-energy electron beam. SE-SEM is useful for imaging the relief or topography of samples at very high magnification. This study utilized images generated through SE-SEM to determine whether SIMS analysis points on the three teeth chosen were placed on cracks or other features not detectable using the Cameca 7F imaging system.

When a beam of electrons impinges upon a sample surface, interactions between the beam electrons and atoms within the sample will alter their trajectory. Often, the angle of this change of trajectory is small, on a scale of 2°-5°. However, alteration of electron trajectories by angles of up to 180° is possible (Goldstein *et al.,* 1992). When the latter is the case, and when these reflected electrons have enough energy to penetrate the sample surface a second time, they are emitted as backscatter electrons (BSE). Backscatter electron images are based on the detection of these electrons, which will depend on the chemical composition of the sample. In this way, BSE-SEM is used to detect very small-scale differences in chemical composition within a sample, which will appear as areas of differential luminescence when electron data is converted into an image using a scanning cathode ray tube (Goldstein *et al.*, 1992). In this study, BSE-SEM was used to assess level of chemical homogeneity within tissues and the level of chemical diagenesis to which tissues had been subjected.

The data obtained through both SE and BSE-SEM can be visualized at many different levels of magnification as two dimensional images which can be stored digitally. In this study, images were taken at a variety of magnifications (30x, 60x, 120x, 250x and 1000x). After imaging, the three samples were returned to storage in Wallace 419.

Chapter 4: Results

Results obtained from SIMS analysis of enamel indicate that individuals from Fidler Mounds can be grouped into at least three discrete categories based on mean $\delta^{18}O$ values. Half of the individuals (Burials 7, 9, 19 and 21) have enamel with relatively high mean $\delta^{18}O$ values between 17 and 25‰ (Figure 1). Other individuals (Burials 11 and 17 and Fill A) have lower $\delta^{18}O$ values that range from 12 to17‰ range (Figure 1). The final category is made up of one individual, Burial 10, who has $\delta^{18}O$ value of 10±2‰ (Figure 1). However, four individuals (Burials 15 and 12 and Fill B and Fill LRC) have mean values that fall within the range of more than one of these groups

$\delta^{18}O$ values obtained from dentin have a much narrower range (Figure 2). Based on mean $\delta^{18}O$ value, dentin can be divided into two groups. The high dentin $\delta^{18}O$ signature is represented by Fill B, with a mean $\delta^{18}O$ value of 15±2‰ and Burials 21 with a mean dentin $\delta^{18}O$ value of 17±3‰, 7, with a mean dentin $\delta^{18}O$ value of 14±2‰ and 9 with a mean dentin $\delta^{18}O$ value of 14±2‰ (Figure 2). The low signature is represented by Burial 10, with a mean dentin $\delta^{18}O$ value of 10±2‰ (Figure 2). All other sampled individuals yield mean dentin $\delta^{18}O$ values which could place them in either group.

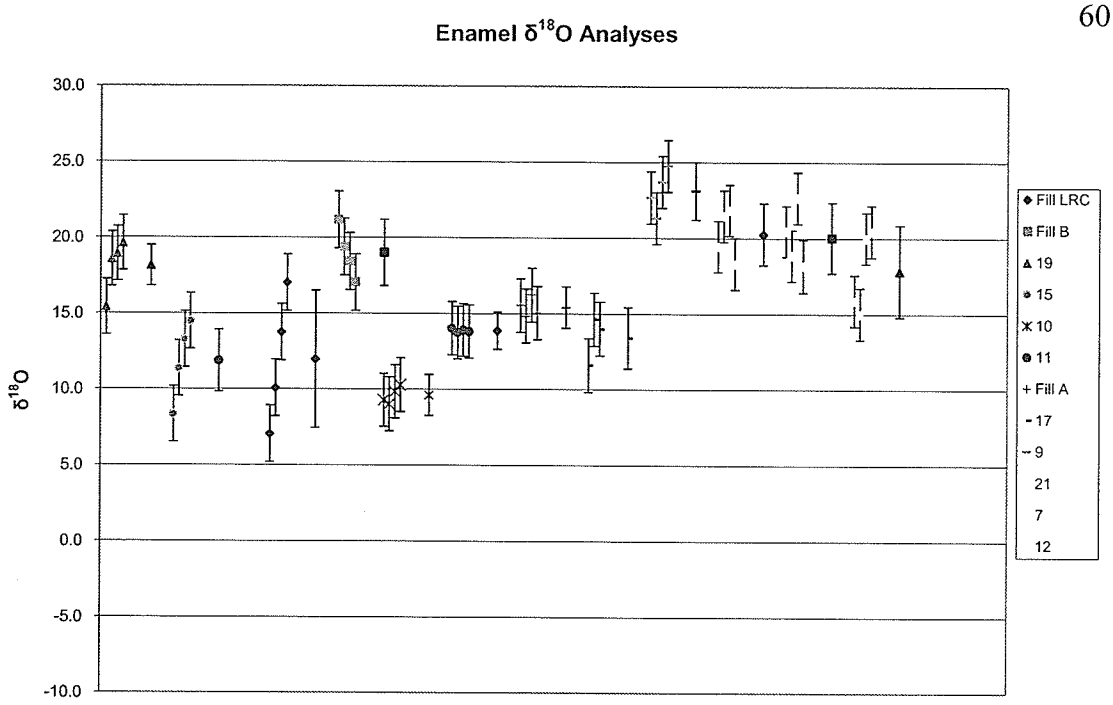

Figure 1: A plot of $\delta^{18}O$ values from enamel within the Fidler Mounds population. Black symbols beside each data series represent average values for the single analysis series immediately to the left.

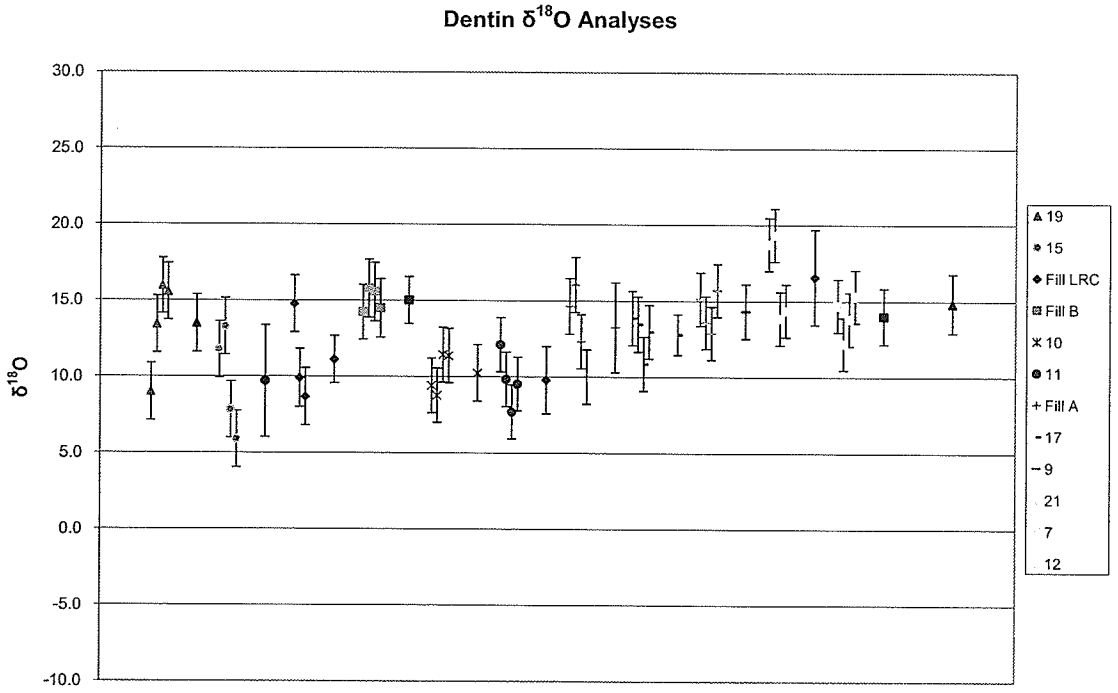

Figure 2: A plot of $\delta^{18}O$ values from dentin within the Fidler Mounds population. Black symbols beside each data series represent average values for the single analysis series immediately to the left.

The $\delta^{18}O$ values obtained from the cementum of the individuals analyzed in this study can be grouped into three clusters. The individual with the highest cementum (Burial 9 at 18±4 ‰) has a range of $\delta^{18}O$ values between 14‰ and 22‰ (Figure 3). Two individuals analysed (Burial 15 and Fill LRC) have $\delta^{18}O$ values from 7 to 12‰. One individual, Burial 10, exhibits remarkably low cementum $\delta^{18}O$ values at 3.±1‰. However, some individuals (Burials 7, 11, 12, 15, 17 and 19 and Fill B and Fill A) have mean cementum values which overlap with more than one $\delta^{18}O$ group.

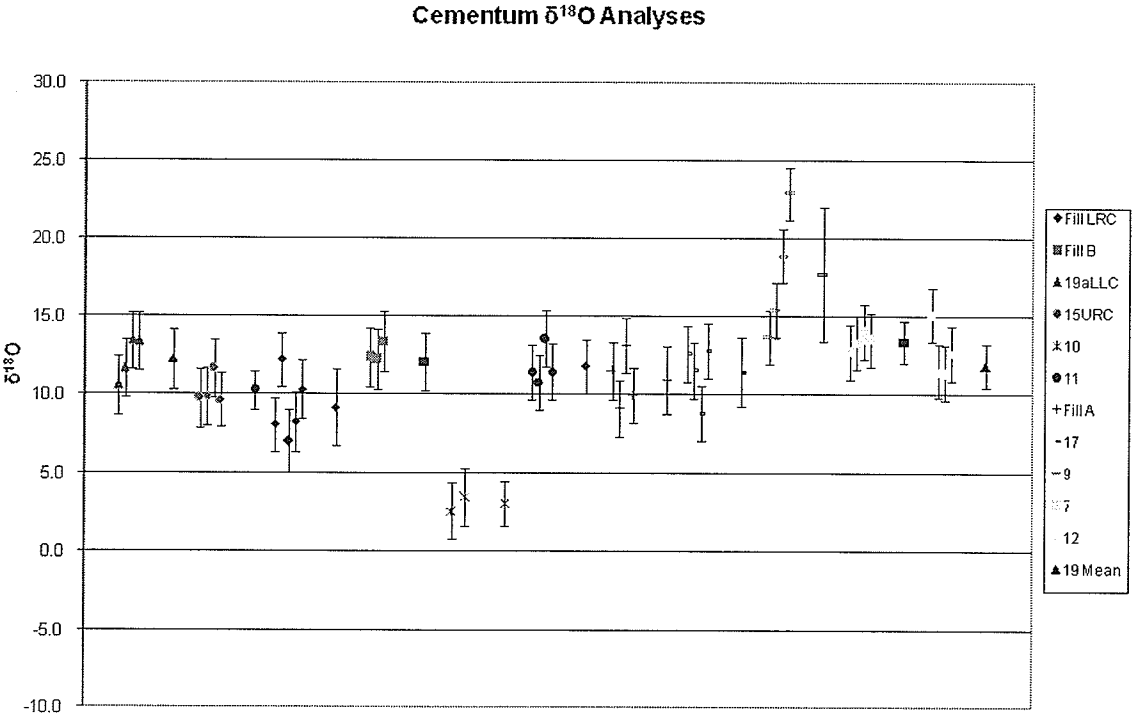

Figure 3: A plot of $\delta^{18}O$ values from cementum within the Fidler Mounds population. Black symbols beside each data series represent average values for the single analysis series immediately to the left.

Table 1: Mean dentin, enamel and cementum $\delta^{18}O$ values and 95% confidence intervals obtained from Fidler Mounds individuals

Burial	Dentin $\delta^{18}O$	2σ	Enamel $\delta^{18}O$	2σ	Cementum $\delta^{18}O$	2σ
FillB	15‰	±2‰	19‰	±2‰	12‰	±2‰
FillLRC	11‰	±2‰	12‰	±5‰	9‰	±2‰
15	10‰	±4‰	12‰	±3‰	10‰	±1‰
19	14‰	±4‰	18‰	±2‰	12‰	±2‰
10	10‰	±2‰	10‰	±1‰	3‰	±1‰
11	10‰	±2‰	14‰	±1‰	12‰	±2‰
FillA	13‰	±3‰	15‰	±1‰	11‰	±3‰
17	13‰	±2‰	13‰	±2‰	12‰	±2‰
9	14‰	±2‰	23‰	±2‰	18‰	±4‰
21	17‰	±3‰	20‰	±2‰		
7	14‰	±2‰	20‰	±2‰	13‰	±1‰
12	15‰	±3‰	18‰	±3‰	12‰	±1‰
Mean CI		±2‰		±2‰		±2‰
2σ		±2‰		±2‰		±2‰

Table 2: Groupings based on enamel $\delta^{18}O$ to which individuals from the Fidler Mounds sample belong

Individual	Group 1	Group 2	Group 3
Burial 7	x		
Burial 9	x		
Burial 10			x
Burial 11		x	
Burial 12	x	x	
Burial 15		x	x
Burial 17		x	
Burial 19	x		

Burial 21	x		
Fill A		x	
Fill B	x	x	
Fill LRC		x	x

Table 3: Groupings based on dentin $\delta^{18}O$ to which individuals from the Fidler Mounds sample belong

Individual	**Group 1**	**Group 2**
Burial 7	x	
Burial 9	x	
Burial 10		x
Burial 11	x	x
Burial 12	x	x
Burial 15	x	x
Burial 17	x	x
Burial 19	x	x
Burial 21	x	
Fill A	x	x
Fill B	x	x
Fill LRC	x	x

Table 4: Groupings based on cementum $\delta^{18}O$ to which individuals from the Fidler Mounds sample belong

Individual	Group 1	Group 2	Group 3
Burial 7	x	x	
Burial 9	x		
Burial 10			x
Burial 11	x	x	
Burial 12	x	x	
Burial 15		x	
Burial 17	x	x	
Burial 19	x	x	
Fill A	x	x	
Fill B	x	x	
Fill LRC		x	

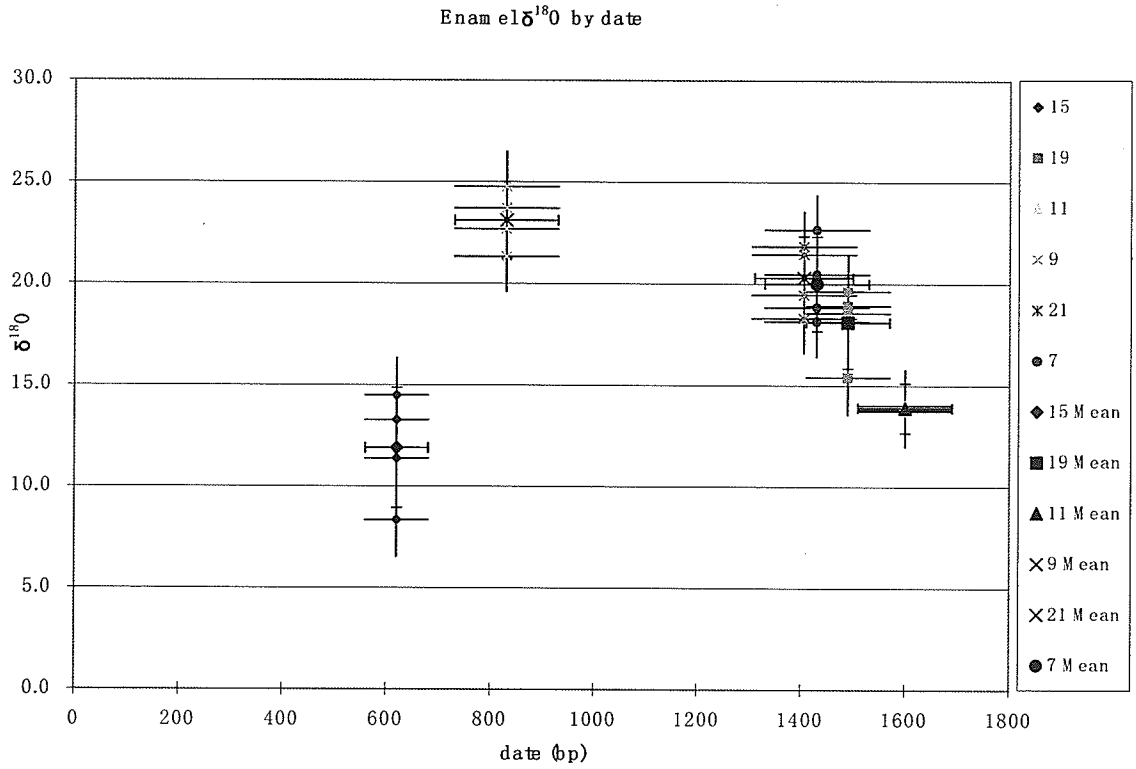

Figure 4: Plot showing mean enamel $\delta^{18}O$ values against radiocarbon age in years before present (BP) as obtained by Hewitt (2004). Error bars represent 95% confidence intervals around the results of each analysis. Black symbols with footed error bars represent mean values with 95% confidence intervals.

When the $\delta^{18}O$ values of enamel are plotted against radiocarbon ages (Figure 4), there is statistically significant inter-individual mean $\delta^{18}O$ variability within both the recent (630-930BP) and older burial (1310-1690BP) groups identified by Hewitt (2004). Dentin and cementum $\delta^{18}O$ values follow a roughly similar distribution, although some slight differences exist (Figures 5 and 6). For instance, when enamel $\delta^{18}O$ is plotted against radiocarbon age, there appears to be a larger range of $\delta^{18}O$ values between individuals in the more recent group than in the older group. While the same pattern is evident when cementum $\delta^{18}O$ is plotted against radiocarbon age (Figure 6), when dentin $\delta^{18}O$ values are considered, there is a similar degree of inter-individual variation in both radiocarbon-defined groups (Figure 5).

There is no significant relationship between the enamel, dentin or cementum $\delta^{18}O$ values obtained in this study and the bone collagen $\delta^{13}C$ values obtained by Garvie (1993) (Figures 7, 8 and 9). The young women identified by Garvie (1993) as potential immigrant brides due to their abnormally high bone collagen $\delta^{13}C$ values (Burials 12, with a $\delta^{13}C$ value of 16.6‰, 15 at 14.4‰ and 21 at 17.7‰) have enamel, dentin and cementum $\delta^{18}O$ values similar to those with "normal" $\delta^{13}C$ values (~19-20‰).

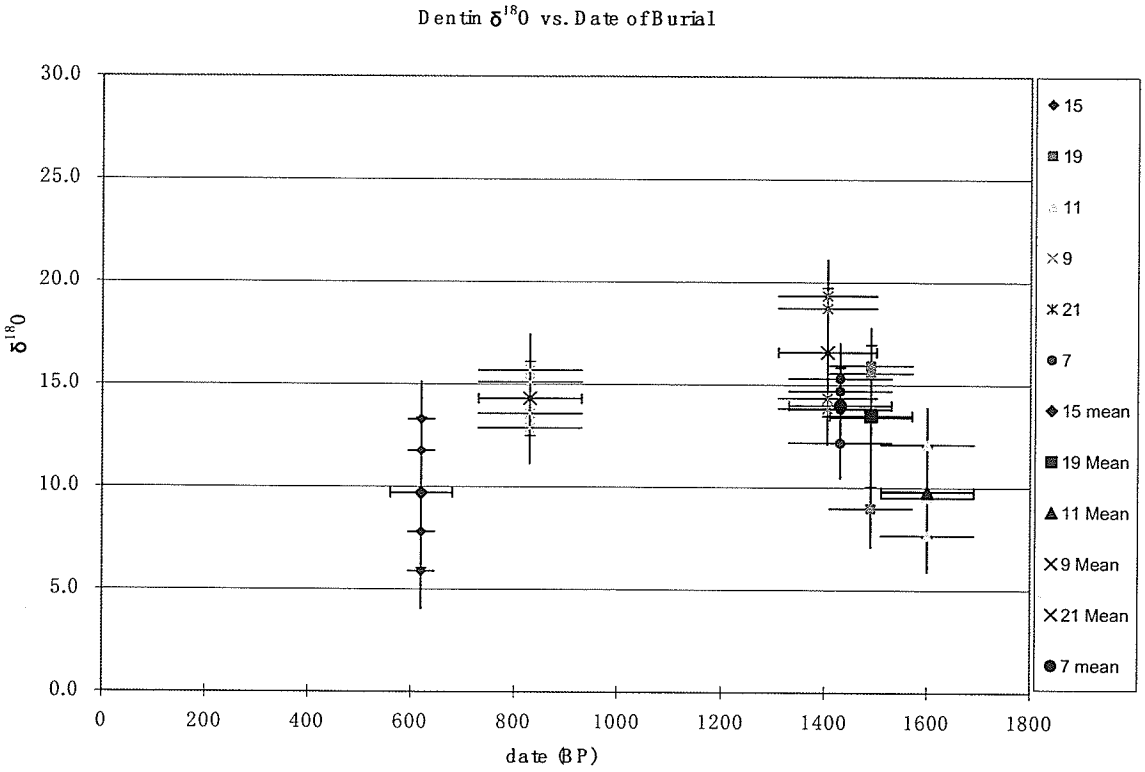

Figure 5: Plot showing individual mean dentin $\delta^{18}O$ values against radiocarbon age in years before present (BP) as obtained by Hewitt (2004). Error bars represent 95% confidence intervals around the results of each analysis. Black symbols with footed error bars represent mean values with 95% confidence intervals

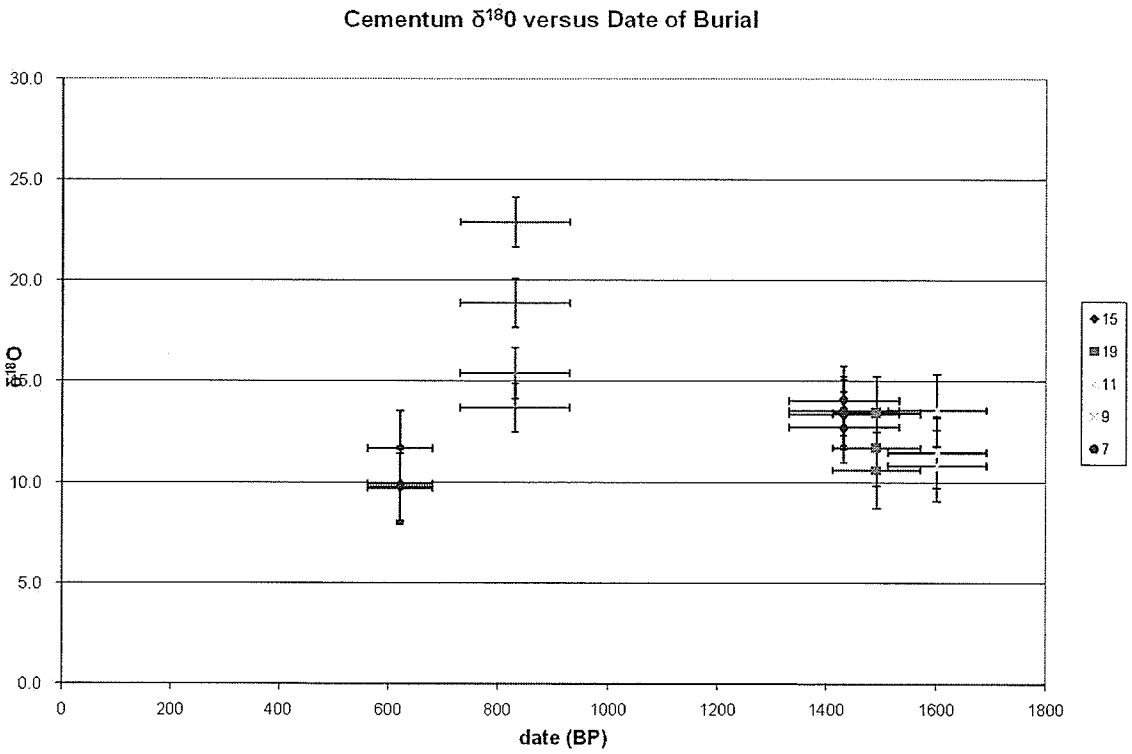

Figure 6: Plot showing individual mean cementum $\delta^{18}O$ values against radiocarbon age in years before present (BP) as obtained by Hewitt (2004). Error bars represent 95% confidence intervals around the results of each analysis. Black symbols with footed error bars represent mean values with 95% confidence intervals.

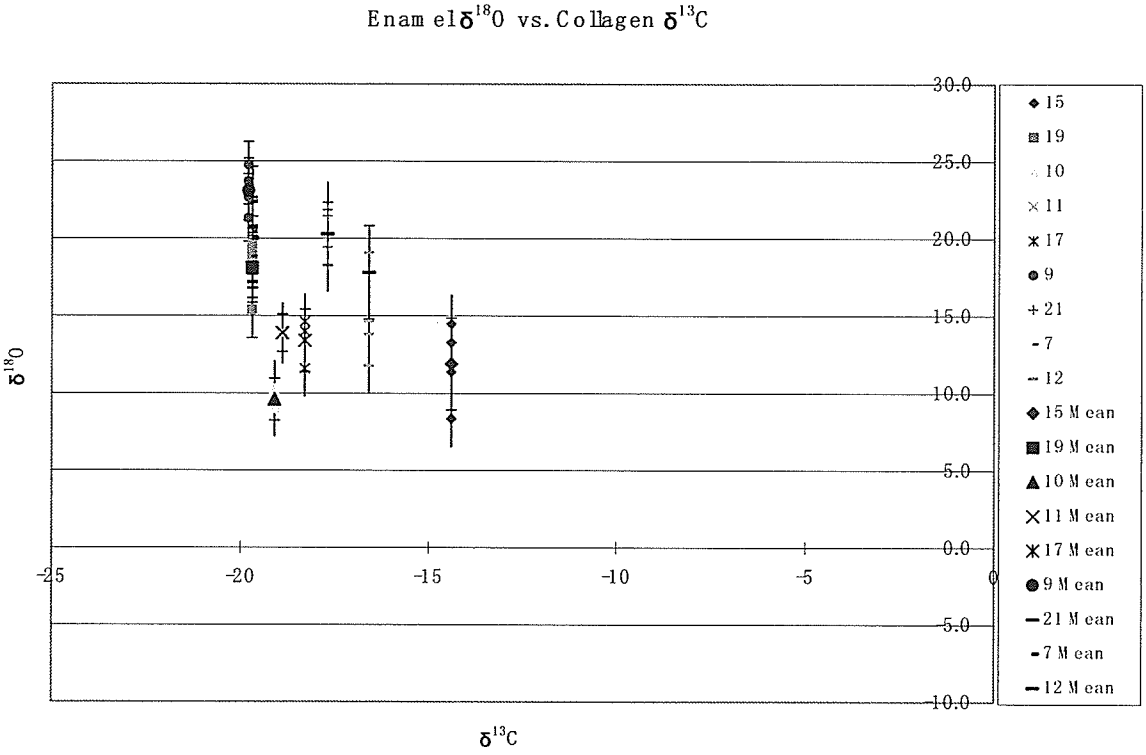

Figure 7: Plot showing individual mean enamel $\delta^{18}O$ values against $\delta^{13}C$ values obtained by Garvie (1993). Error bars represent 95% confidence intervals around the results of each analysis. Black symbols with footed error bars represent mean values with 95% confidence intervals.

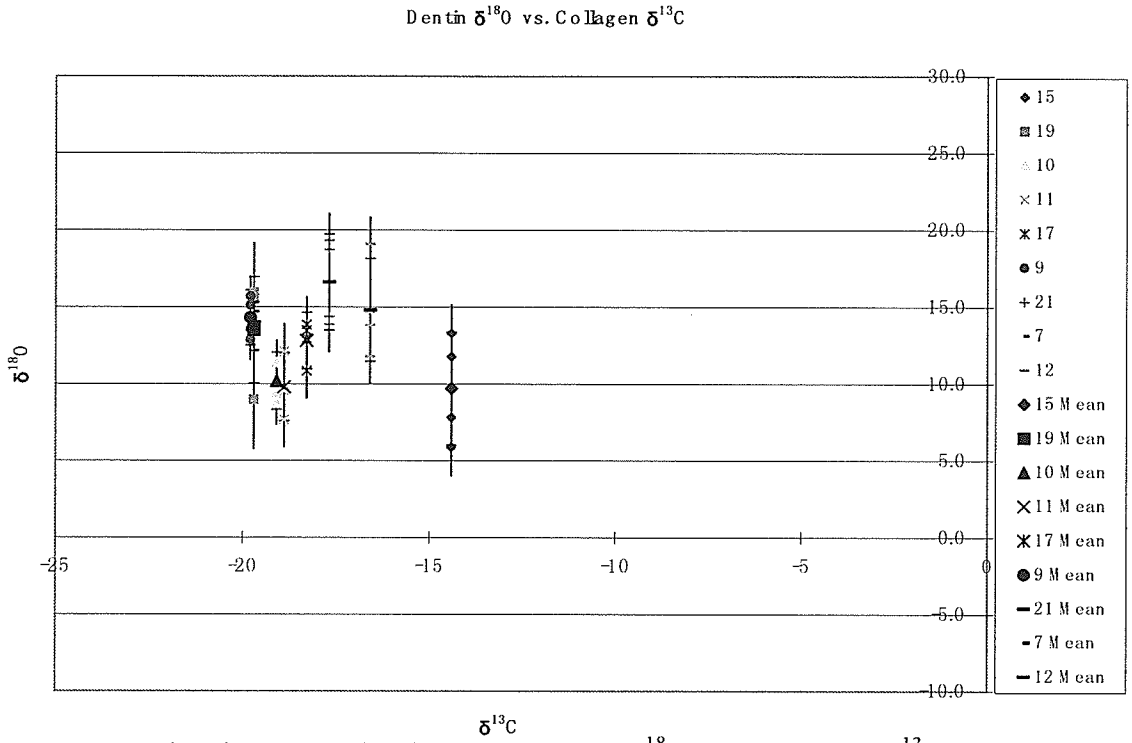

Figure 8: Plot showing individual mean dentin $\delta^{18}O$ values against $\delta^{13}C$ values obtained by Garvie (1993). Error bars represent 95% confidence intervals around the results of each analysis. Black symbols with footed error bars represent mean values with 95% confidence intervals.

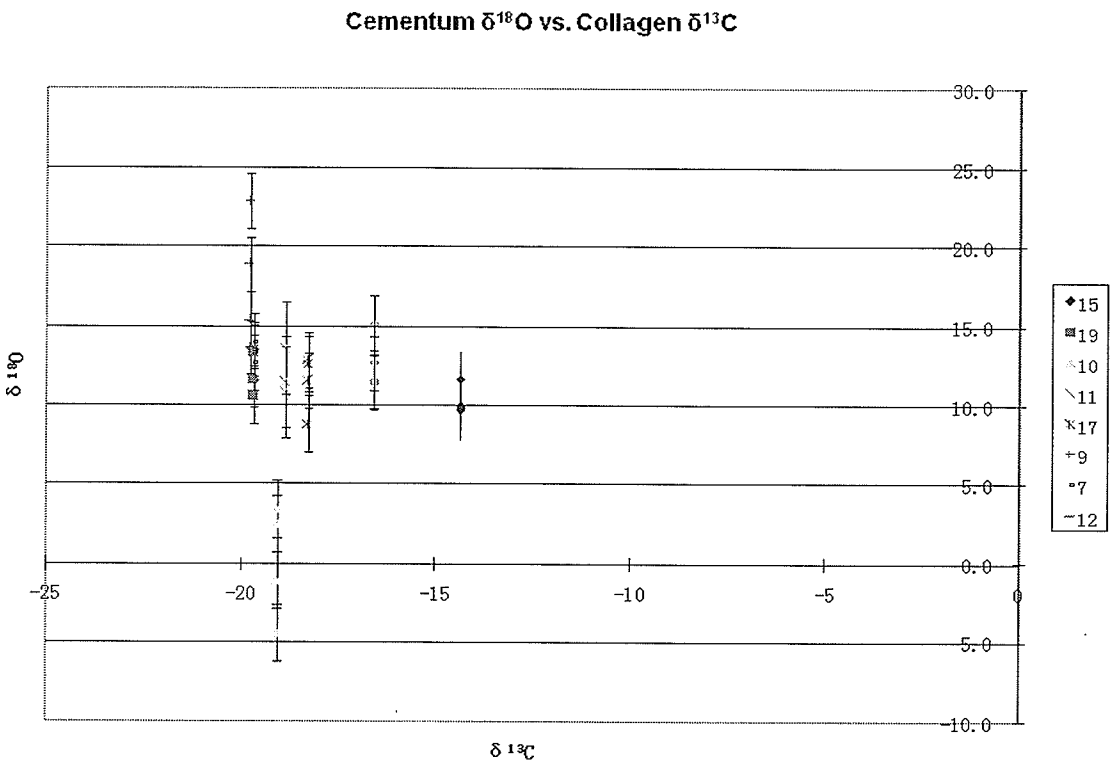

Figure 9: Plot showing individual mean cementum $\delta^{18}O$ values against $\delta^{13}C$ values obtained by Garvie (1993). Error bars represent 95% confidence intervals around the results of each analysis. Black symbols with footed error bars represent mean values with 95% confidence intervals.

Hypotheses regarding individual or population mobility founded on comparisons of inter-tissue $\delta^{18}O$ values obtained by SIMS must be considered preliminary at best, and fraught with potential difficulties at worst, due to the lack of suitable externally calibrated standards for dentin, cementum and enamel. However, while the interpretation of these kinds of data is, at this point, problematic and founded on several large assumptions, statements regarding intra-individual $\delta^{18}O$ variation in the population from the Fidler Mounds can certainly be made and may be important to further work aimed at simplifying future interpretations of multi-tissue SIMS analyses.

For the purposes of this study, the individuals analyzed are divided into two groups: those that show statistically significant variation in $\delta^{18}O$ between enamel, representing childhood $\delta^{18}O$ values, and cementum, which represents $\delta^{18}O$ values accumulated over a larger span of the lifetime, and those who show no significant variation in $\delta^{18}O$ between these two tissues.

Six individuals fit into the first category, Burials 7, 10, 12, 19, and Fill A and Fill B (Figures 10-15). Burial 7 is a man aged 25-35, who died between AD1330 and AD1530 (Saylor, 1976; Hewitt, 2004). This individual has a mean $\delta^{18}O$ value for enamel of 20 ± 2 ‰, a mean dentin $\delta^{18}O$ value of 14 ±2‰ and a mean cementum $\delta^{18}O$ value of 13 ± 1‰. The $\delta^{18}O$ values for dentin and cementum overlap, while enamel $\delta^{18}O$ value is distinct (Figure 10).

This individual exhibits statistically indistinguishable single analysis $\delta^{18}O$ values within both his dentin and cementum. However, two significantly differen

t $\delta^{18}O$ values were obtained during the course of *in situ* enamel analysis (18±2‰; 22±2‰)

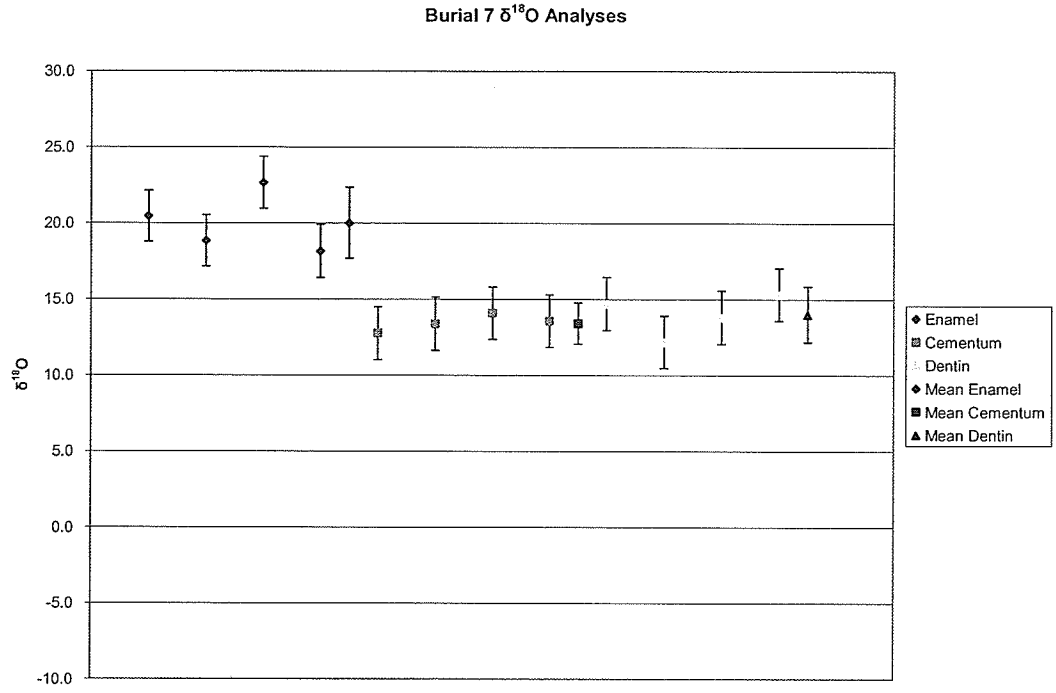

Figure 10: Burial 7 mean enamel, dentin and cementum $\delta^{18}O$ values in parts permil (‰). Black symbols represent mean $\delta^{18}O$ value of the data set directly to their left. Black bars represent 95% confidence intervals.

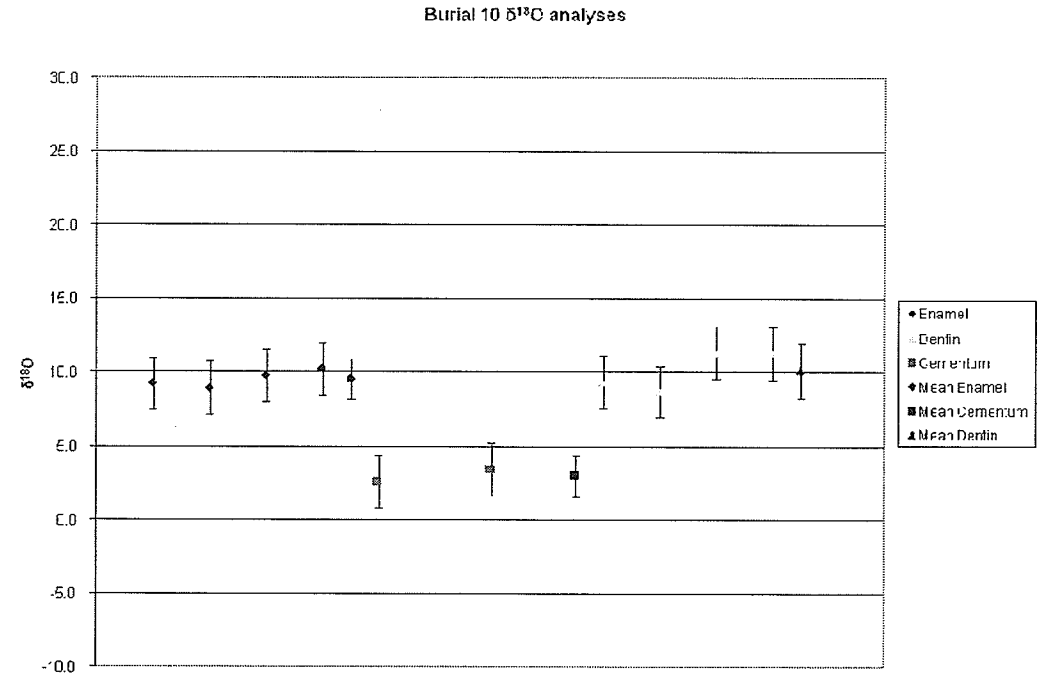

Figure 11: Burial 10 enamel, dentin and cementum $\delta^{18}O$ values in parts permil (‰). Black symbols represent mean $\delta^{18}O$ value of the data set directly to their left. Black bars represent 95% confidence intervals.

Burial 10 is a 35-50 year old woman (Saylor, 1976). She exhibits a mean enamel $\delta^{18}O$ value of 10±1, a mean dentin $\delta^{18}O$ value of 10±2‰ and the lowest mean cementum $\delta^{18}O$ value of the analyzed Fidler Mounds population at 3±1‰ (Figure 11). Enamel and dentin $\delta^{18}O$ values overlap within this individual, while the recorded mean cementum $\delta^{18}O$ value is significantly lower than that of the other two tissues. Two of the cementum single analysis values obtained from this individual were excluded from the final data set because SE-SEM images showed that they were located on or proximal to cracks in the tissue (Figure 25). Only one isotopic signature was obtained from the remaining two analyses (Figure 11).

Burial 12 is an 18-25-year-old woman (Saylor, 1976). A mean enamel $\delta^{18}O$ value of 18±3‰, a mean dentin $\delta^{18}O$ value of 15±3‰ and a mean cementum $\delta^{18}O$ value of 12±1‰ have been obtained from this individual (Figure 12). The enamel and dentin $\delta^{18}O$ values overlap, whereas the dentin and cementum $\delta^{18}O$ values overlap. , however, mean enamel and cementum values are significantly different.

Dentin is the most heterogeneous of the three tissues, and exhibits two distinct $\delta^{18}O$ values (19±2‰; 12±2‰, 14±2‰, 15±2‰). Enamel is somewhat less heterogeneous, yet, once again, two distinct $\delta^{18}O$ values were obtained from this tissue (20±2‰; 15±2‰). Cementum is the most homogeneous of the three tissues analysed, and also includes two distinct $\delta^{18}O$ signatures (15±2‰; 12±2‰) (Figure 12).

Burial 19 is a man, aged 22-26, who died sometime between 1410 and 1570 BP (Saylor, 1976; Hewitt, 2004). Burial 19 has a mean enamel $\delta^{18}O$ value of 18.1±2.25‰, a mean dentin $\delta^{18}O$ value of 13.5±3.46‰ and a mean cementum $\delta^{18}O$ value of 12.3±1.91‰ (Figure 13). Single-spot analyses of Burial 19's dental tissues exhibit differing degrees

of intra-tissue variability between cementum, dentin and enamel. The dentin and enamel both exhibit two significantly different $\delta^{18}O$ values over four analyses (enamel: 20±2‰, 19±2‰; 15±2‰ dentin: 16±2‰, 13±2‰; 9±2‰) while all values obtained from cementum are the same (15±2‰, 11±2‰) (Figure 13).

Fill A is represented by a single canine tooth excavated from mound fill and, as such, it has no provenience and has not been dated or sexed. This individual has a mean enamel $\delta^{18}O$ value of 15.4±1.36‰, a mean dentin $\delta^{18}O$ value of 13.2±2.94‰ and a mean cementum $\delta^{18}O$ value of 11±2.18‰ (Figure 14). The mean dentin and enamel $\delta^{18}O$ values obtained from this individual overlap, as do the cementum and dentin $\delta^{18}O$, while mean enamel and cementum $\delta^{18}O$ values are distinct.

This individual's enamel $\delta^{18}O$ values are quite similar over the four analyses conducted on this tissue, while two significantly different $\delta^{18}O$ values were obtained from similar analysis of dentin and cementum (dentin: 16±2‰, 15±2‰; 12±2‰, 10±2‰ cementum: 13±2‰; 10±2‰, 9±2‰) (Figure 14)

The last individual in this group, Fill B, is also represented by a single tooth, and so represented by a single tooth excavated from mound fill. This individual has not been sexed or aged. Additionally, no radiocarbon analysis has been undertaken on Fill B. Because of its exceptional preservation and lack of wear, dentin from the Fill B canine was used as this study's internal standard. This tooth exhibited some decay on the labial enamel surface. The tissue surrounding this defect was not analyzed.

This individual has a mean enamel $\delta^{18}O$ value of 19±2‰, a mean dentin $\delta^{18}O$ value of 15±2‰ and a cementum $\delta^{18}O$ value of 12.±2‰ (Figure 15). Dentin and enamel mean $\delta^{18}O$ values obtained from this individual are not significantly different, while Fill

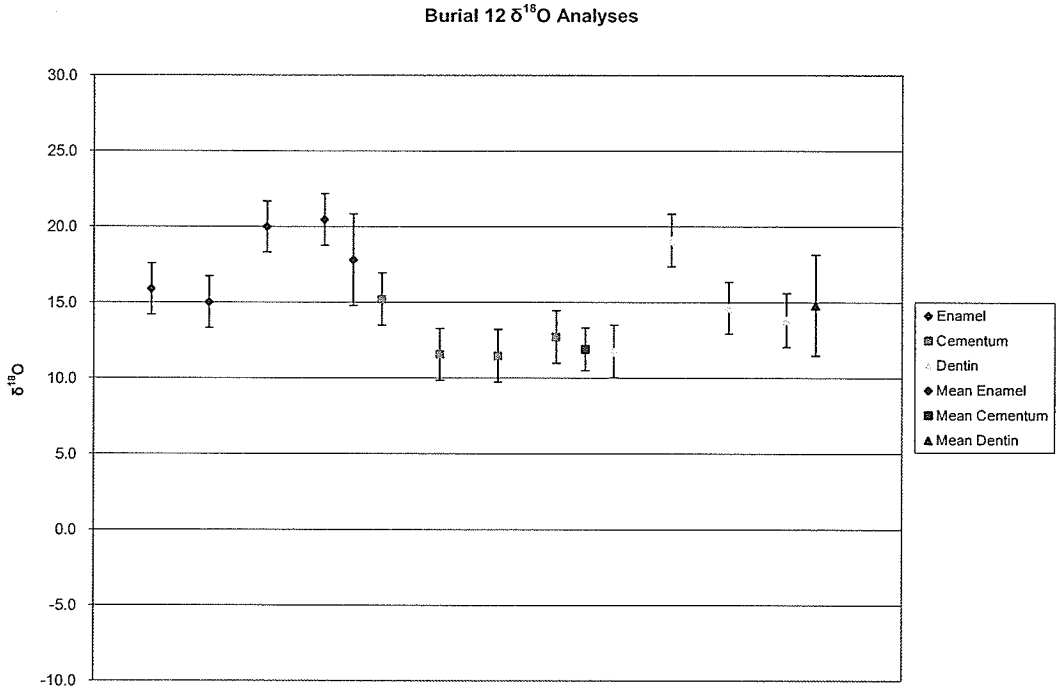

Figure 12: Burial 12 mean enamel, dentin and cementum $\delta^{18}O$ values in parts permil (‰). Black symbols represent mean $\delta^{18}O$ value of the data set directly to their left. Black bars represent 95% confidence intervals.

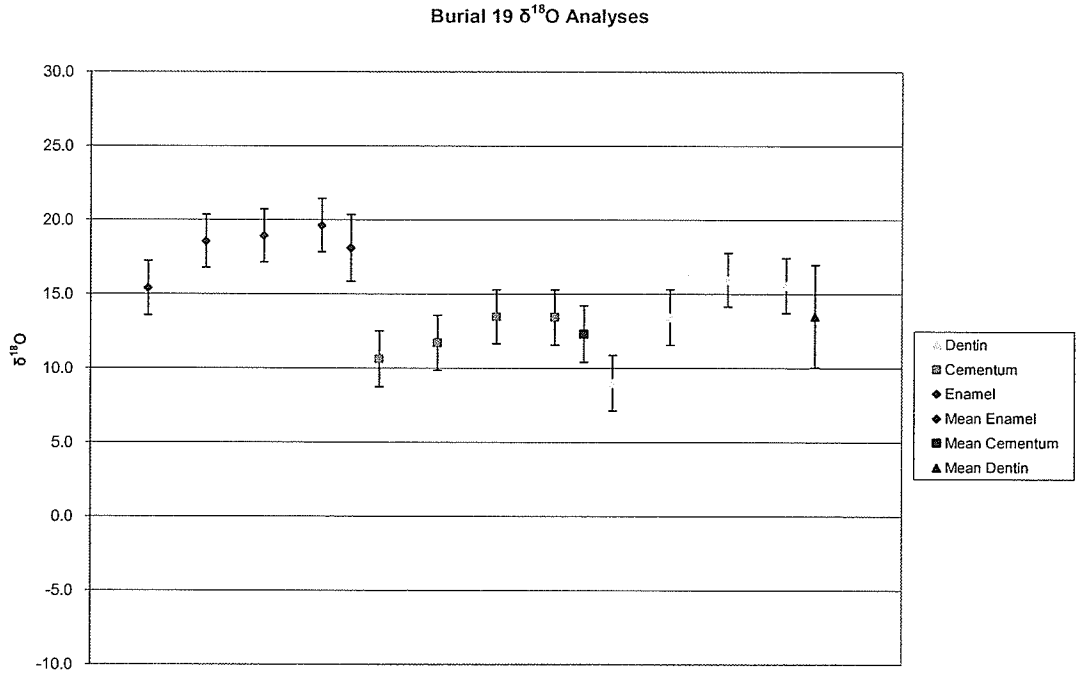

Figure 13: Burial 19 mean enamel, dentin and cementum $\delta^{18}O$ values in parts permil (‰). Black symbols represent mean $\delta^{18}O$ value of the data set directly to their left. Black bars represent 95% confidence intervals.

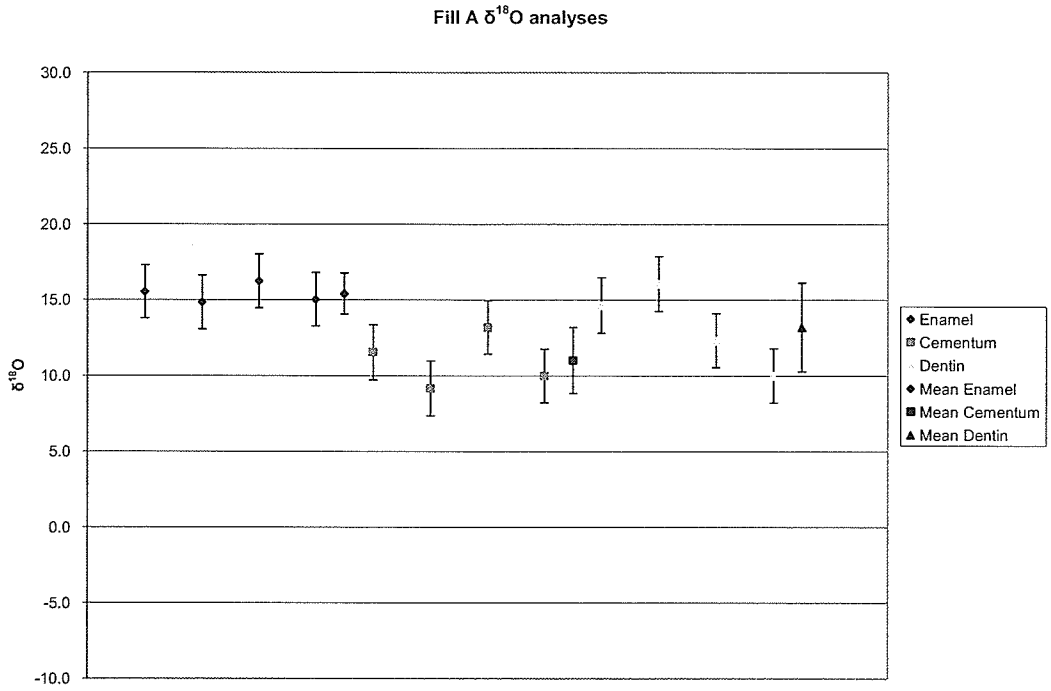

Figure 14: Fill A mean enamel, dentin and cementum $\delta^{18}O$ values in parts permil (‰). Black symbols represent mean $\delta^{18}O$ value of the data set directly to their left. Black bars represent 95% confidence intervals.

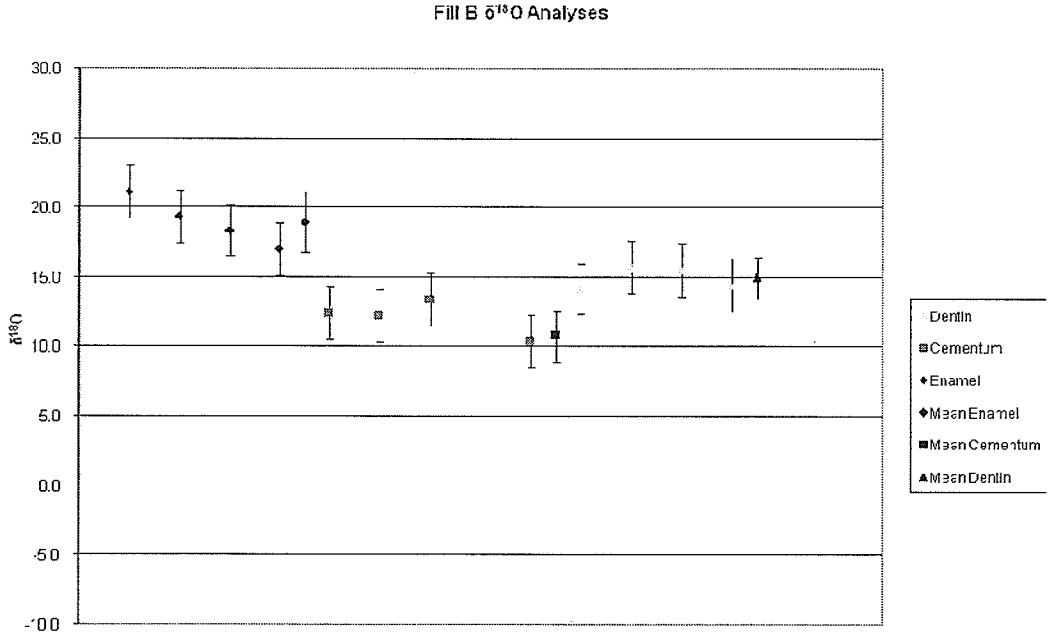

Figure 15: Fill B mean enamel, dentin and cementum $\delta^{18}O$ values in parts permil (‰). Black symbols represent mean $\delta^{18}O$ value of the data set directly to their left. Black bars represent 95% confidence intervals.

Dentin is the most homogeneous of this individual's tissues, as all four analyses produced B's mean cementum $\delta^{18}O$ value is significantly different from that obtained from both other dental tissues statistically indistinguishable results, making it an ideal internal standard. Enamel and cementum, however, were less homogeneous, and each exhibits two distinct $\delta^{18}O$ signatures over the four in situ analyses conducted (enamel: 21±2‰; 18±2‰, 17±2‰ cementum: 14±2‰; 10±2‰) (Figure 15).

The rest of the individuals from this population (Burials 9, 11, 15, 17 and Fill LRC) do not show statistically significant variation between enamel $\delta^{18}O$ and cementum $\delta^{18}O$ values (Figs 16-21).

Burial 9 is a child aged 7-8 who was radiocarbon dated to 730AD-830AD. Because this individual is a subadult, they could not be sexed (Saylor, 1976; Hewitt, 2004). Burial 9 has the highest mean enamel $\delta^{18}O$ value out of the entire Fidler Mounds population at 23.1±1.9‰, a mean dentin $\delta^{18}O$ value of 14.3±1.8‰ and a mean cementum $\delta^{18}O$ value of 17.7±4.25‰ (Figure 16). The mean dentin and enamel $\delta^{18}O$ values do not overlap, however, the relatively large range in data associated with cementum $\delta^{18}O$ value overlaps with both of the other tissues.

There is no difference between the four $\delta^{18}O$ values obtained from dentin or enamel analysis of Burial 9. However, this individual's cementum exhibits two significantly distinct $\delta^{18}O$ values over four analyses (23±2‰; 15±2‰; 14±2‰) (Figure 16).

Burial 11 is a male over 40 years of age who died sometime between AD1510 and AD1690 (Saylor, 1976; Hewitt, 2004). He exhibits a mean enamel $\delta^{18}O$ value of 13.9 ± 1.22‰ a mean dentin $\delta^{18}O$ value of 9.8±2.21‰ and a mean cementum $\delta^{18}O$ value of 11.9±1.73‰ (Figure 17). Mean enamel and cementum $\delta^{18}O$ values are not significantly

different at 95%. Mean cementum and dentin $\delta^{18}O$ values are similarly indistinct. There is no significant intra-tissue difference between single analysis $\delta^{18}O$ values obtained from this individual's dentin, cementum or enamel (Figure 17)

. Burial 15 is a woman aged 25-35 years old who died between AD560 and AD680 (Saylor, 1976; Hewitt, 1976). She was identified by Garvie (1993) as having an abnormally high bone collagen $\delta^{13}C$ value, suggesting that C_4 plants may have played a larger role in this woman's diet than in the diets of other Fidler Mounds individuals. It was suggested that she may have been a non-local woman brought up from southern regions, where maize agriculture was more prevalent, as a bride for a local man (Garvie, 1993). She exhibits a mean enamel $\delta^{18}O$ value of 11.9±2.96‰, a mean dentin $\delta^{18}O$ value of 9.7±3.67‰ and a mean cementum $\delta^{18}O$ value of 9.8±1.25‰ (Figure 18). The data from all three dental tissue overlap. Two significantly distinct $\delta^{18}O$ signatures were obtained from Burial 15's dentin (13±2‰, 12±2‰; 8±2‰, 6±2‰) and enamel (15±2‰; 8±2‰), while cementum values were, for all intents and purposes, the same (Figure 18).

Burial 17 is a woman aged 50+, who has not been radiocarbon dated (Saylor, 1976). She has a mean enamel $\delta^{18}O$ value of 13.4±2.01‰, a mean dentin $\delta^{18}O$ value of 12.8±1.83‰ and a mean cementum $\delta^{18}O$ value of 11.5±2.22‰ (Figure 19). The $\delta^{18}O$ values from all three dental tissues are similar. Her enamel and dentin single analysis $\delta^{18}O$ values are statistically indistinguishable, while her cementum single analysis values display two significantly different $\delta^{18}O$ signatures (13±2‰; 10±2‰, 9±2‰) (Figure 19).

Burial 21 is a 17-23-year-old woman who was radiocarbon dated to AD1310-AD1500 (Saylor, 1976; Hewitt, 2004). This individual was identified by Garvie (1993) as having an abnormally high bone collagen$\delta^{13}C$ value, suggesting that she was a "foreign"

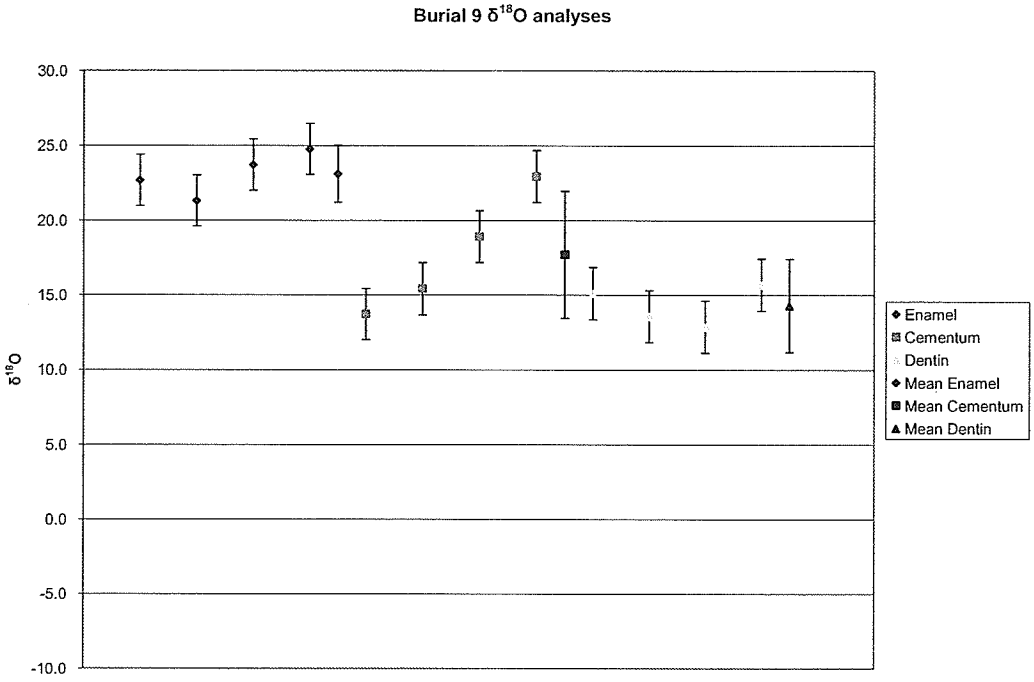

Figure 16: Burial 9 mean enamel, dentin and cementum $\delta^{18}O$ values in parts permil (‰).Black symbols represent mean $\delta^{18}O$ value of the data set directly to their left. Black bars represent 95% confidence intervals.

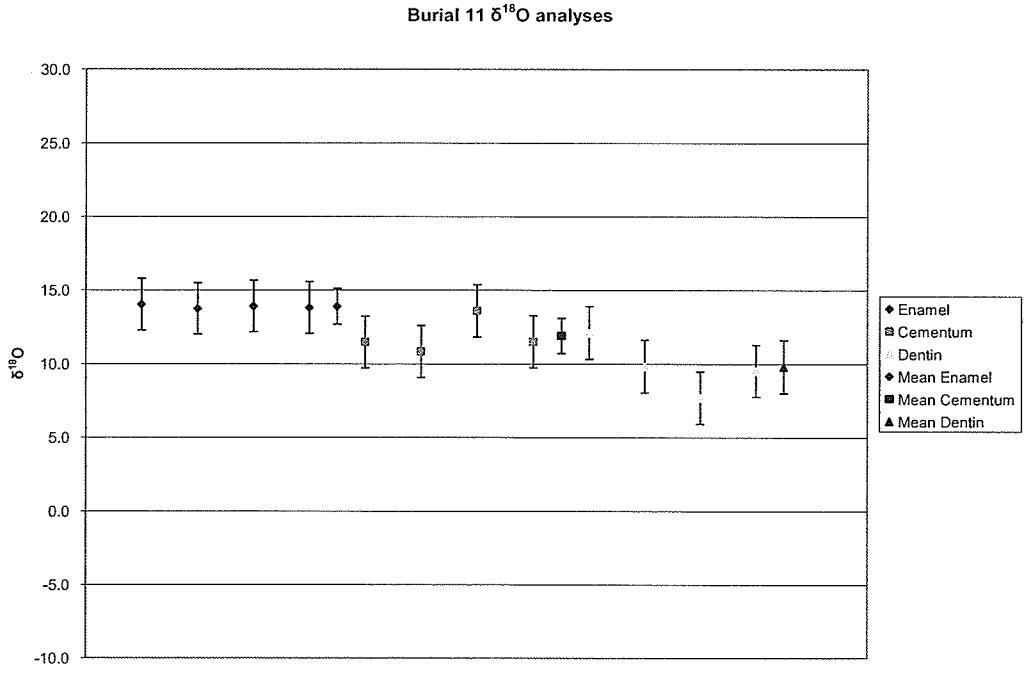

Figure 17: Burial 11 mean enamel, dentin and cementum $\delta^{18}O$ values in parts permil (‰). Black symbols represent mean $\delta^{18}O$ value of the data set directly to their left. Black bars represent 95% confidence intervals.

individual. Burial 21 has a mean enamel $\delta^{18}O$ value of 20.3±2.04‰ and a mean dentin $\delta^{18}O$ value of 16.6±3.12‰ (Figure 20). Cementum data were excluded from this study because BSE-SEM images showed these data were not obtained from cementum but were obtained from the cementodentin junction (Figure 28). In this individual the mean enamel and dentin $\delta^{18}O$ values overlap. Both of the tissues sampled from this individual exhibit two significantly distinct $\delta^{18}O$ values (enamel: 22±2‰; 18±2‰ dentin: 19±2‰; 14±2‰) (Figure 20).

In Burial 21, SEM imaging showed that cementum was not analyzed. Values thought to represent cementum from Burial 21 were excluded from further analysis (Figure 26). SE-SEM analysis confirmed that two of the cementum values obtained from Burial 10 were placed on or directly beside tissue cracks (Figure 23-24). These values were also excluded from the analysis. BSE-SEM analysis of the three teeth revealed that dentin was, in all cases, far more porous than was readily visible through transmitted light microscopy or the SIMS imaging systems. Visualization of this porosity was serendipitously aided by the gold coating previously applied to the sample surfaces. While almost all of the gold sputtered onto the sample surface was removed via the methods described above, many of the pores within the dentin of each tooth retained a small amount of gold coating (See Figure 22). This gold was highly visible under both SE and BSE-SEM, and showed that SIMS analyses on the three teeth imaged had been placed in areas of varying porosity (see Figure 23). This varying porosity presents a potential source of $\delta^{18}O$ variability other than living body chemistry. Epoxy used in standard embedding procedures – which are designed to ensure epoxy saturation of embedded samples – may have become trapped in dentin pores. If so, this would

introduce a matrix difference between areas of high porosity (high epoxy content) and areas of low porosity, which would result in these different areas producing different $\delta^{18}O$ values, even though they may originally have been isotopically homogeneous. Although, analyses of dentin were generally obtained from relatively non-porous areas near contact with enamel and cementum, porosity levels were not quantified during analysis, and thus, cannot be precisely accounted for in interpretation

Fill LRC is represented by a single tooth recovered from the mound fill, and has not been dated. This individual has a mean enamel $\delta^{18}O$ value of 12±4.52‰, a mean dentin $\delta^{18}O$ value of 11±1.56‰ and a mean cementum $\delta^{18}O$ value of 9.2±2.43‰ (Figure .21). This individual's mean enamel $\delta^{18}O$ value is not significantly different from dentin or cementum $\delta^{18}O$ values. All three of this individual's dental tissues exhibit two different $\delta^{18}O$ values when single analysis data is considered rather than mean values (enamel: 17±2‰; 10±2‰, 7±2‰ cementum: 12±2‰; 7±2‰ dentin: 15±2‰; 9±2‰) (Figure 21).

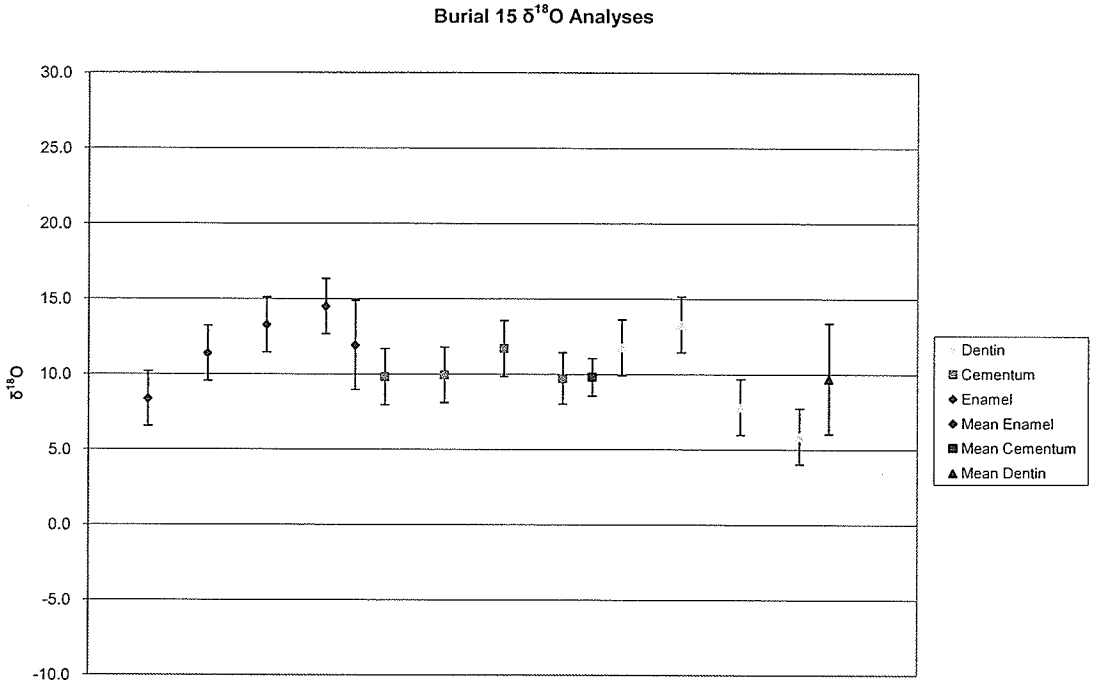

Figure 18: Burial 15 mean enamel, dentin and cementum $\delta^{18}O$ values in parts permil (‰). Black symbols represent mean $\delta^{18}O$ value of the data set directly to their left. Black bars represent 95% confidence intervals.

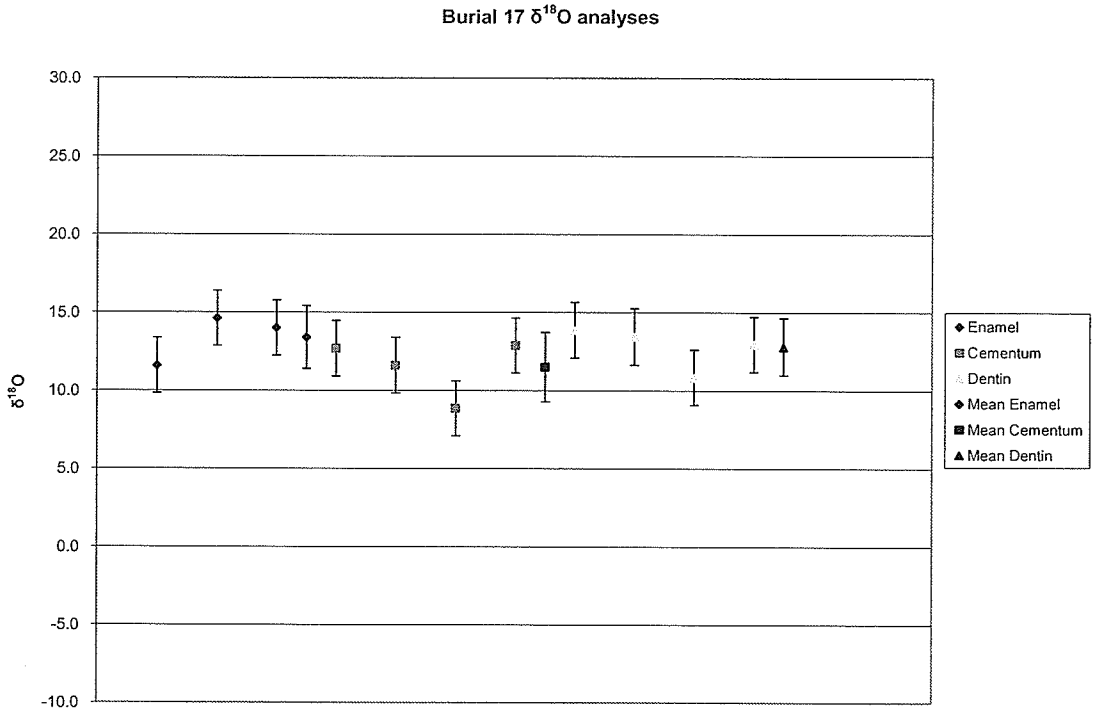

Figure 19: Burial 17 mean enamel, dentin and cementum $\delta^{18}O$ values in parts permil (‰). Black symbols represent mean $\delta^{18}O$ value of the data set directly to their left. Black bars represent 95% confidence intervals.

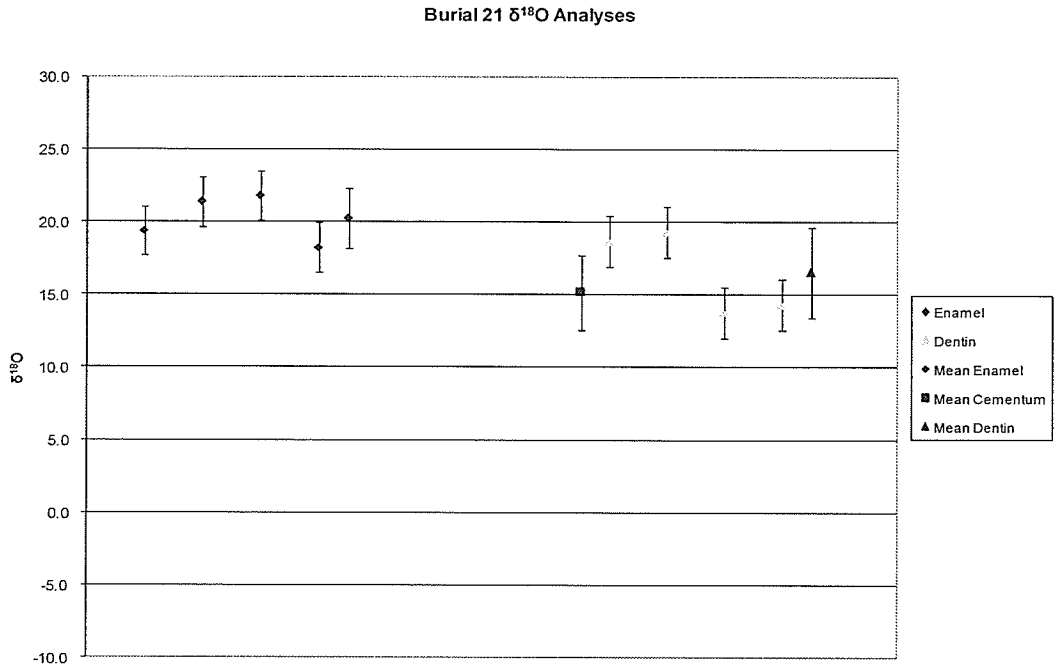

Figure 20: Burial 21 mean enamel, dentin and cementum $\delta^{18}O$ values in parts permil (‰). Black symbols represent mean $\delta^{18}O$ value of the data set directly to their left. Black bars represent 95% confidence intervals.

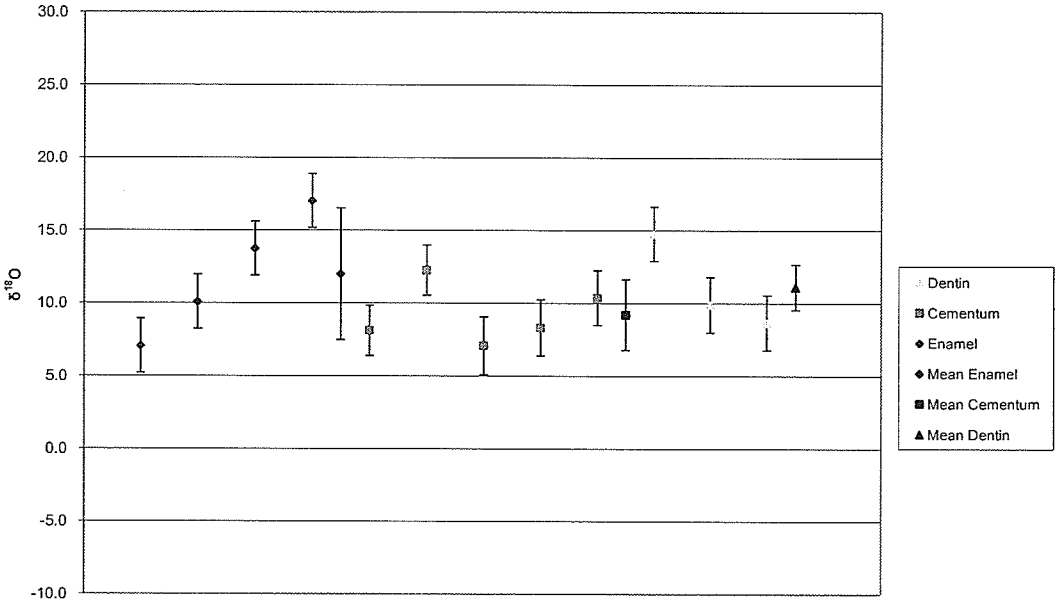

Figure 21: Fill LRC mean enamel, dentin and cementum $\delta^{18}O$ values in parts permil (‰). .Black symbols represent mean $\delta^{18}O$ value of the data set directly to their left. Black bars represent 95% confidence intervals.

Burials 10 and 21 and Fill B were selected for SE and BSE-SEM analysis (Figures 22-26). SIMS analysis test sites were imaged using both techniques to determine whether structural defects or chemical diagenesis, rather than actual, *in vivo* body chemistry, could possibly account for the $\delta^{18}O$ results obtained. It was not possible to locate any of the analysis craters within the enamel. This was not of great concern as enamel is known to be the least susceptible of all dental hard tissues to diagenetic alteration and was shown by SE-SEM to be generally less prone to structural imperfections than dentin or cementum. Test sites within dentin and cementum were located easily.

Backscattered electron images of cementum show that this tissue is compositionally heterogeneous (Figure 24). In some cases, these areas of differing chemical composition appear to be distributed in apicocoronal striae similar to annulations observed under transmitted light. This indicates that annulations formed during different years exhibit differences in chemical composition, the extent and cause of which would make a very interesting topic of research. In other samples, BSE and SE-SEM images showed areas of varying chemical composition distributed in striae running perpendicular to the expected angle of cementum annulations. These could represent cracks in the tissue caused by any number of diagenetic factors, including freeze-thaw or wet-dry cycles, or possibly from storage in a non climate-controlled laboratory atmosphere. The results of SIMS analyses placed on or near tissue voids are often inaccurate. Therefore, the ubiquity of these voids in the cementum of some individuals means that extreme caution must be exercised in interpreting $\delta^{18}O$ values obtained from archaeological cementum using SIMS

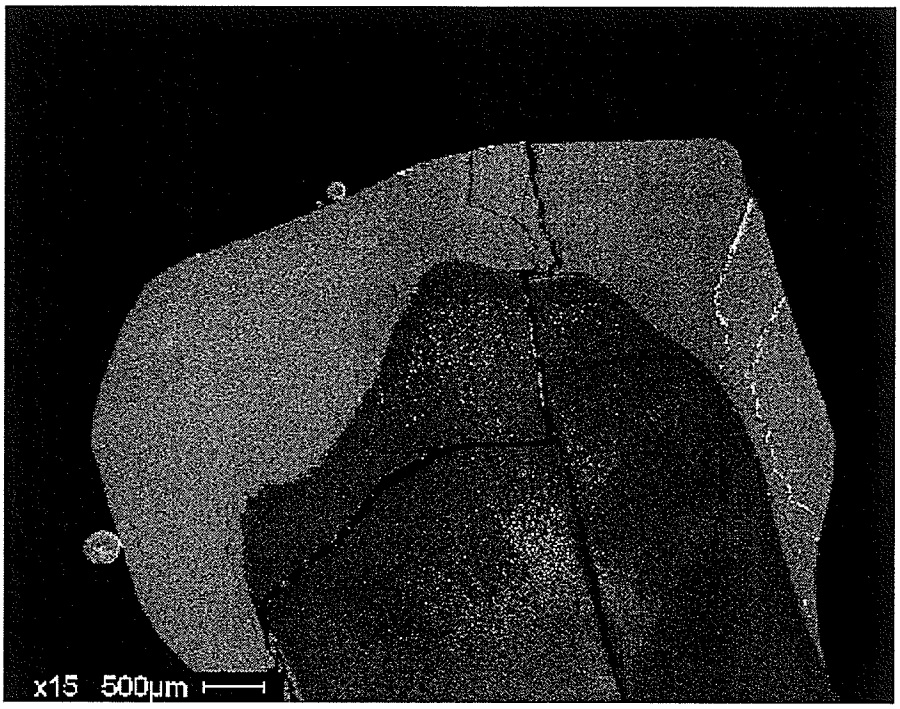

Figure 22: BSE-SEM image of canine from Burial 21. Note the luminescent points diffusing from the centre of the tooth. These are caused by minute amounts of gold coating trapped in dentin pores.

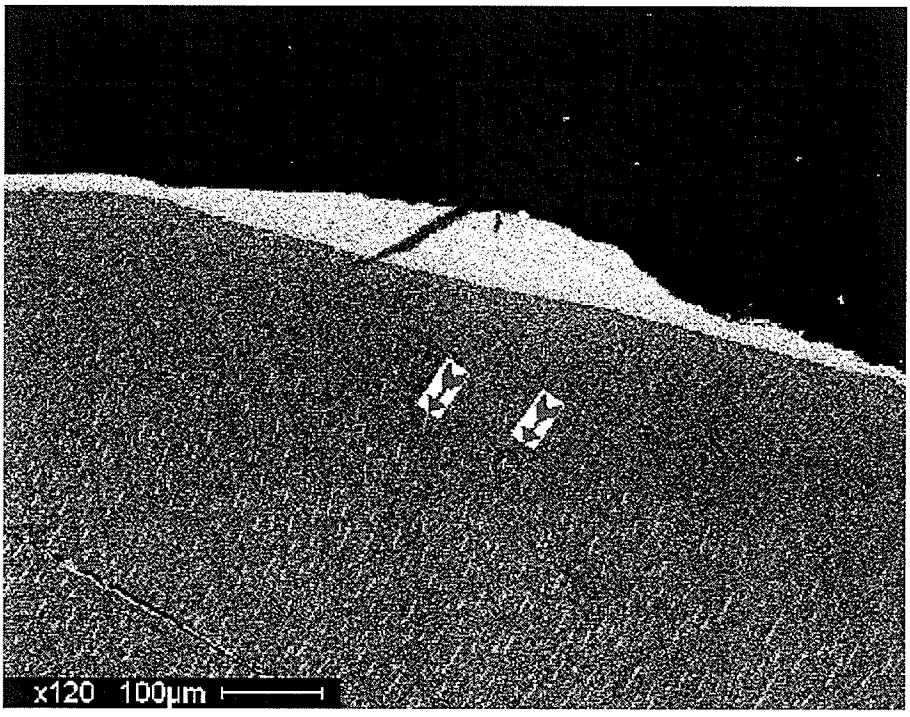

Figure 23: BSE-SEM image of Burial 10 showing enamel (light area) and dentin with pores (mottled grey). Arrows indicate SIMS analysis sites.

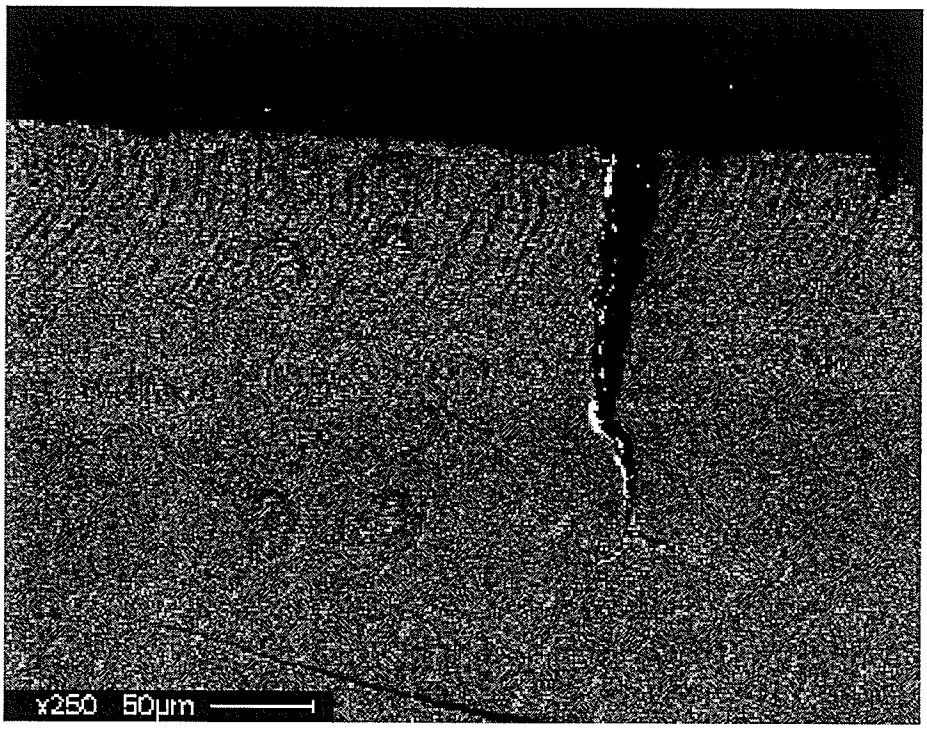

Figure 24: BSE-SEM image of cementum (top layer) from Burial 10. Note the compositional heterogeneity of cementum. Note horizontal and vertical striations within cementum.

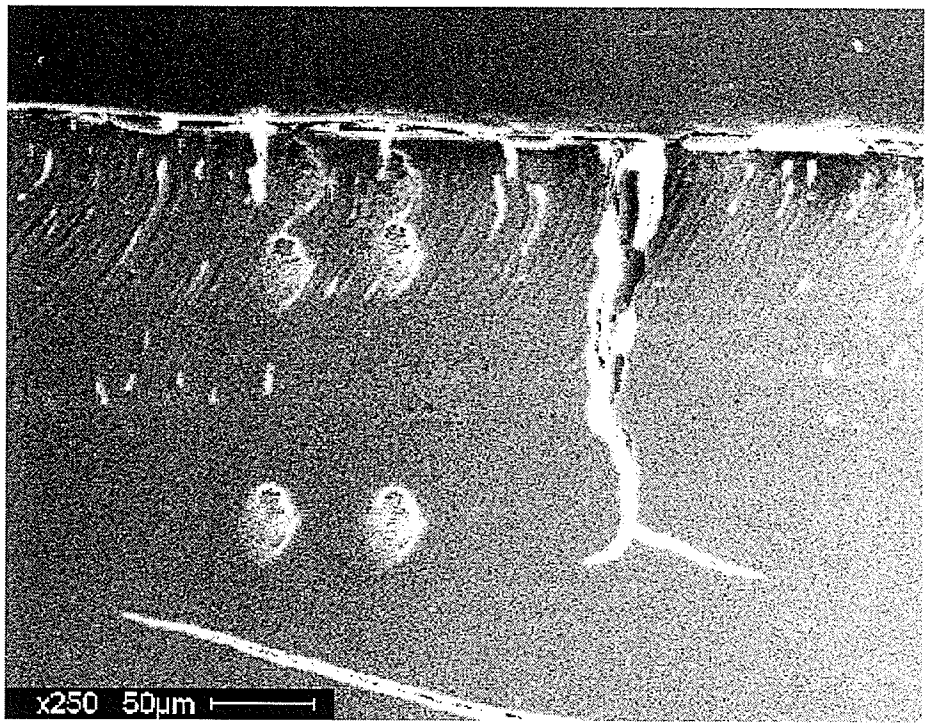

Figure 25: SE-SEM image of same showing location of SIMS analyses and tissue cracks.

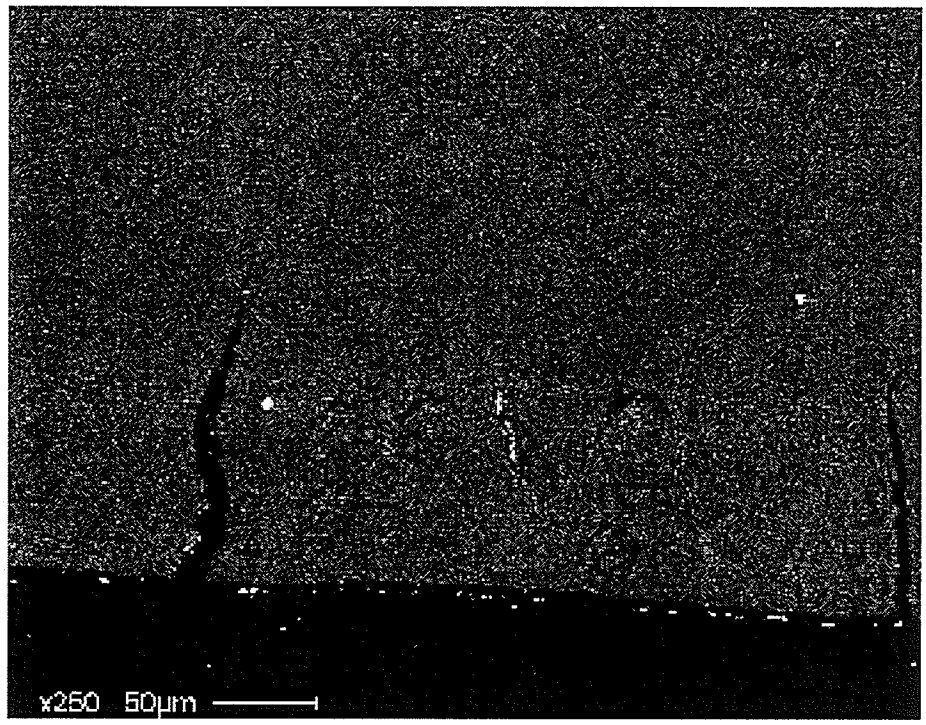

Figure 26: BSE-SEM image of cementum (bottom layer) from Fill B. Note faint horizontal striations within cementum.

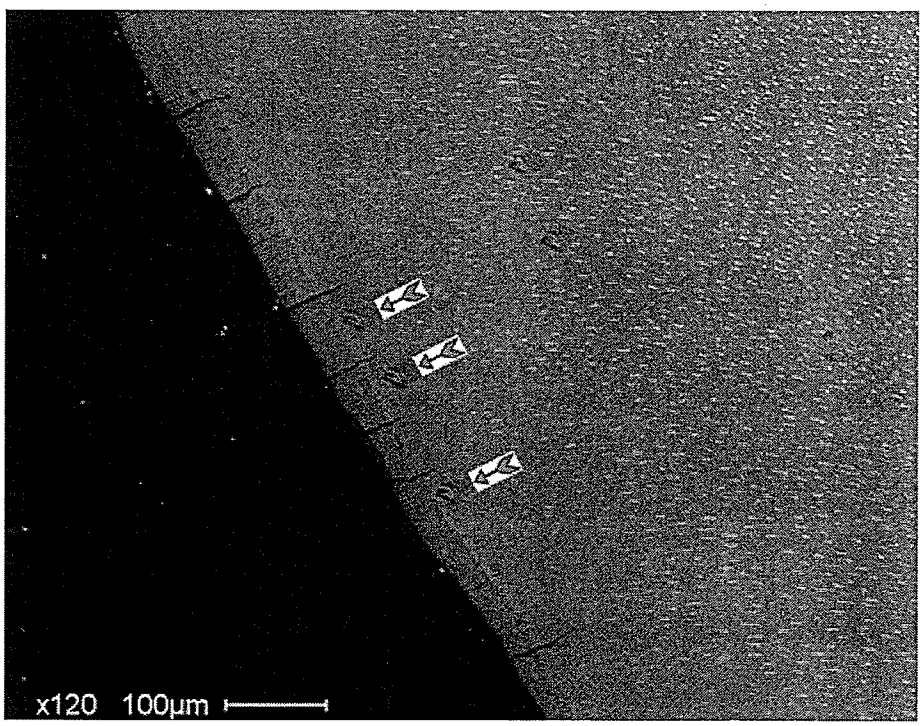

Figure 28: SE-SEM image of Burial 21 showing analyses mistakenly placed on cementodentin junction.

Chapter 5: Discussion

The Fidler Mounds population exhibits statistically significant inter-individual variation in mean $\delta^{18}O$ values within enamel, dentin and cementum samples. There are several potential explanations for this variation. First, inter-individual $\delta^{18}O$ variation could be interpreted as the result of diagenesis. It is widely acknowledged that cementum and dentin are prone to diagenetic alteration of original $\delta^{18}O$ values in post-burial environments (Kohn and Cerling, 2002; Hillson, 2005). Enamel, however, is considered relatively immune to post-burial isotopic contamination (Kohn and Cerling, 2002; Hillson, 2005). Post burial chemical alteration of dental tissues may have played some role in determining the results obtained by SIMS. While dentin and enamel appeared largely chemically homogeneous when analysed using BSE-SEM – which argues against diagenetic alteration, cementum was observed to be much more chemically heterogeneous. In some cases, the chemical composition of cementum varied from annulation to annulation as expected (Figure 24). However, some non-annular chemical variability and structural voids were also observed (Figs. 24 and 25). These could possibly represent diagenetic tissue alteration.

It is unlikely that inter-individual variation is the product of instrumental error. Standard dentin was analysed daily to monitor instrumental fluctuations, ensuring the comparability of analyses conducted on different days. The spot-to-spot reproducibility of the internal dentin standard was around 1‰, which suggests that instrumental factors alone could cause the range in δ18O values observed for some tissues.

The structural anomalies in dentin and cementum noted above could possibly introduce a source of variability other than *in vivo* body chemistry. Most dentin analyses were placed near the cementodentin or dentoenamel junctions, which are areas of relatively low porosity, so it is likely that this factor only slightly influences the results presented above. Large cracks in cementum can be avoided during SIMS analysis. However, small, widespread tissue voids apparent in SEM images of cementum surrounding some teeth are not visible during SIMS analysis. It is likely that some analyses were obtained on or near these voids, which would produce erroneous data that would not accurately reflect living body chemistry at the time of cementum formation.

Although diagenetic and structural variability in dental tissue can contribute to variation in $\delta^{18}O$ values, it is likely that much of the variation observed in Fidler Mounds dentin, cementum and enamel $\delta^{18}O$ is a reflection of actual, *in vivo* $\delta^{18}O$ variation within this population's dental tissues. Whether this variation is the product of variability in geographic origin and place of adult residence, however, is not entirely certain. While geographic location can be considered the major variable controlling individual tissue $\delta^{18}O$ values (Levinson *et al.*, 1987), and variability in place of origin or adult residence (depending on the dental tissue under analysis) is considered the main source of $\delta^{18}O$ variability within inter-individual samples (Levinson *et al.,* 1987), other human behaviours have been shown to contribute to variability in $\delta^{18}O$ values within populations (Wright and Schwarcz, 1998).

One behaviour pattern that can introduce non-geographically related dental tissue $\delta^{18}O$ value variation is breastfeeding (Wright and Schwarcz, 1998). For most individuals, the main factor determining body water $\delta^{18}O$ values (and, thus, dental tissue $\delta^{18}O$), is

drinking water $\delta^{18}O$ values (Longinelli *et al.*, 1984; Luz *et al.*, 1984; Luz and Kolodny, 1985; Levinson *et al.*, 1987). However, the major contributor to body water $\delta^{18}O$ values in breastfeeding infants is breast milk, which is always ^{18}O enriched relative to regional drinking water due to the fractionation that occurs between drinking water and breast milk within the lactating woman's body (Roberts *et al.*, 1988; Wright and Schwarcz, 1998). Therefore, the infant's body water and dental tissue will have higher $\delta^{18}O$ values (Roberts *et al.*, 1988). Thus, dental tissues formed during the period of breast milk consumption should have relatively higher $\delta^{18}O$ values than tissues formed after weaning (Wright and Schwarcz, 1998). Canine teeth form between 1 and 4 years of age (Liversidge, 2000), a period during which weaning has been shown to have taken place in some Plains populations (Tuross and Fogel, 1994). This could be an important contributing factor to $\delta^{18}O$ values obtained in this thesis. Study of the impact of breastfeeding behaviour on dental tissue $\delta^{18}O$ values has been preliminary thus far. Wright and Schwarcz (1998) suggest that enamel formed during periods of breastfeeding is enriched over post-weaning enamel by ~0.5-0.7%. It is interesting to note that the tooth with the highest mean enamel and cementum $\delta^{18}O$ values out of the entire sample was also the only deciduous tooth analysed (Burial 9). The mean dentin $\delta^{18}O$ value obtained from this tooth was also relatively high, surpassed only by the mean dentin $\delta^{18}O$ value obtained from Burial 21. Whether this is related to the fact that this tooth likely formed entirely *in utero* or during breastfeeding – during which infant $\delta^{18}O$ values would be derived exclusively from maternal sources – is unknown.

It is also possible that bacterial infection of dental tissues may have an effect on $\delta^{18}O$ values obtained from those tissues (Blake *et al.,* 1997). In geological systems,

anomalously depleted $\delta^{18}O$ values are often explained as the result of bacterial action, and bacteria are recognised as a threat to isotopic preservation in the burial environment (Blake *et al.*, 1997; Kohn *et al.*, 1999; Schoeninger and Moore, 1992). However, the effect on dental tissue $\delta^{18}O$ values of bacterial infections contracted *in vivo* has yet to be explored. Teeth with carious lesions are often excluded from studies of dental tissue isotopics due to suspected alteration (e.g. Daux *et al.*, 2005). Only one tooth from the Fidler Mounds showed an obvious carious lesion (Fill B). Areas near the lesion were not sampled.

All other population-level variability in Fidler Mounds dental tissue $\delta^{18}O$ values likely reflects inter-individual variability in body water $\delta^{18}O$. Body water $\delta^{18}O$ is, in turn, related to drinking water $\delta^{18}O$. The relationship between geographic region and meteoric water $\delta^{18}O$ values is clear and well established. However, the relationship between geography and *drinking* water $\delta^{18}O$ is somewhat more complicated. While meteoric water $\delta^{18}O$ is thought to be the major factor determining drinking water $\delta^{18}O$ (White *et al.*, 2004), populations may choose to utilize a drinking water resource with an isotopic signature different from that of local meteoric water.

For example, a population utilizing a distantly sourced river for drinking water will likely exhibit $\delta^{18}O$ values that are inconsistent with local meteoric water $\delta^{18}O$ values. Similarly, two populations located in areas with isotopically different meteoric water, but who use the same river as a drinking water source, will have similar $\delta^{18}O$ values, in spite of their geographic distance (White *et al.*, 2004). Fidler Mounds is located directly on the Red River, which originates at the confluence of the Otter Tail and Bois de Sioux Rivers in the United States, flows north for 885km and empties into Lake Winnipeg. It is

possible that the Red River provided a source of drinking water for people living in the vicinity of Fidler Mounds. If so, their dental tissue $\delta^{18}O$ values would be a reflection of water $\delta^{18}O$ values at the river's source, rather than local meteoric water $\delta^{18}O$ values. The overall effect of this phenomenon would be the minimisation of variation in inter-individual $\delta^{18}O$, potentially masking migrant individuals making use of this type of water resource throughout their travels.

Conversely, alternation between distantly-sourced and local, meteoric-source drinking water over a person's lifetime, could mimic the effects of a long-distance migration if each drinking water source was utilized consistently for a considerable period of time. It is uncertain whether this presents a potential problem for this study, specifically. The major potential drinking water resource of this type in the area of Fidler Mounds is the Red River. From source to mouth, much of the Red River and its two sources, the Otter Tail and Bois de Sioux Rivers, lie within a region characterized by modern distribution maps of precipitation $\delta^{18}O$ as relatively isotopically homogeneous (Bowen *et al.,* 2005). Therefore, the $\delta^{18}O$ value of water from the Red river should not be significantly different from local, meteoric water. However, it is not known whether this level of $\delta^{18}O$ homogeneity was in operation during the millennium or so over which Fidler Mounds was used as a cemetery. Meteoric water $\delta^{18}O$ distributions are not static; they depend upon a number of climatological factors, such as temperature, which change over time (Bentley and Knipper, 2005). It is possible that central North America was an area of greater meteoric $\delta^{18}O$ variability in the past. If this is the case, then it is possible that some of the variability observed in dental tissue $\delta^{18}O$ values obtained from the Fidler

Mounds individuals may be due to long-term changes in resource-use patterns between distant- and local-source drinking water.

Water that is stored in such a way that it is allowed to undergo evaporation will become ^{18}O enriched over time as ^{16}O is preferentially incorporated into water vapour. This enrichment occurs in water storage containers of all sizes, from ceramic pots, to dam reservoirs and in natural, enclosed sources such as ponds (White *et al.*, 2004; Wright and Schwarcz, 1998). This phenomenon is particularly pronounced in arid environments where evaporation occurs rapidly. In Manitoba, the degree to which evaporation has an effect on stored water $\delta^{18}O$ is likely seasonally determined. Mobility patterns consistent with precontact North American hunter-gatherer lifeways would likely rule out the long-term drinking water storage necessary to produce significant $\delta^{18}O$ enrichment, although naturally evaporated drinking water resources, such as ponds or oxbows may have been utilized on a seasonal basis. The degree to which this occurred cannot, of course, be quantified to the extent which would allow it to be accounted for in this study.

Whether or not changes in resource-use patterns between distantly sourced, meteoric and/or stored drinking water over an individual's lifetime have the potential to mimic the effects of long-distance migration needs to be investigated. The probability that peoples in the past confined themselves exclusively to directly meteoric-sourced drinking water is low, especially in areas where other sources of clean water are readily available (i.e. distantly sourced rivers or evaporated ponds). Some of the minor $\delta^{18}O$ variability observed within the population, specifically intra-tissue $\delta^{18}O$ variability, may be the result of drinking water resource choices. However, major variation, especially between mean tissue $\delta^{18}O$ values within the same individual are likely the result of the

drastic changes in drinking water chemistry that would likely be caused by a long-distance migration.

Meteoric water $\delta^{18}O$ is a reflection, in part, of regional climate, especially temperature (Dansgaard, 1964). Changes in regional climate, therefore, may affect meteoric water $\delta^{18}O$ values, which would, in turn, affect the dental tissue $\delta^{18}O$ values of populations utilizing those meteoric waters (Fricke *et al.*, 1995). When interpreting $\delta^{18}O$ values obtained from chronologically heterogeneous population, such as the one sampled in this study, it is important to rule out large-scale climatic events as a source of potential inter-individual $\delta^{18}O$ variability.

Over the roughly one thousand years that Fidler Mounds was used as a cemetery site, several major climatic changes took place. The most significant of these was the warming, drying trend which marked the beginning of the Medieval Warm Period c. AD800. During this period, which lasted until around AD1400, Europe, the North Atlantic and North America all experienced a trend towards warmer weather (Lamb, 1982). While this climatic phase was by no means experienced all over the globe as a monolithic increase in temperature, it is likely that during the MWP, mean annual temperatures in southern Manitoba would have been appreciably higher than during the preceding, cooler period (Flynn, 2002). Archaeologists point to this increase in temperature as one of the factors contributing to the spread of maize hoe-agriculture, and possibly agricultural peoples into southern Manitoba c. AD1200 (Flynn, 2002). This temperature increase would likely have had an effect on meteoric water $\delta^{18}O$ values in the area of Fidler Mounds. According to Rozanski and colleagues (1993), a change of roughly 0.4-0.7‰ per degree Celsius is observed in modern meteoric waters, depending

on latitude. Because of the large error ranges produced by SIMS (1.5-2.0‰), temperatures would have had to have changed by 2-5°C in order to produce detectable $\delta^{18}O$ variability in the teeth analysed. Without a detailed palaeoclimatological reconstruction of southern Manitoba between AD260 and AD1390, it cannot be said for sure that such a change in mean annual temperature did not occur over the period during which Fidler Mounds was formed. Climate change should, therefore, be considered as a possible cause of $\delta^{18}O$ variability between undated individuals and individuals dated to different time periods. However, variability between contemporaneous individuals, such as that observed among individuals making up the earlier date cluster identified within the Fidler Mounds population, cannot be explained as the result of long-term, major climatic changes.

Fidler Mounds mean enamel $\delta^{18}O$ values can be placed into three, significantly different categories. If the values obtained through these analyses represent *in vivo* body chemistry, it is likely, in spite of the above caveats regarding potential deviations in drinking water sourcing behaviour, that at least three different geographic regions of childhood residence are represented by the Fidler Mounds population. Because an internal dentin standard was used to calculate $\delta^{18}O$ values in this study, it is currently impossible to relate any of these values to regional water resource $\delta^{18}O$ values. Therefore, it cannot be said which, if any, of the mean enamel $\delta^{18}O$ clusters identified in Figure 1 represent a "local" $\delta^{18}O$ signature. Logically, at least two of the three clusters must represent individuals from areas isotopically different, and thus geographically distant from south-central Manitoba, where the mounds are located. However, for the

same reason that "local" enamel $\delta^{18}O$ values cannot be identified, it cannot be said which clusters, if not all three, represent "foreign" signatures.

Inter-individual variation in mean dentin $\delta^{18}O$ is less pronounced than for enamel. This presents something of a quandary. If both enamel and dentin $\delta^{18}O$ values are taken to represent body chemistry over the same period of childhood, then these data conflict. While the enamel data suggests three regions of childhood residence, dentin values suggest only two. However, unlike enamel, dentin *can* undergo limited remodelling after its initial formation, particularly towards the apical portion of the tooth (Budd *et al.*, 2000; Hillson, 2005). It is possible, therefore, that enamel and dentin mean $\delta^{18}O$ values do not represent body chemistry from exactly the same life stage in all individuals. Multiple individuals exhibit mean dentin and enamel $\delta^{18}O$ values that are significantly different from each other, which either suggests diagenetic alteration of dentin $\delta^{18}O$, instrumental error due to inter-tissue matrix differences – which will be discussed more thoroughly below – or that dentin and enamel can potentially reflect body chemistry at different life stages. It is also possible that more than one of these factors is responsible for the disparity between enamel and dentin $\delta^{18}O$ data. Out of the two tissues indicative of childhood body chemistry, $\delta^{18}O$ values obtained from enamel are more reliable. Overall, enamel is less prone to diagenetic alteration of oxygen isotope ratios than dentin. It is likely that the relatively higher degree of $\delta^{18}O$ heterogeneity seen in the enamel sample is indicative of the true level of variability in childhood body chemistry among the Fidler Mounds people.

Mean cementum $\delta^{18}O$ values, like enamel $\delta^{18}O$ values, can be grouped into three, significantly different clusters. Two of these clusters, however, are made up of only one

individual. The more depleted cluster is represented by Burial 10, who exhibits an extremely low mean cementum $\delta^{18}O$ value of 3±1.42‰, while the other is made up of Burial 9, who exhibits a mean cementum $\delta^{18}O$ value of 17.7±4.25‰. It is uncertain whether results obtained from Burial 9, who still retained a deciduous canine, can be compared to results gathered from adult individuals. Additionally, because Burial 10's mean cementum $\delta^{18}O$ value was calculated using only two single analysis values for reasons which were discussed above, it is uncertain whether this value is an accurate representation of this individual's cementum $\delta^{18}O$. Therefore, it is not possible to say with any great confidence how many regional isotopic signatures are represented by the cementum of the individuals from Fidler Mounds.

When population-level single-analysis data, rather than mean $\delta^{18}O$ values, is considered, a slightly different picture of mobility within the Fidler Mounds population emerges. Enamel $\delta^{18}O$ values are still divisible into three separate groups based on this data. However, the number of individuals who can be assigned to a single $\delta^{18}O$ cluster drops dramatically from eight to three. This high degree of intra-individual enamel heterogeneity would not be noted in a study utilizing standard, bulk enamel analysis, which assumes a certain degree of internal homogeneity. In some cases, multiple, significantly different single-analysis $\delta^{18}O$ values are obtained from the enamel of a single individual. This seems to indicate that, in these individuals, some change in body chemistry took place over the period during which the enamel of the canine was formed. These results indicate that some of the people interred in the Fidler Mounds may have followed a relatively high-mobility lifeway during childhood, which is in keeping with Saylor's (1976) hypothesis that this site represents the burial remains of a mobile group

of hunter-gatherers. However, not all individuals show a high degree of enamel $\delta^{18}O$ variability. Some enamel samples exhibit statistically indistinguishable enamel $\delta^{18}O$ values. This suggests that some of the Fidler Mounds people may not have moved around very much during childhood, or, if they did, they did not move beyond the boundaries of a single $\delta^{18}O$-characterised geographic region.

This differential intra-tissue $\delta^{18}O$ variation could be the result of variability in enamel $\delta^{18}O$ sampling strategies, which was described in the "methods" chapter above. However, there is variation in $\delta^{18}O$ intra-tissue consistency between individuals who were sampled using only the standard method. Fill A and Fill LRC, for example, were both sampled in this manner, yet the former exhibits very tightly clustered single analysis $\delta^{18}O$ values, while the latter shows the highest degree of enamel $\delta^{18}O$ variability within the data set.

It is unlikely that diagenesis or laboratory contamination is responsible for intra-individual variability in enamel single-analysis $\delta^{18}O$ values. Enamel is widely considered to be the least prone of all hard tissues to post-burial chemical alteration (Kohn and Cerling, 2002). Teeth were thoroughly cleaned prior to analysis. Additionally, areas surrounding cracks or tissue defects, where diagenetic agents could more easily influence SIMS results were avoided during analysis. If diagenetic alteration was responsible for intra-individual enamel $\delta^{18}O$ variability, one would expect that time spent in the burial environment would have an impact on this variability. However, this does not appear to be the case. It can be seen in Figure 4 that individuals separated by nearly a millennium exhibit similar levels of intra-enamel variation.

It is likely that the intra-tissue variability in $\delta^{18}O$ seen in individuals from the Fidler Mounds is an accurate representation of their childhood body chemistry. This being the case, these data indicate that individuals interred in the mounds followed lifestyles characterised by varying degrees of mobility. While this certainly supports idea that the Fidler Mounds represents the burial activities of multiple people groups, the diachronic pattern of $\delta^{18}O$ data obtained is somewhat at odds with current interpretations of the archaeological record from nearby sites.

Early occupations at the nearby Lockport village site are commonly attributed to mobile hunter-gatherer groups such as Laurel or Larter peoples (Buchner, 1988). Based on evidence such as the presence of bell-shaped storage pits, some later occupations of the Lockport site (750-550 BP) are attributed to more sedentary maize horticulturalists (Buchner, 1988). Because of this, one would expect individuals who lived during the later time period to exhibit a lower degree of intra-tissue enamel $\delta^{18}O$ variability. However, the opposite appears to be the case. The single dated individual from the Fidler Mounds who lived during the period at which the Lockport site was supposedly occupied by more sedentary individuals exhibits a greater degree of intra-enamel variability than any of the individuals from the earlier, supposedly more mobile burial group. If Fidler Mounds, as is commonly thought, does represent the burial component of Lockport village occupations, it is possible that individuals from that site's horticultural period practiced more intense mobility than was previously thought. The alternate possibility is, of course, that people groups other than those represented by the Lockport site material culture contributed to the burial population of the Fidler Mounds. However, before such statements can be made with any degree of firmness, more than one

individual from this period should be identified and analysed. Unfortunately, further radiocarbon dating of individuals from the Fidler Mounds is beyond the scope of current research.

Similar variability in intra-tissue $\delta^{18}O$ was obtained from population level analyses of dentin, however, certain idiosyncrasies of dentin formation mean that this might not, in all cases, be the product of varying levels of childhood mobility. Instead, this differential variation might reflect differences in mobility patterns over a much longer period of life. As well, sampling sites with differing levels of porosity could also be responsible for intra-tissue dentin $\delta^{18}O$ variability within some individuals, as differing levels of epoxy contamination between dentin test sites would lead to matrix differences which could not be adjusted for during data interpretation.

There is also a wide range in δ18O values for intra-tissue cementum between individuals in this population. Once again, some individuals show very tightly clustered single analysis $\delta^{18}O$ values, while other individuals have (in the case of Burial 9) a very wide range in $\delta^{18}O$ values. While it was established that differences in sampling strategy between individuals was likely not a major factor contributing to this type of variability in enamel data, it is possible that sampling strategy may have contributed to population-level differences in cementum intra-tissue $\delta^{18}O$ variation. The cementum of the Fidler Mounds people sampled was, on average, more poorly preserved than other dental tissues. Abundant cracks and voids between cementum and surrounding resin led to the implementation of a sampling strategy that was far more opportunistic than standardised. This means that certain individuals may have had a greater period of their overall lifetime sampled than others. The presence of a higher degree of intra-tissue variability in these

individuals could be argued to be a product of sampling error rather than higher mobility. Additionally, most scholars agree that cementum, because of its relatively high organic content and loose structure, is prone to post-burial diagenetic alteration (Kohn and Cerling, 2002; Stutz, 2002; Hillson, 2005). In some analyses, areas surrounding tissue cracks could not be avoided. For example, cementum $\delta^{18}O$ analyses of Fill LRC were conducted almost entirely on tissues surrounding cracks. In this case, the ubiquity of flawed analyses prevents any remarks as to the veracity of the results from being made. In some cases, values obtained from cementum near cracks were not significantly different from results obtained from normal tissue. However, all values obtained from cracked tissue or from areas near tissue junctions should be interpreted with caution (see appendix C for a summary of single analysis data, including analyses performed on flawed tissue). Cementum analysed via SE-SEM was seen to be riddled with microscopic tissue voids too small to be observed through light microscopy or the SIMS imaging system (Figure 24). Areas of differential chemical composition were also noted when cementum was viewed as BSE-SEM images (Figure 23).

The inter-individual differences in enamel $\delta^{18}O$ variability observed within the Fidler Mounds population could be argued to lend some support to the veracity of the variability observed in the cementum data. The presence of variation in mobility during childhood years in this population lends some legitimacy to data interpretations which suggest that variable mobility might be an observed phenomenon in adulthood as well. However, for the reasons discussed above, these interpretations must be made with caution. Until a standardized analytic protocol that ensures even sampling of all age periods and prevents analysis of cracked tissue can be developed and applied to this

sample group, all that can be said is that individuals from the Fidler Mounds followed diverse mobility patterns during childhood, as indicated by enamel data, and may also have done so during adulthood.

When viewed diachronically, Fidler Mounds dental tissue $\delta^{18}O$ data seem to indicate that variability in childhood and adulthood $\delta^{18}O$ values is not restricted to either of the temporal burial clusters identified by Hewitt (2004) (Figures 4-6). In both the early and more recent burial groups, there is statistically significant intra-individual differences between individual mean dentin, cementum and enamel $\delta^{18}O$ values. At first, this seems to suggest that regional heterogeneity in place of childhood and lifetime residence characterised the Fidler Mounds burial population over the entire 1000 years of mound utilization. However, of the dated individuals analysed, only two fell within the more recent burial cluster, and one of these is Burial 9 who was only 7 or 8 at the time of their death, and thus contributed a deciduous canine to the sample. It is unlikely that data taken from deciduous teeth are directly comparable to data taken from permanent dentition, unless the effects of tooth formation *in utero* on dental isotopics can be identified and controlled for. If this tooth is excluded from diachronic inter-individual comparisons of $\delta^{18}O$, then the recent burial cluster is made up of only one individual. It is therefore impossible to make any concrete statements about levels of childhood and adulthood regional heterogeneity among this burial cluster without additional radiocarbon dating and SIMS analysis.

Some meaningful statements can be made about dental tissue $\delta^{18}O$ variability in the earlier burial cluster. Among these people, there are at least two significantly different $\delta^{18}O$ signatures apparent in mean values for dentin, cementum and enamel (Figures 4-6).

Burials 7, 21 and 19 have statistically indistinguishable dentin and enamel mean $\delta^{18}O$ values, while, for both tissues, Burial 11 appears to be somewhat less enriched than other individuals within the same burial group. This suggests that Burial 11 – a man who died at some point after the age of forty – spent his childhood in a different area than other individuals who were interred in the mound during the same period.

When the cementum $\delta^{18}O$ values are considered, the difference between Burials 7, 19 and 11 vanishes ("cementum" $\delta^{18}O$ values obtained from Burial 21 were excluded) (Figure 6). This seems to indicate that Burials 19, 7 and 21 spent their childhoods in the same isotopic region as one another, while Burial 11 lived out his childhood somewhere else. Once these individuals reached later childhood and adulthood, however, Burials 11, 19 and 7 (incidentally, all males) were all living in the same isotopic region.

Single analysis data from radiocarbon dated individuals is somewhat difficult to interpret. When enamel analyses are considered, it does not appear that intra-tissue variability is a function of time since burial. Although the individuals with the highest and lowest intra-tissue variability are the most recent and oldest burial respectively, individuals dated to similar periods also show significantly different levels of enamel $\delta^{18}O$ intra-tissue variability. As mentioned above, this phenomenon can be used to argue against suggestions that enamel intra-tissue $\delta^{18}O$ variability is a product of diagenesis.

This phenomenon also suggests that date of burial is not an important factor in determining mobility levels within this population. For example, Burials 11 and 19 are dated to roughly the same time period, yet single analysis $\delta^{18}O$ values from the former are tightly clustered, while values from the latter show at least two significantly different $\delta^{18}O$ signatures. This indicates that these individuals followed different mobility patterns

during their early childhood, in spite of their contemporaneous lifespans and shared place of burial. Furthermore, Burial 15, who died over 1000 years after Burial 19, also exhibits two statistically different $\delta^{18}O$ values, indicating that these individuals followed a common mobility pattern, at least in terms of scale. The fact that $\delta^{18}O$ values from Burial 15 are, on average, significantly less enriched than those from Burial 19, indicates that they likely did not have a shared place of origin.

Single analysis dentin $\delta^{18}O$ data also indicates that date of burial is not a significant determining factor of intra-tissue $\delta^{18}O$ variability. Multiple, significantly different $\delta^{18}O$ values were obtained from the dentin of individuals in both date clusters (Figure 5). It is interesting to note that Burial 10, who showed relatively low levels of enamel intra-tissue $\delta^{18}O$ variability, shows a rather high degree of dentin intra-tissue $\delta^{18}O$ variability, especially when one considers the notion that these tissues represent body $\delta^{18}O$ over roughly the same period of life. Disparities between dentin and enamel data, such as this one, may be due to secondary dentin growth during adult years, or possibly to matrix differences within dentin due to differential levels of porosity between analysis sites.

If single analysis cementum $\delta^{18}O$ data is considered to be the result of lifetime body chemistry, rather than a sampling error or a product of diagenesis, dates obtained from the Fidler Mounds individuals seem to indicate that date of burial does not play a significant role in determining the scale of lifetime mobility, which is the expected result, given the above interpretations of enamel and dentin single analysis $\delta^{18}O$ data (Figure 6).

The results of analysis of dentin, cementum and enamel $\delta^{18}O$ were plotted against $\delta^{13}C$ values obtained from the same individuals by Garvie (1993) (Figures 7-9). Under her hypothesis, that women with high $\delta^{13}C$ values constituted non-local women brought

into the area as brides as a part of patrilocal marriage practice, there should be some correlation between $\delta^{13}C$ and $\delta^{18}O$ values (Garvie, 1993). Women with high $\delta^{13}C$ values should have outlying mean dentin and enamel $\delta^{18}O$ values, demonstrating that they spent their childhoods in a different area from other members of the mound population. Burials 12, 15, and 21 (Garvie, 1993) should all display outlying $\delta^{18}O$ values, but no such patterning is apparent. Mean enamel $\delta^{18}O$ values obtained from these three individuals do not cluster together, nor do they appear to differ from other members of the Fidler Mounds population (Figure 7). The same is true for cementum values, which indicate that C_4 plant consumption and place of origin and adulthood residence are not strongly linked in this group (Figure 9).

When single analysis enamel $\delta^{18}O$ data are compared to $\delta^{13}C$ data, however, a rather interesting pattern emerges. The individuals with the two highest $\delta^{13}C$ values out of Garvie's (1993) data set (Burials 15 and 12) also have relatively high levels of enamel intra-tissue $\delta^{18}O$ variability, while most of the individuals with "normal" $\delta^{13}C$ values – with the exception of Burial 19 – exhibit more homogeneous enamel $\delta^{18}O$ single-analysis values (Figure 7). It should be re-emphasized here that the bone collagen $\delta^{13}C$ values obtained by Garvie (1993) are a representation of *adulthood* body chemistry, while enamel single analysis $\delta^{18}O$ values are a record of body chemistry during *childhood.* Thus, the positive relationship between high enamel intra-tissue $\delta^{18}O$ variability and high $\delta^{13}C$ values seems to indicate that childhood mobility might have some impact on adult diet. Put another way, two of the women identified by Garvie (1993) as having more of a C_4 plant based diet during adulthood may have practiced relatively higher mobility as children than other individuals in the group.

Single analysis dentin data also seems to indicate that the females identified as having relatively enriched $\delta^{13}C$ were more highly mobile as children than other individuals sampled (with the exception of Burial 19) (Figure 8). However, relatively high dentin intra-tissue $\delta^{18}O$ variability throughout the sample population means that the relationship between this variability and respective $\delta^{13}C$ values is less pronounced than in the enamel data.

Oddly enough, this relationship becomes reversed when cementum single analysis $\delta^{18}O$ data is considered. Individuals with very high intra-tissue variability tend to have relatively low $\delta^{13}C$ values, and vice versa (Figure 9). If cementum values are taken to be representative of lifetime body chemistry, rather than the effects of sampling error or diagenesis, then this data would seem to indicate that individuals with more enriched $\delta^{13}C$ values engaged in relatively high low mobility lifeways over the course of their lifetimes, in spite of elevated mobility during early childhood. This pattern would be in keeping with archaeological evidence which suggests that maize horticulturalists in North America tended to be slightly less mobile than groups solely dependent on hunted food resources (Odell, 1998). However, it should be re-emphasized that cementum is more prone to diagenetic alterations than other dental tissues (Kohn and Cerling, 2002). Additionally, when cementum $\delta^{18}O$ data obtained from tissue near cracks in the tooth extracted from Burial 10 are discounted, the relationship between cementum intra-tissue $\delta^{18}O$ variability and bone collagen $\delta^{13}C$ becomes less pronounced. Thus, such an interpretation of cementum data, in spite of its agreement with established mobility-subsistence patterns, should be considered cautiously.

Comparisons of $\delta^{18}O$ values obtained from multiple tissues formed at different life-stages can be used to build life-histories of individual migration and to support hypotheses of population mobility within a given archaeological context (White *et al.*, 2004; Evans *et al.*, 2006). In most studies, the stable isotopic composition of skeletal and dental tissue is generally obtained through analysis of isolated chemical components of hard tissue using gas source mass spectrometry. For example, $\delta^{18}O$ values of apatite from bone are usually obtained to study population migration, while the organic component of bone is excluded. (White *et al.*, 1998; Dupras and Schwarcz, 2001).

Stable isotopic analyses of hard tissue by secondary ion mass spectrometry differ from standard stable isotopic methods because individual tissue components such as collagen or apatite are not isolated for analysis. Cementum and dentin both contain collagen to an appreciable extent (about 21% and 18% of dry weight respectively), whereas enamel does not (Hillson, 2005). This difference in matrix could result in differences in ion yields and therefore produce a different mass bias, which would require a unique correction factor for each tissue (i.e., enamel, dentin and cementum). Currently, the exact effect of the chemical differences between dental tissues on SIMS results is unknown, and, thus, no correction factors exist. However, mass bias can often be detected as a difference in secondary beam ion emission between tissues, requiring adjustment of the primary beam to achieve optimum emission. Slight adjustments of beam intensity were necessary when switching analyses between tissues during testing of the Fidler Mounds individuals. It is somewhat likely then, that differential mass bias is at least partially responsible for variations in $\delta^{18}O$ between tissues within the same individual.

It is also possible that differential diagenesis between tissues is responsible for individual inter-tissue variability. Numerous studies have found that enamel maintains its structural and chemical integrity within a variety of burial environments far better than dentin or cementum (Hillson, 2005; Kohn and Cerling, 2001; Kohn *et al.*, 1999). It is possible that dentin and cementum were chemically altered by post-burial diagenetic processes, while enamel chemistry remained intact. This kind of differential diagenesis could create inter-tissue $\delta^{18}O$ variation within a single individual post-burial, where none existed during life, mimicking the effects of long-term migration. This could potentially explain why some individuals exhibit mean dentin $\delta^{18}O$ values that are so different from mean enamel $\delta^{18}O$ values, when these tissues are supposed to have formed largely over the same stage of life. Differential diagenesis could also be invoked to explain the nearly consistent enrichment of enamel over the other two tissues observed in intra-individual analyses. One of the most common isotopic contaminants in burial environments is groundwater (Hedges and Millard, 1995; Hedges, 2002), which, in the case of the Fidler Mounds, would be mostly meteoric. If meteoric water was a major drinking-water resource for the Fidler Mounds people, then their body water, and consequently dental tissue $\delta^{18}O$ values should have been consistently enriched over the $\delta^{18}O$ of local precipitation. If this water also constituted a major isotopic contaminant in the Fidler Mounds burial environment, and thus contributed to $\delta^{18}O$ values obtained from diagenetically affected tissues – i.e. cementum and dentin – all things being equal, one would expect to consistently obtain relatively enriched $\delta^{18}O$ values from less altered tissues within the same individual. This appears to be the case within the Fidler Mounds population. No individuals exhibit mean enamel $\delta^{18}O$ values that are lower than both

dentin and cementum, and only two individuals (Burials 9 and 10) exhibit enamel values less enriched than either dentin or cementum. BSE-SEM images of enamel show it to be relatively free of chemical alteration (with the exception of extra gold added through the sample preparation process), which means that diffusion of oxygen from the burial environment is likely not a factor contributing to SIMS $\delta^{18}O$ results. That being said, it is still difficult to say whether this phenomenon is the result of diagenesis, matrix differences between the tissues or long-distance migration, or a combination of the three.

The first individual to be considered here is Burial 7 (Figure 10). He is a young man, aged 25-35 who died between 1530 and 1330 BP, which means that he lived during the Laurel occupation of the region surrounding the Fidler Mounds (Saylor, 1976; Buchner, 1988; Hewitt, 2004). He was buried on his side in a tightly flexed position in a subsoil pit, perhaps before the construction of the overlying mound (Saylor, 1976). This individual displays multiple pathologies including gross enlargement of the long bones, including the tibia, fibula, radius and ulna of the right side (Saylor, 1976; Hewitt, 2004). A portion of Burial 7's occipital was also removed during the perimortem period, which is consistent with Laurel mortuary practices observed within burial mound populations from areas to the south of the Fidler Mounds (Wilford, 1940). Green staining on this individual's right wrist indicates that he was interred with a piece of copper, and there is red ochre staining on the right arm. Artefacts associated with this burial include a trumpeter swan ulna whistle, two brown chalcedony bifaces, a chert flake, a polished, drilled bone and a flat scratched bird humerus (Saylor, 1976). The noted pathological status, occipital removal and burial with a bone whistle all suggest that Burial 7 was a significant individual.

In addition to having distinct cementum and enamel $\delta^{18}O$ mean values, there is no inter-tissue overlap between the single analysis values obtained from this individual's enamel or cementum. However, there is no significant difference between the single analysis $\delta^{18}O$ values obtained from this individual's cementum and dentin, which is odd, considering the prevailing idea that dentin and enamel represent body chemistry over roughly the same period of life. It is possible that differential mass bias between dentin and enamel has led to this disparity. If this is the case, then it is likely that the differences between cementum and enamel are also the product of matrix effects, as dentin and cementum are composed of a roughly similar proportion of apatite and collagen, while enamel is almost entirely composed of apatite. If this mass bias was adjusted for, then, it is likely that there would be no significant difference between enamel and cementum $\delta^{18}O$ values. However, this situation is purely hypothetical, as adjustments for differential dental tissue SIMS IMF have not yet been explored. On the basis of single analysis enamel $\delta^{18}O$ values, though, it is possible to say that this individual likely undertook a long-distance migration during his early childhood, as two significantly different $\delta^{18}O$ values were obtained from this tissue.

The next individual in this sample set who shows a significant difference between mean enamel and cementum $\delta^{18}O$ values is Burial 10 (Figure 11), a woman who died between the ages of 35 and 50 and who was interred, likely in a primary burial, in the slope into the depression of mound 1 (Saylor, 1976). This individual was interred with an unworked mammal calcaneus. There is a statistically significant difference between enamel and dentin mean and single analysis $\delta^{18}O$ values and cementum $\delta^{18}O$ values obtained from this individual. Burial 10's cementum values are the lowest in the entire

Fidler Mounds population. Single analysis and mean dentin and enamel values obtained from this individual are statistically indistinguishable, which is likely the product of normal dental development, through which $\delta^{18}O$ values obtained from these two tissues would be representative of body chemistry over roughly the same time period.

It is possible that the inter-tissue differences in $\delta^{18}O$ seen in this individual are the result of differential mass bias between the two childhood tissues (dentin and enamel) and cementum. However, one would expect that dentin and cementum, being composed of roughly similar proportions of organic tissue and apatite, would require similar mass bias adjustments, while enamel, which is largely inorganic, would require a somewhat different adjustment factor. Adjustment of Burial 10's dental tissue $\delta^{18}O$ values in this way would likely still result in a difference between mean values obtained from two of the three different tissues.

It is also possible that this variation is the result of differential diagenetic alteration of Burial 10's three dental tissues. As noted above, cementum is, by far, the most prone of the three tissues to post-burial alteration (Kohn and Cerling, 2002). However, if this were the case, one would also expect that dentin would also have suffered some degree of alteration, especially as this individual's dentin would have been fully exposed to the burial environment

If either of these situations could be properly adjusted for, some intra-tissue $\delta^{18}O$ variability would likely remain and would have to be accounted for. Which tissues this variability would affect, however, will remain unknown until further analysis is able to clarify the effects of mass bias on the results of SIMS analyses of dental tissue oxygen isotopes.

If the $\delta^{18}O$ values obtained through analysis of Burial 10's dental tissues are a reflection of this individual's body chemistry during life, then it seems likely that this is a migrant individual. The presence of a migrant woman in the Fidler Mounds population would strengthen Garvie's (1993) hypothesis of "foreign" brides being brought into the region from areas further to the south. However, bone collagen $\delta^{13}C$ values obtained from this individual indicate that maize did not play a significant role in her diet as an adult. It is still possible that this woman represents a non-local brought into the area as a wife to a local man, however, for this hypothesis to be consistent with this individual's $\delta^{13}C$ data, she would have to have adopted a "local" non-C_4 based diet upon entering the region, and would have to adhered to such a regimen for several years prior to her death. This woman's enamel and dentin $\delta^{18}O$ values are similar to those obtained from one of Garvie's (1993) proposed migrant women (Burial 15), indicating that they may have spent their childhoods in the same isotopic region, but they are 5-10‰ less enriched than those obtained from the other two women (Burials 12 and 21) indicating that they do not share their region of origin with Burial 10.

Burial 10's aberrantly low cementum $\delta^{18}O$ values may indicate that this individual was a native to the area surrounding the Fidler Mounds, migrated to a different area after her childhood, and was returned to her place of origin for burial. However, very few of the other individuals buried in this mound have enamel $\delta^{18}O$ values similar to those of Burial 10, indicating that this individual not only spent their adulthood in a different region than the rest of the mound population but also had a different place of childhood residence. It is possible, given this data that Burial 10 represents a woman from a completely different people group buried in the mound as a part of a multi-group

interment. There is some indication in the ethnographic literature that multiple, distinct people groups may have participated in mound ceremonies, with some authors suggesting that this may have served as an inter-group cohesion mechanism (Snortland, 1994). If this was the case in southern Manitoba during the Middle to Late Woodland period, then it would certainly not be surprising to find an individual with anomalous dental tissue $\delta^{18}O$ values among the people in the mounds.

Burial 12 is one of the three women hypothesized by Garvie (1993) to represent foreign women brought into the Fidler Mounds region as brides to local men. Inclusion in this group was based on this individual's relatively high $\delta^{13}C$ value of -16.6‰, indicating that she may have had a more maize-based diet than most other individuals in the mound (Garvie, 1993). Burial 12 was the only burial recovered from mound 2 by Fiske's team (Saylor, 1976). She was interred in a supine, primary fashion, her knees tightly flexed, a limestone slab on her chest, and two stones beside her right femur.

There is a statistically significant difference between Burial 12's mean enamel and cementum $\delta^{18}O$ values, while her enamel and dentin mean $\delta^{18}O$ values and cementum and dentin mean $\delta^{18}O$ values are indistinguishable (Figure 12). This pattern could potentially be interpreted as the result of a migration between childhood and adulthood, or the result of other factors discussed above. When single analysis $\delta^{18}O$ data is considered, however, all three dental tissues show some degree of overlap. Of particular interest, is the cementum single analysis $\delta^{18}O$ value that is similar to two of the enamel single analysis $\delta^{18}O$ values. Unless diagenesis and/or differential mass bias played a significant role in determining the $\delta^{18}O$ values obtained from this individual, then this aberrant value could be explained as resulting from the analysis of an area of

cementum representing childhood body chemistry, while other analyses were placed in areas representing later body chemistry.

In addition to the disparity between enamel and cementum $\delta^{18}O$ values, the multiple, significantly different $\delta^{18}O$ values obtained through single analysis of all three tissues indicate that this individual likely underwent at least one long-distance migration during their lifetime. Because this study utilized an internal standard, thus making it impossible to meaningfully compare $\delta^{18}O$ values from this research to established regional $\delta^{18}O$ patterns, it is impossible to track the migration of this individual. These high bone collagen $\delta^{13}C$ values suggested to Garvie (1993) that this woman was from an area to the south of Manitoba, where corn played a more important role in local subsistence patterns. After arriving in Manitoba, this woman would have either have to have maintained her maize supplemented dietary pattern, or have passed away before a local, less enriched $\delta^{13}C$ pattern manifested itself in her bones.

Given the established ethnographic literature on the multi-group nature of some mound burials, it is also entirely possible that this woman spent her childhood in the area of the Fidler Mounds, migrated into southern, maize-growing areas, where she would have been more likely have followed a maize-supplemented dietary pattern, and then returned to the place of her birth shortly before or after death (Snortland, 1994). It is also possible that she was never a resident of the area surrounding the mounds, and was interred there as a part of a multi group ritual

The hypothesis that this woman is in some way different from other individuals in the Fidler Mounds population could be supported by her unique burial location and associations. Multiple studies have reinforced the link between the spatial distribution of

burials and social identity (Saxe, 1970; Goldstein, 1981). If this association holds true in the context of the Middle to Late Woodland of Southern Manitoba, then the discovery of Burial 12 in Mound 2, while other full burials were located Mound 1, would indicate that this individual belongs to a different social group than the other members of the Fidler Mounds population. This hypothesis is also supported by $\delta^{13}C$ and $\delta^{18}O$ data obtained from this individual (Garvie, 1993).

Burial 19 was a young man at the time of his death between 1570 and 1410 BP during the Laurel occupation of the areas surrounding the Fidler Mounds (Saylor, 1976; Buchner, 1988; Hewitt, 2004). He was interred in a primary fashion in a partly flexed supine position in a subsoil pit under the northern rim of mound 1 (Saylor, 1976). This individual's face was ochre-stained, and green stains on his occipitals, parietals and temporal bones indicate the interment of a copper artefact near the individual's head. A copper ring was found on the ribcage, near the left humerus.

Mean enamel and cementum $\delta^{18}O$ values obtained from this individual are significantly different, indicating that he may have undergone a long-distance migration at some point during his life, though without further analysis to rule out the possibility of diagenesis and/or matrix effects on $\delta^{18}O$ values obtained, this interpretation should be taken with caution. However, the hypothesis that this man was involved in a long-distance migration at some point in his life is supported by the high degree of intra-tissue $\delta^{18}O$ variability seen in Burial 19's enamel and dentin. Each of these tissues exhibits two significantly different $\delta^{18}O$ signatures, which is consistent with the pattern expected from an individual who had undergone a long-distance migration at some point during his childhood.

Fill A is another individual from the Fidler Mounds who exhibits significantly different enamel and cementum $\delta^{18}O$ values (Figure 14). Unfortunately, this individual has not been dated or sexed, which severely limits the possibility of forming interpretations regarding the influence of demographics upon this individual's mobility. This individual exhibits statistically homogenous enamel single analysis $\delta^{18}O$ values, which seems to indicate a certain level of residential stability during childhood. However, this individual's dentin single analysis $\delta^{18}O$ values yielded two significantly different $\delta^{18}O$ signatures, which seems indicate the contrary. It is possible, however, that dentin $\delta^{18}O$ values represent a record of body chemistry over a longer period of life than enamel values. Dentin, particularly towards the apical portion of the tooth, is prone to regeneration, even during adulthood (Budd *et al.*, 2000; Hillson, 2005). Thus, the disparity between enamel $\delta^{18}O$ values and some dentin $\delta^{18}O$ values would be the effect of this later regeneration. This explanation is further supported by considering dentin $\delta^{18}O$ values according to the anatomical location of analysis sites. In many individuals, there is a statistically signification difference between dentin values obtained adjacent to enamel test sites and those obtained from areas adjacent to cementum test sites (See appendix B). In still other individuals, there is a definite trend towards this type of variation, although this trend is not statistically significant. There are a few individuals in which there appears to be no relationship whatsoever between dentin $\delta^{18}O$ values and anatomical location of dentin analysis sites, however, these represent a minority. In cases where there does appear to be some chemical heterogeneity between dentin test sites, such as Fill A, one could certainly argue that this represents evidence for a long-term migration at some point after initial dentin formation. In the case of Fill A, this assertion

would be further supported by the disparity between enamel and cementum $\delta^{18}O$ values. As noted above, this could also be the effect of differential IMF between apical and coronal test sites due to differing levels of porosity and epoxy retention between these areas

The only other individual from this data set to exhibit significantly different enamel and cementum mean $\delta^{18}O$ values is represented by the tooth used as this study's internal standard, Fill B. Once again, there is no demographic information available for this individual, save that they survived long enough to develop a permanent canine tooth. The lack of occlusal wear and overall robusticity of this tooth suggests to the author that the individual from which it came was a young man, however this is merely speculation, and cannot be supported with any objective data at this point. Two significantly different $\delta^{18}O$ signatures were obtained from this individual's cementum and enamel, while Fill B's single analysis dentin $\delta^{18}O$ values were relatively homogeneous. As these dentin values were all obtained from the same anatomical portion of the tooth, their homogeneity further supports assertions that there is a relationship between the anatomical location of SIMS test sites within dentin (i.e. coronal vs. apical dentin) and the $\delta^{18}O$ values obtained. Whether this relationship has biological or instrumental roots remains to be explored.

When single-analysis data obtained from this individual's cementum and enamel are considered, the distinction between the two tissues becomes even more apparent. Within this population there is often a generous degree of overlap of $\delta^{18}O$ values obtained from tissues that have significantly different mean values. However, in the case of Fill B only one cementum analysis produced results which were not significantly different from

each of the $\delta^{18}O$ values obtained through enamel analysis. This indicates strongly that this individual undertook a long-distance migration at some point after their early childhood. Dentin $\delta^{18}O$ values overlap with values obtained from both enamel and cementum.

One of the cementum values obtained from Fill B through SIMS analysis returned an abnormally low $\delta^{18}O$ value. SEM imaging of the cementum analysed shows that one analysis was over a crack in the tissue. It is highly likely that this is the analysis which produced the anomalously low cementum $\delta^{18}O$ value. This value was subsequently eliminated from consideration in this study. This individual's enamel exhibits two significantly different $\delta^{18}O$ signatures, however no cracks were apparent in the region analysed. This indicates that this individual, in addition to undertaking a long-distance migration sometime after early childhood, was also mobile *during* early childhood. While there is no such variability among dentin $\delta^{18}O$ values, this is likely the result of the sampling of a single analysis site within this tooth in order to produce a viable tissue standard for this study. In all likelihood, then, Fill B pursued a relatively mobile lifestyle.

It is interesting to note that, while mean enamel and cementum values taken from the above individuals – which are comparable to the type of data produced through traditional methods of bulk tissue analysis – are all significantly different, there is often a degree of overlap between tissue $\delta^{18}O$ values taken from each of the three dental tissues. This is an excellent example of the advantages of in situ analysis over bulk testing of tissues. Furthermore, single analyses of tissues often revealed the presence of multiple, significantly different $\delta^{18}O$ within the enamel, dentin or cementum of a single individual, allowing the author to make statements not only about migration between different life-

stages, but also about mobility patterns *during* specific periods of life, such as early childhood. This is data that is lost when tissues are analysed in bulk.

The remainder of the individuals from the Fidler Mounds showed no significant difference between mean enamel and cementum $\delta^{18}O$ values. While this does not necessarily mean that these individuals' lives were not characterised by a high degree of mobility, it does indicate that any migration between childhood and adulthood was not on a large enough scale to cause detectable changes to individual body chemistry. However, in some individuals, intra-tissue variability in single analysis $\delta^{18}O$ values indicates migration during early childhood, or, in some cases, later life-stages.

Burial 9 is a 7-8 year-old subadult who died between 730 and 930 BP, during the Blackduck occupation of the area surrounding the mounds. This individual was interred in the central pit of mound 1 as a primary, sitting burial with some ochre staining (Saylor, 1976; Hewitt, 2004). The upper confidence interval of the radiocarbon date obtained for this individual would place his or her life within the earliest portion of the period when maize agriculture was practiced at the nearby Lockport village site (Buchner, 1988). However, this individual's bone collagen $\delta^{13}C$ value (-19.8) is not consistent with a maize-supplemented diet (Garvie, 1993). There is no significant difference between cementum and enamel mean $\delta^{18}O$ values obtained from Burial 9 (Figure 16). There is also no significant difference between dentin and cementum mean values. However, there is a significant difference between enamel and dentin values, which, once again, adds weight to the argument that these two tissues either do not represent exactly the same period of life, or the argument that they are affected by differential IMF, either due to *in vivo* chemical variation or epoxy contamination of dentin. If the former is the case,

then this individual would have to be acknowledged as a potential migrant individual. This conclusion would be further strengthened by the heterogeneity of cementum single analysis $\delta^{18}O$ values obtained from Burial 9. Three significantly different $\delta^{18}O$ signatures were obtained from this tissue. None of the analyses conducted on cementum from Burial 9 utilized tissue surrounding cracks, so it seems unlikely that diagenesis is responsible for this variability. It is more likely that these different $\delta^{18}O$ values represent the effects of at least two migration events during this individual's short lifetime. $\delta^{18}O$ data from burial 9 indicate that high mobility characterised the lifestyles of precontact peoples on the North-eastern Plains periphery into the Blackduck period, and possibly into the period when maize horticulture was introduced into the region.

Burial 11 was at least middle aged when she died, during the Laurel period of south-central Manitoba (Saylor, 1976). She was interred as a prone, primary, partly flexed burial. This burial was capped by four large rocks, stained with ochre and associated with a possible antler-hafted beaver tooth gouge (Saylor, 1976). There is no statistically significant difference between Burial 11's enamel and cementum mean $\delta^{18}O$ values, or between her cementum and dentin values. However, as in Burial 9, there is a significant difference between her enamel and dentin mean $\delta^{18}O$ values (Figure 17). In this case, however, the argument that this disparity is the result of migration and differential life-period representation between the tissues is not supported by high levels of intra-tissue $\delta^{18}O$ variability. There are two significantly different $\delta^{18}O$ values represented in the single analysis dentin data; these values appear to vary according to anatomical region of test sites. When apical dentin $\delta^{18}O$ values are eliminated, the resulting mean dentin $\delta^{18}O$ value (11±2‰) is no longer significantly different from mean

enamel $\delta^{18}O$ (13.9±1.22‰). Furthermore, at least one of the coronal dentin single analysis $\delta^{18}O$ values is indistinguishable from several enamel single analysis $\delta^{18}O$. Apical dentin, on the other hand has the same $\delta^{18}O$ value as cementum analyses, once again suggesting that the anatomical position of dentin analysis sites has an impact on $\delta^{18}O$ values obtained. Thus far, it appears that apical dentin represents later periods in life, while coronal dentin is a reflection of body chemistry during earlier periods.

Burial 15 is one of the young women with relatively enriched $\delta^{13}C$ values (-14.4‰) that Garvie (1993) suggests was a non-local individual brought into the Fidler Mounds area as a wife for a local man. This individual died sometime between 560 and 680BP, meaning that she lived during the period when maize horticulture was likely practiced in the area surrounding the Fidler Mounds (Saylor, 1976; Buchner, 1988). She was interred in a subsoil pit towards the southern edge of mound 1. She was placed in a sitting, semi-flexed position facing west.

Contrary to Garvie's (1993) hypothesis, $\delta^{18}O$ values from all three of Burial 15's dental tissues are indistinguishable at 95% confidence. This suggests that this individual did not undertake any long distance migration during their lifetime. However, intra-tissue $\delta^{18}O$ variability within enamel and dentin single-analysis data obtained from this individual suggests the contrary. Two significantly different $\delta^{18}O$ values were obtained from both tissues, suggesting that a change in body chemistry, on scale with the effects expected from a long-distance migration, occurred during the period when these tissues were forming, likely early childhood (Figure 18). This does not seem quite in keeping with the hypothesis that this woman migrated to south-central Manitoba immediately prior to or after her marriage, unless some marriage pattern henceforth unknown to North

American ethnographers was at play during the Middle to Late Woodland of Manitoba and surrounding areas. In any case, evidence for the practice of maize horticulture in the area of the Fidler Mounds during the period between 800 and 600 BP means that individuals with relatively enriched $\delta^{13}C$ values dated to this period do not necessarily have to be migrants from other areas. A fuller discussion of Garvie's (1993) carbon stable isotope data in light of newly obtained $\delta^{18}O$ values and radiocarbon dates obtained by Hewitt (2004) will follow below.

Burial 17 was over the age of 50 years when she passed away. She was interred in an irregular pit with three other individuals and a broken clay pipe. There is no statistically significant (2σ) difference between mean enamel, dentin or cementum $\delta^{18}O$ values obtained from this individual, suggesting that she did not migrate between regions characterised by different drinking-water oxygen isotope signatures. However, two significantly different $\delta^{18}O$ signatures were obtained from this individual's cementum, suggesting a long-distance migration occurring after dentin and enamel formation during early childhood (Figure 19).

Burial 21 is another of the individuals identified by Garvie (1993) as being a potential immigrant to the Fidler Mounds area, based on her relatively enriched $\delta^{13}C$ value (-17.7‰). Her burial was a primary, flexed interment in a subsoil pit underneath mound 1. She was found in association with a polished trumpeter swan ulna. According to radiocarbon dates obtained from Burial 21, this young woman lived during the Laurel occupation of south-central Manitoba (Syms, 1977; Buchner, 1988; Hewitt, 2004). There is no indication of any horticultural practices occurring in the area during this cultural period (Buchner, 1988), so this woman's $\delta^{13}C$ enriched bone collagen is something of a

mystery. It could be that Burial 21 spent her adult life in a region where maize horticulture was practiced. However, maize was not grown in areas directly southern to Manitoba until around 950bp, well after the death of Burial 21 (Gibbon and Caine, 1980). If she had come to Manitoba from a maize-growing region, she would have to have come much farther than Garvie (1993) hypothesized.

The association of a trumpeter swan ulna with Burial 21 is interesting, and seems to echo the bone whistle associated with Burial 7, perhaps suggesting some connection between the two individuals. In addition, both burials were oriented in an east-west fashion with the head to the east, while other individuals in the mound are oriented in a north-south fashion, or east-west, but with heads to the west. Orientation of burials, along with spatial distribution, is thought to be strongly linked to cultural identity (Goldstein, 1981; Brown, 1970). Both of these individuals date to roughly the same time period (Hewitt, 2004), and both have extremely similar enamel and dentin mean and single analysis tissue $\delta^{18}O$ values (cementum values from Burial 21 were excluded from analysis) (Figures 10 and 20). In light of this shared body chemistry – which indicates a shared place of origin – shared burial orientation and shared material culture association, it seems extremely likely that these individuals belonged to the same cultural group, likely Laurel given the dates of the two individuals and the partial removal of Burial 7's occipital. The inclusion of certain animal remains with burials – such as crow's feet– in other mound sites has been explained as a symbol of familial identity (Johnson, 1963). While this could possibly be the case for the trumpeter swan ulnae interred at the Fidler Mound, in light of the use of bird bone whistles in dance (Howard, 1953; Jilek, 1982) and Shamanic ceremonies (LaFlesche, 1890) among historic and contemporary Aboriginal

groups, the whistle and swan ulna were likely buried with these individuals for reasons other than family ties.

The evidence noted above strongly suggests that Burials 7 and 21 were culturally related. In light of this hypothesized shared cultural identity, the difference between Burial 7 and Burial 21's bone collagen $\delta^{13}C$ values is curious. From Garvie's (1993) data, it appears that Burial 7 did not supplement his diet with maize, while Burial 21 did. However, Hewitt (2004) also obtained $\delta^{13}C$ values from some of the Fidler Mounds individuals. For the most part, these values tally rather nicely with Garvie's (1993) data, however, in the case of Burial 21, they do not. While the earlier study (Garvie, 1993) obtained a $\delta^{13}C$ value of -17.7‰ for this individual, which is somewhat more enriched than most of the Fidler Mounds population – though not significantly so – Hewitt (2004) obtained a value of -18.3‰ from this individual, which places her within the "normal" range of Fidler Mounds $\delta^{13}C$ values. Given the extraordinary amount of evidence suggesting that Burials 7 and 21 belonged to the same cultural group, one not known to have included maize in its subsistence pattern, the author is inclined to accept Hewitt's $\delta^{13}C$ value as the value best reflecting *in vivo* body chemistry of Burial 21.

Fill LRC, the final individual in this sample, has not been sexed or dated, and was excavated as a single tooth from the fill of one of the Fidler Mounds, once again limiting the degree to which $\delta^{18}O$ data can be used to make statements about the effects of demography on mobility. All three of this individual's dental tissues overlap, suggesting, it would seem, that this individual had never migrated between isotopically different regions. However, all three dental tissues yielded more than one significantly different $\delta^{18}O$ signature, suggesting the contrary. Three $\delta^{18}O$ values were obtained from

enamel, while both cementum and dentin exhibited two different $\delta^{18}O$ values. This suggests that this individual moved between areas characterised by isotopically different drinking water at least twice during early childhood alone.

At this point, it should be clear to the reader that interpretations of mobility based on mean tissue $\delta^{18}O$ values – which represents the type of data provided by bulk tissue analyses – are quite different from interpretations based on single-analysis $\delta^{18}O$ data. Many individuals who have different mean tissue $\delta^{18}O$ values actually show a large degree of inter-tissue overlap when single analysis data is considered. Conversely, individuals who appear to have statistically indistinguishable tissue mean $\delta^{18}O$ values, which would lead a researcher to classify them as non-migrant individuals, are shown to have significant levels of intra-tissue $\delta^{18}O$ variation, which indicates movement between isotopically different geographic regions at some point during the formation of those tissues. If anything, this study must serve to underline the importance of collecting *in situ* isotopic data, especially in contexts, such as precontact Manitoba, where mobility is shown by the archaeological record to have been rather high (Syms, 1977; Pettipas, 1996). Data indicating multiple, frequent migration occurring during periods of tissue formation cannot be obtained through traditional bulk analyses, whereas SIMS in situ analysis is able to capture this information.

Garvie's (1993) study of $\delta^{13}C$ variability among Fidler Mounds individuals led her to hypothesize that mobility patterns within this group consisted, in some part, of long-distance migration of young women out of the south, into areas surrounding the mounds as wives for local men. However, in light of the data obtained through this study, as well as the radiocarbon dates and $\delta^{13}C$ values obtained by Hewitt (2004), this

hypothesis will have to be reconsidered. At the time when Garvie (1993) initially formed her hypothesis, the temporal depth of this site was unknown. The single radiocarbon date obtained by Fiske (1963), which placed the mounds' construction in the Late Woodland period, was the only indication of the age of the Fidler Mounds. However, dates obtained by Hewitt (2004) indicate that the mounds are far older than this, and that utilization of this site continued over at least 1,000 years. Moreover, dates obtained appear to cluster into two groups of burials, those which occurred roughly 1500 years ago, and those which occurred around 500 years ago. Clearly, this gap between burial clusters must be considered in any interpretation of variability in both $\delta^{13}C$ data also in mobility. Garvie identified only three individuals with $\delta^{13}C$ values indicative of a maize supplemented diet: Burials 12, 15 and 21, all of whom were female. Of these individuals, one (Burial 21) was found to date to the earlier period of mound utilization, while another (Burial 15) was found to be the most recent burial in the mounds. The third (Burial 12), was not dated. All of these individuals were female. No male within the Fidler Mounds was found to have elevated $\delta^{13}C$ values, leading Garvie (1993) to hypothesize some kind of sex-linked mechanism behind stable carbon isotope ratios, and thus, diet in this population. Based on ethnographic evidence, Garvie (1993) hypothesized that this mechanism must have been a patrilocal bride-trade between groups indigenous to the area surrounding the Fidler Mounds (likely residents of the Lockport village site), and maize-producing people to the south. For the earlier burial cluster, the relationship between sex and $\delta^{13}C$ level seems secure, at first. None of the three men dated to this period exhibit elevated $\delta^{13}C$ values, while the only woman from this cluster does. Furthermore, this woman's high level of enamel and cementum intra-tissue variability seems to indicate

that she undertook at least one large-scale migration during her life. This seems to argue in favour of Garvie's (1993) hypothesis. However, the fact that enamel data indicates that perhaps the only migration this individual participated in was undertaken during early childhood seems to argue against this mobility being the result of a betrothal or marriage. Furthermore, the elevated bone collagen $\delta^{13}C$ value obtained from this woman is a record of *adult* diet. During Manitoba's Laurel period, which is when this woman would have lived, maize-agriculture was likely not practiced in areas directly surrounding the Fidler Mounds (Buchner, 1988). If this woman, as the $\delta^{13}C$ data seem to indicate, had a maize-supplemented diet during the years immediately prior to her death, then she must have obtained this food resource from somewhere other than south-central Manitoba. Additionally, further carbon stable isotope analysis of this individual has shown that her bone collagen $\delta^{13}C$ values may not, in fact, be outside of the normal distribution of Fidler Mounds individuals. Based on this, and based on the archaeological context of this individual, the author is in favour of accepting the $\delta^{13}C$ value obtained from this individual by Hewitt (2004) and excluding her from the category of $\delta^{13}C$ anomalous individuals.

In the case of the later burial cluster, the bride-trade hypothesis must also be reconsidered. Firstly, because there is only one individual dated to this cluster to whom sex and a bone collagen $\delta^{13}C$ value can be attributed. This is hardly the type of sample from which meaningful interpretations regarding the demographic distribution of $\delta^{13}C$ values can be made. Additionally, archaeological evidence strongly indicates that maize horticulture was occurring in the immediate vicinity of the Fidler Mounds at the time when this single individual was buried (Buchner, 1988). In light of this, it does not seem

necessary to postulate a bride-trade with areas to the south to explain the presence of an individual with relatively enriched $\delta^{13}C$ values in a burial assemblage from this context. If anything, the fact that the sole other individual from this cluster, Burial 9, a sub-adult, does not exhibit a bone collagen $\delta^{13}C$ value consistent with a non C_4 supplemented diet suggests an age-linked mechanism of $\delta^{13}C$ distribution, rather than a sex linked one.

Furthermore, the difference between Burial 15 and Burials 21 and 12 in terms of enamel $\delta^{18}O$ values argues against the hypothesis that all three women had a common place of origin to the south of the Mounds. These three women appear to have followed very different paths of movement during their lives, and do not appear to constitute a regionally homogeneous sample, as Garvie (1993) hypothesized. After the exclusion of Burial 21, Burials 15 and 12 are left as the sole two individuals with anomalously high $\delta^{13}C$ values. These individuals were interred in a very different manner from one another and exhibit very different dental tissue $\delta^{18}O$ data. Before a link between these two factors and their relevance to $\delta^{13}C$ data can be addressed, more research, including radiocarbon dating of Burial 12, must be undertaken.

Unlike elevated bone collagen $\delta^{13}C$ values, mean tissue and single analysis $\delta^{18}O$ data indicative of migratory behaviour is not restricted to any demographic group. Men, women, the elderly, the young and even subadults all show some degree of inter- or intra-tissue $\delta^{18}O$ variability consistent with the undertaking of at least one migration during their lifetime. Furthermore, high mobility appears to have characterised the lives of people buried in the Fidler Mounds for the entire known period of mound use, even during the period when maize horticulture was practiced in the area. The conclusions

which can be drawn from this data, along with their significance to current interpretations and future research in Manitoba archaeology will be discussed below.

Chapter 6: Conclusions and Directions for Future Research

Several conclusions can be drawn from the research detailed above. The degree to which these conclusions are of direct significance to our understanding of precontact long-distance human migration on the northeastern Plains, or solely to the development of secondary ion mass spectrometry as a bio-archaeometric technique, is reliant upon the feasibility of several assumptions. First, that instrumental mass fractionation resulting from chemical differences between enamel, dentin and cementum does not have a significant effect on the SIMS $\delta^{18}O$ data collected for this thesis. Second, that post-burial structural or chemical alteration of dental tissue is not severe enough to have a significant effect on the SIMS $\delta^{18}O$ data collected for this thesis. And third, that the chemistry of the drinking water ingested by the Fidler Mounds population accurately reflects the chemistry of meteoric water in the area in which each individual lived.

If these statements are acceptable, then $\delta^{18}O$ values generated by this study can be interpreted at face value as indicators of fluctuation in geographic area of residence throughout the lives of the 12 individuals analysed and several conclusions about mobility during Manitoba's Woodland period can be reached:

1. **Long-distance migration occurred in the vicinity of Fidler Mounds during the Middle and Late Woodland periods.**
2. **There is no strong link between demography or chronology and mobility among the 12 individuals analysed.**

3. **The life histories of the individuals interred at Fidler Mounds were characterized by varying levels of mobility.**
4. **Long-distance migration may have played a role in the introduction of "foreign" material culture and subsistence strategies into southern Manitoba during the Middle and Late Woodland periods.**

The results of SIMS $\delta^{18}O$ analysis of the individuals from Fidler Mounds indicate that long-distance human migration occurred – perhaps with great frequency – during the Middle and Late Woodland periods in the northeastern Plains. All of the individuals analysed in this study show either significant variability in inter-tissue mean $\delta^{18}O$ values and/or variability in intra-tissue single-analysis $\delta^{18}O$ values indicative of a change in body chemistry which fits the pattern expected of a migrant individual. In both cases, the degree of variability differs across the sample population, indicating that different levels of mobility characterized the lives of people interred in the Fidler Mounds.

The sample population drawn from the Fidler Mounds burial assemblage is demographically diverse. Male and female, juvenile, young and elderly, chronically ill and osteologically "healthy" individuals are all represented. Additionally, radiocarbon dates taken from some of the individuals analysed span over a millennium, making this an incredibly chronologically diverse sample. Because of the ubiquity of $\delta^{18}O$ evidence for migration within this population, very little can be said about relationships between demography or chronology and mobility among the Fidler Mounds individuals. However, at twelve individuals, the sample population analysed in this study was very small. It is possible that including more individuals from the site in this research would

have led to the establishment of links between date of burial, age, sex or health and migration. However a larger study was beyond the scope of this thesis.

The ubiquity of $\delta^{18}O$ data indicative of long-distance migration among the Fidler Mounds individuals should not, of course, lead us to believe that migration was practiced by all Middle and Late Woodland peoples on the northeastern Plains, nor even by a very large proportion of them. Bioarchaeologists are familiar with the degree to which almost every sample population drawn from the archaeological record is biased by factors such as archaeological sampling strategies, ancient mortuary practices and differential taphonomy between age classes, burial styles and chronological groups. Such bias was definitely present in the selection of the sample population for this thesis. For instance, if mound burial was the preferred mortuary practice of individuals who were not local to the area surrounding Fidler Mounds, while local individuals practiced some other, less conspicuous or more destructive form of interment, it is possible that the 100% frequency of migrant individuals within the population considered above may be influenced more by sampling strategies than the prevalence of long-distance human migration during the Woodland period of the northeastern Plains.

The mere presence of migrant individuals within the Fidler Mounds population, whether or not their high mobility was characteristic of all peoples living in the area during the Middle and Late Woodland, contributes towards formulating an answer for the original question posed by this thesis, that is, whether long-distance migration occurred in the area of Fidler Mounds over the thousand years of that site's formation and, if so, whether it was responsible for the "foreign influence" suggested by material culture excavated from Fidler Mounds and surrounding sites. Given the above stated

assumptions, it is possible to state that migration almost certainly did occur in the area surrounding Fidler Mounds during the Middle and Late Woodland periods. However, it is less clear whether this mobility led to the utilization of distantly-influenced material culture or the introduction of maize agriculture to the area during the Late Woodland period. Though the presence of both migrant individuals and material culture heavily influenced by Mississippian and other southern traditions at the same site in southern Manitoba might be highly suggestive of such a link, it is not conclusive. It is possible that other processes, such as long distance trade or diffusion led to the culturally diverse material record of Fidler Mounds and surrounding areas. However, if the level of mobility exhibited by the Fidler Mounds population analysed is indicative of overall mobility patterns on the northeastern Plains during the Woodland period, it seems highly likely that some traces of this behaviour would be left on the archaeological record. A much more concrete link between migration and "foreign" material culture in southern Manitoba could be drawn with the aid of a suitable, externally calibrated standard against which the $\delta^{18}O$ values of Fidler Mounds dental tissues could be calculated. This would allow the researcher to geographically track the migration of the individuals analysed, and compare these paths of mobility to the geographic origins of the traditions thought to have influenced material culture in southern Manitoba. Consistency between the two would strongly supplement the argument that long-distance human migration was a factor in introducing "foreign" material culture styles and subsistence patterns into the area.

The above conclusions are reliant upon the validity of the assumptions listed at the beginning of this chapter. By now, the reader should be aware that this validity is highly suspect, especially in the case of the first two assumptions. Because of the

chemical differences between enamel and dentin and cementum, instrumental mass fractionation likely *did* contribute to the $\delta^{18}O$ values obtained through SIMS analysis. Without the aid of an externally calibrated standard, which would allow for the calculation of correction factors for each of the three dental tissues analysed, the impact of IMF likely invalidates interpretations based on direct, inter-tissue comparisons. However, this phenomenon need not be considered when comparing mean $\delta^{18}O$ values or single analysis $\delta^{18}O$ values from only one of the three tissues.

Backscatter electron (BSE) and secondary emission (SE) scanning electron microscope (SEM) images of dentin and cementum provide sufficient evidence to call into question the structural and chemical integrity of these two tissues. Cementum from all three of the individuals analysed appears to be riddled with cracks in SE-SEM images, and shows widespread chemical alteration when viewed through BSE-SEM. Additionally, SEM images show that the dentin of the three people analysed was quite porous, with minute traces of gold coating trapped in each pore. While it is not certain, it is at least possible that these pores also served as reservoirs for the epoxy used to mount the teeth. If this is indeed the case, matrix differences between areas of differential porosity could have added variability to SIMS $\delta^{18}O$ results that could not be accurately accounted for, and thus eliminated. Because of this, comparisons of dentin $\delta^{18}O$ values to $\delta^{18}O$ values obtained from other tissues, as well as comparisons of single analysis $\delta^{18}O$ values obtained from different areas within the dentin of a single individual, may not be valid.

The validity of the third assumption – that the chemistry of the drinking water ingested by the Fidler Mounds population accurately reflects the chemistry of meteoric

water in the area in which each individual lived – is somewhat more difficult to assess. Middle and Late Woodland water resource utilization patterns on the northeastern plains and surrounding areas have not been thoroughly researched. However, it is certainly possible that drinking-water sources, such as oxbows or ponds, which would have undergone significant evaporation, rendering them isotopically different from meteoric water, were utilized by peoples in the area. The exact degree to which this phenomenon might impact $\delta^{18}O$ values obtained from any given individual's dental tissues likely could not be accounted for with the accuracy required to compensate for it during data interpretation, even in cases where contextually relevant archaeological or ethnographic information pertaining to drinking water resource choices is available.

The above caveats should not be thought of as barriers to future investigation of ancient mobility patterns utilizing SIMS analysis of dental tissue $\delta^{18}O$ values. Instead, they should be thought of as avenues for novel and significant research in the field of archaeometry. Perhaps the only assumption-free conclusion that can be drawn from this thesis is that there remains much work to be done to refine this technique to the level where results will be both acceptable to the academic community at large and comparable to results obtained by other studies utilizing different methods of dental stable oxygen isotope analysis. Opportunities for theoretical refinement abound: relevant ethnographic research into drinking water resource scheduling behaviours, investigation into the comparability of $\delta^{18}O$ values obtained from deciduous and permanent teeth and research into the effect of dental pathologies on oxygen isotope results obtained from teeth are all open fields of exploration. Furthermore, SIMS methodologies tailored to dental analysis, including the establishment of standardized sampling procedures which collect

information from specific, known growth periods and externally calibrated dental standards from which correction factors for different dental tissues could be calculated, have yet to be developed. Even if these fields of research are eventually exhausted, the potential applications of theoretically and methodologically sound *in situ* SIMS analysis of dental tissue stable oxygen isotopes are almost limitless. Data resulting from SIMS dental analysis are nothing if not versatile. The information provided by *in situ* analyses of individual dental isotopics will eventually allow archaeologists to explore different aspects of migration in contexts ranging from individual life histories to massive, population level phenomenon. The potential borders of this exploration are limited only by the diligence, practicality and imagination of current and future researchers.

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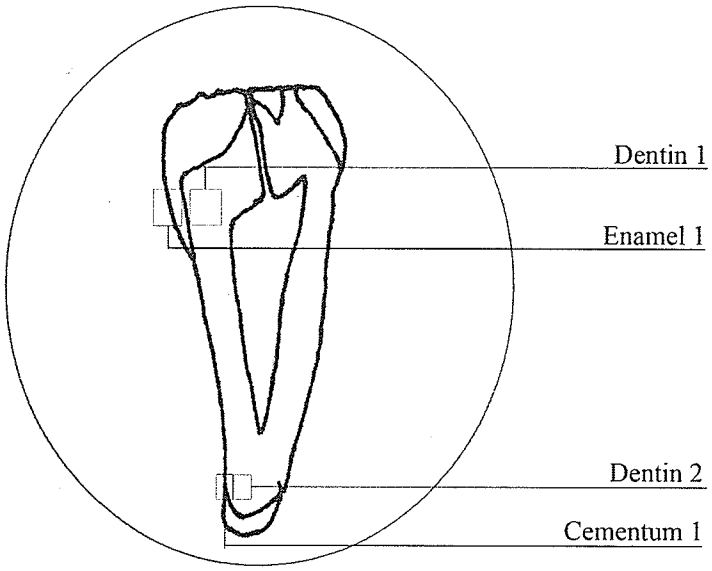
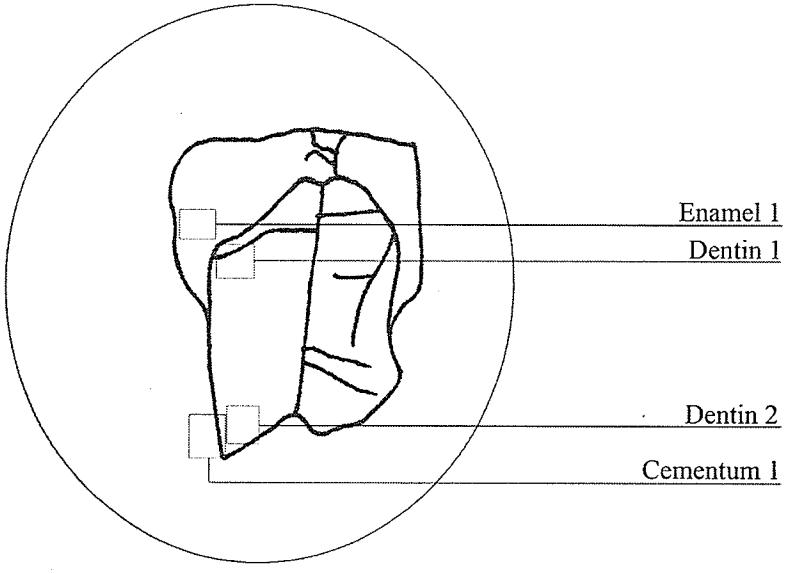
Appendix A: Diagrams of teeth analysed with tissue test sites indicated (not to scale)



Burial 9



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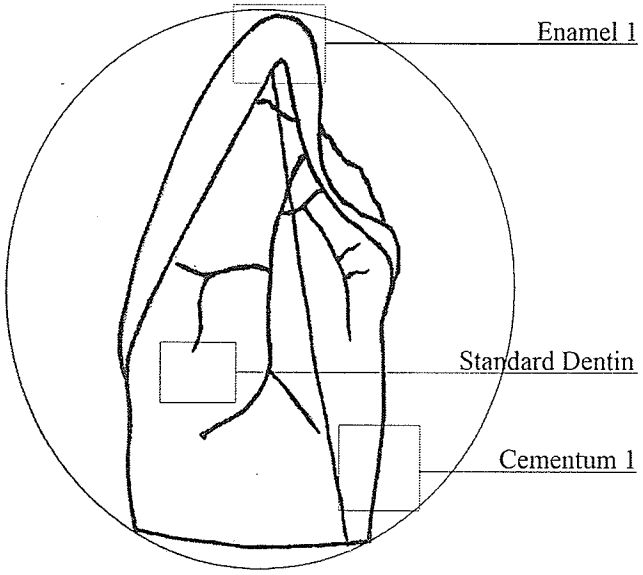
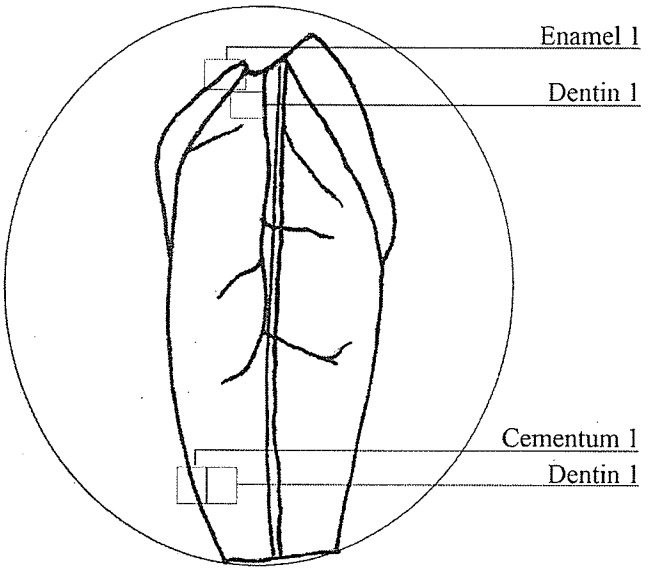
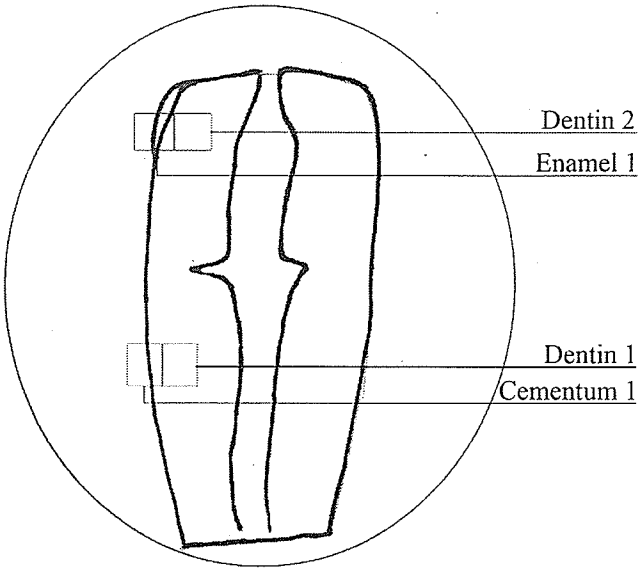


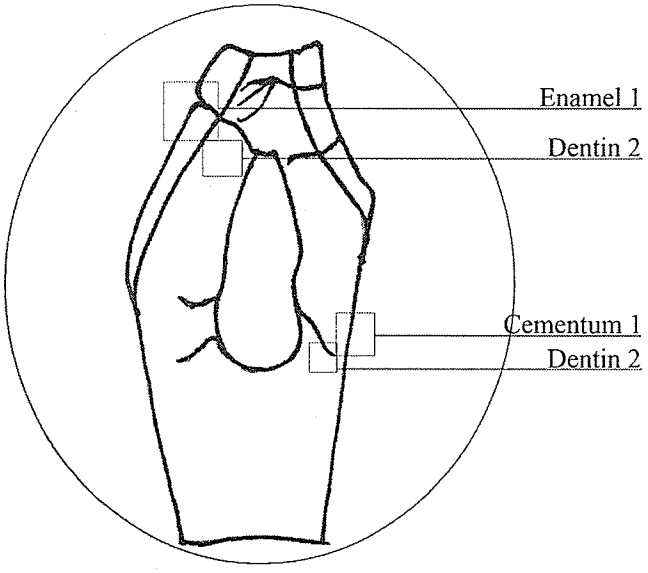
Fill B



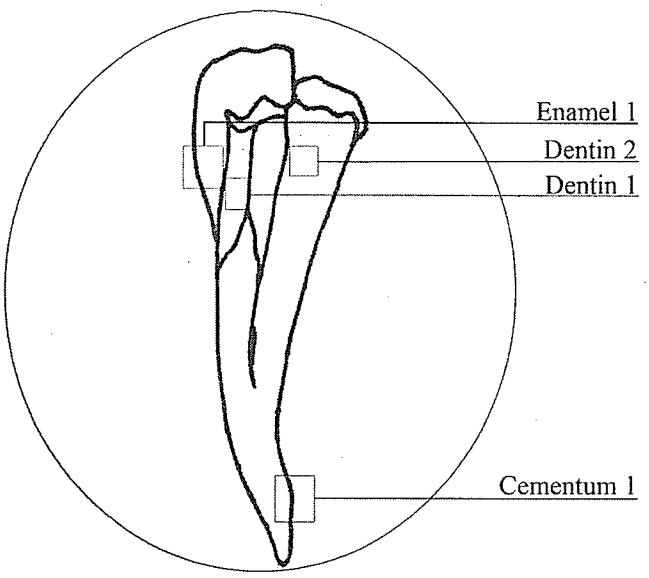
Burial 15



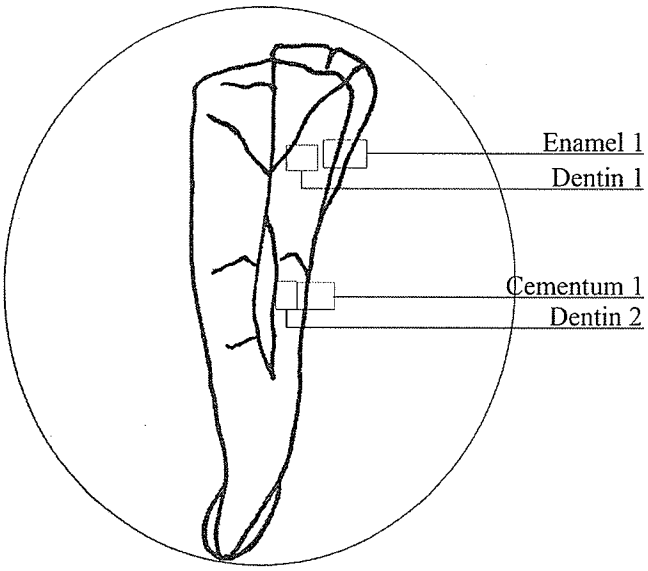
Burial 10



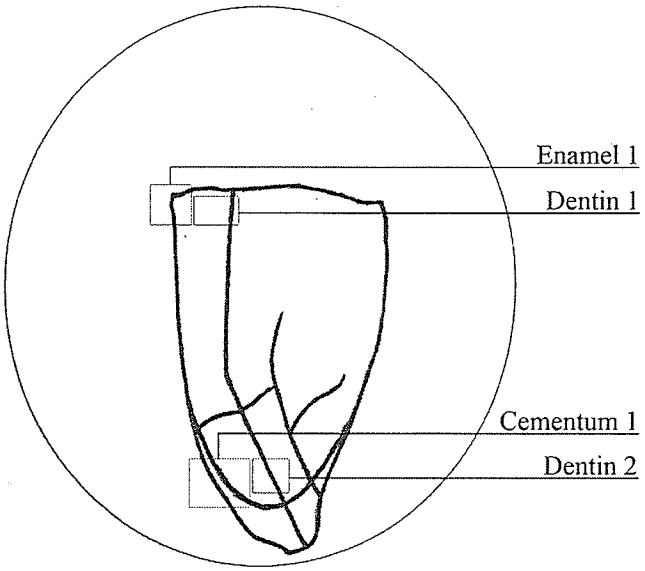
Burial 19



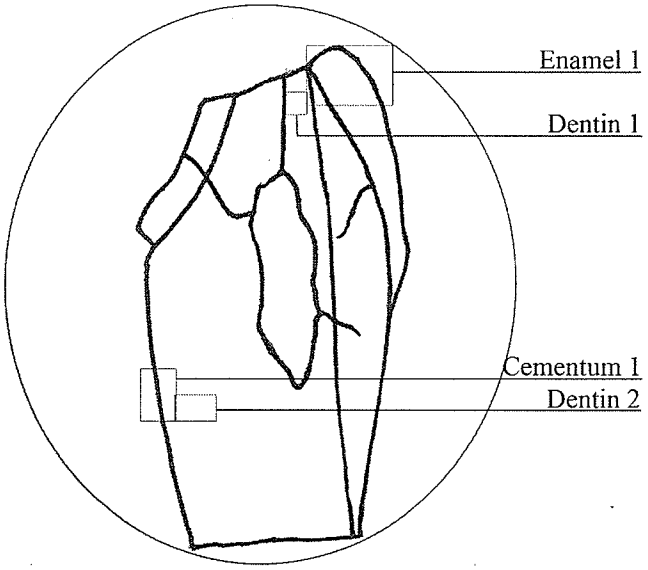
Burial 12



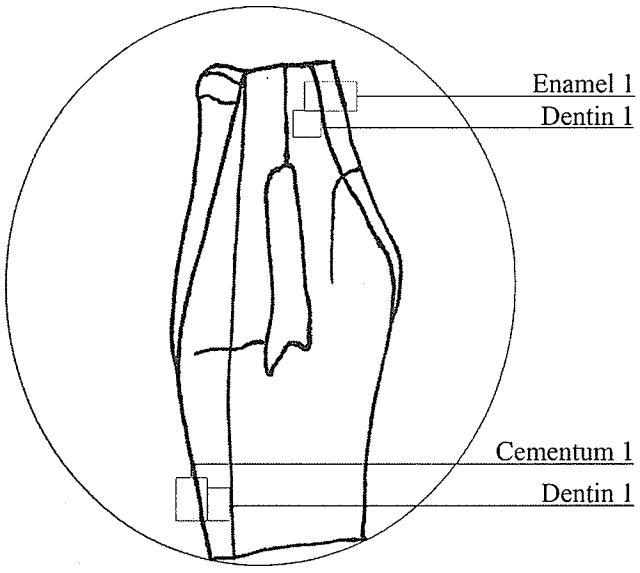
Burial 7



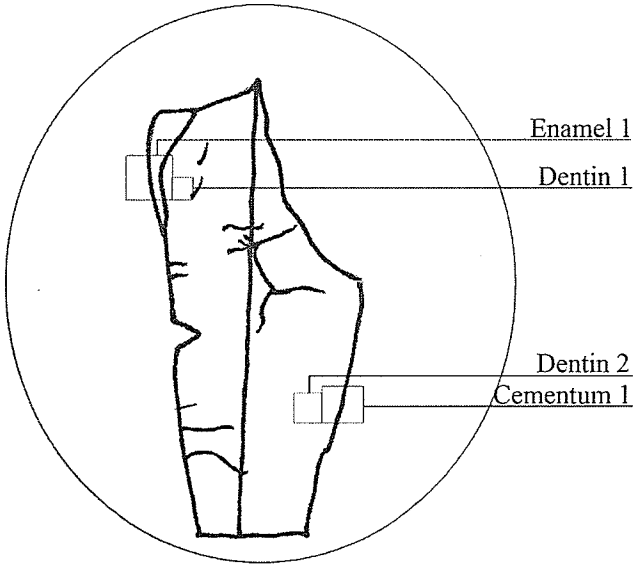
Burial 17



Fill A



Fill LRC



Burial 11

Appendix B: Single-analysis $\delta^{18}O$ results by individual and tissue

Table B.1: Single-analysis data from 12 individuals analysed. Superscript indicates area from which dentin results were obtained. $\delta^{18}O$ values with * were obtained from cracked or otherwise altered tissue and should be considered with caution. $\delta^{18}O$ values with ** were excluded from this study as SEM analysis showed them to be unreliable.

Individual	Tissue		$\delta^{18}O$ v-SMOW (‰)	95% ci
Fill LRC	Dentin[1]		15	2
Fill LRC	Dentin[1]		10	2
Fill LRC	Dentin[2]		9	2
		Tissue Average	**11**	**3**
		Standard Dev	**3**	
			2	
Fill LRC	Cementum		8*	2
Fill LRC	Cementum		12*	2
Fill LRC	Cementum		7*	2
Fill LRC	Cementum		8*	2
Fill LRC	Cementum		10	2
		Tissue Average	**9**	**2**
		Standard Dev	**2**	
			3	
Fill LRC	Enamel		7	2
Fill LRC	Enamel		10	2
Fill LRC	Enamel		14	2
Fill LRC	Enamel		17*	2
		Tissue Average	**12**	**5**
		Standard Dev	**4**	
Fill B	Cementum		12	2
Fill B	Cementum		12	2
Fill B	Cementum		15*	2*
Fill B	Cementum		6**	2**
Fill B	Cementum		10.4	2
		Tissue Average	**12**	**2**
		Standard Dev	**1**	
Fill B	Enamel		21	2
Fill B	Enamel		19	2
Fill B	Enamel		18	2

Fill B	Enamel		17	2
		Tissue Average	**19**	**2**
		Standard Dev	**2**	
Fill B	Dentin[1]		14	2
Fill B	Dentin[1]		16	2
Fill B	Dentin[1]		16	2
Fill B	Dentin[1]		15	2
		Tissue Average	**15**	**2**
		Standard Dev	**1**	
Burial 19	Enamel		15	2
Burial 19	Enamel		19*	2
Burial 19	Enamel		19	2
Burial 19	Enamel		20	2
		Tissue Average	**18**	**2**
		Standard Dev	**2**	
Burial 19	Cementum		11	2
Burial 19	Cementum		12	2
Burial 19	Cementum		13	2
Burial 19	Cementum		13	2
		Tissue Average	**12**	**2**
		Standard Dev	**1**	
Burial 19	Dentin[1]		9	2
Burial 19	Dentin[1]		13	2
Burial 19	Dentin[2]		16	2
Burial 19	Dentin[2]		16	2
		Tissue Average	**14**	**4**
		Standard Dev	**3**	
Burial 15	Enamel		8	2
Burial 15	Enamel		11	2
Burial 15	Enamel		14	2
Burial 15	Enamel		15	2
		Tissue Average	**12**	**3**
		Standard Dev	**3**	
Burial 15	Cementum		10*	2
Burial 15	Cementum		10	2
Burial 15	Cementum		12	2
Burial 15	Cementum		10	2
		Tissue Average	**10**	**2**
		Standard Dev	**1**	
Burial 15	Dentin[1]		12	2

Burial 15	Dentin[1]		13	2
Burial 15	Dentin[2]		8	2
Burial 15	Dentin[2]		6	2
		Tissue Average	**10**	**4**
		Standard Dev	**3**	
Burial 10	Enamel		9	2
Burial 10	Enamel		9	2
Burial 10	Enamel		10	2
Burial 10	Enamel		10	2
		Tissue Average	**10**	**1**
		Standard Dev	**1**	
Burial 10	Cementum		3	2
Burial 10	Cementum		-4**	2
Burial 10	Cementum		4	2
Burial 10	Cementum		-1**	2
		Tissue Average	**3**	**1**
		Standard Dev	**1**	
Burial 10	Dentin[1]		9	2
Burial 10	Dentin[1]		9	2
Burial 10	Dentin[2]		11	2
Burial 10	Dentin[2]		11	2
		Tissue Average	**10**	**2**
		Standard Dev	**1**	
Burial 11	Enamel		14	2
Burial 11	Enamel		14	2
Burial 11	Enamel		14	2
Burial 11	Enamel		14	2
		Tissue Average	**14**	**1**
		Standard Dev	**0**	
Burial 11	Cementum		12	2
Burial 11	Cementum		11	2
Burial 11	Cementum		14	2
Burial 11	Cementum		12*	2
		Tissue Average	**12**	**2**
		Standard Dev	**1**	
Burial 11	Dentin[1]		12	2
Burial 11	Dentin[1]		10	2
Burial 11	Dentin[2]		8	2
Burial 11	Dentin[2]		10	2
		Tissue Average	**10**	**2**
		Standard Dev	**2**	

Fill A	Enamel		16	2
Fill A	Enamel		15	2
Fill A	Enamel		16	2
Fill A	Enamel		15	2
		Tissue Average	**15**	**1**
		Standard Dev	**1**	
Fill A	Cementum		12	2
Fill A	Cementum		9	2
Fill A	Cementum		13	2
Fill A	Cementum		10	2
		Tissue Average	**11**	**2**
		Standard Dev	**2**	
Fill A	Dentin[1]		15	2
Fill A	Dentin[1]		16	2
Fill A	Dentin[2]		12	2
Fill A	Dentin[2]		10	2
		Tissue Average	**13**	**3**
		Standard Dev	**3**	
Burial 17	Enamel		12	2
Burial 17	Enamel		15	2
Burial 17	Enamel		14	2
		Tissue Average	**13**	**2**
		Standard Dev	**2**	
Burial 17	Cementum		13	2
Burial 17	Cementum		12	2
Burial 17	Cementum		9	2
Burial 17	Cementum		13	2
		Tissue Average	**12**	**2**
		Standard Dev	**2**	
Burial 17	Dentin[1]		14	2
Burial 17	Dentin[1]		14	2
Burial 17	Dentin[2]		11	2
Burial 17	Dentin[2]		13	2
		Tissue Average	**13**	**2**
		Standard Dev	**1**	
Burial 9	Enamel		23	2
Burial 9	Enamel		21	2
Burial 9	Enamel		24	2
Burial 9	Enamel		25	2
		Tissue Average	**23**	**2**
		Standard Dev	**2**	

Burial 9	Cementum		14	2
Burial 9	Cementum		15	2
Burial 9	Cementum		19	2
Burial 9	Cementum		23	2
		Tissue Average	**18**	**4**
		Standard Dev	**4**	
Burial 9	Dentin[1]		15	2
Burial 9	Dentin[1]		14	2
Burial 9	Dentin[2]		13	2
Burial 9	Dentin[2]		16	2
		Tissue Average	**14**	**2**
		Standard Dev	**1**	
Burial 21	Enamel		20	2
Burial 21	Enamel		22	2
Burial 21	Enamel		22	2
Burial 21	Enamel		18	2
		Tissue Average	**20**	**2**
		Standard Dev	**2**	
Burial 21	Cementum		12**	2
Burial 21	Cementum		16**	2
Burial 21	Cementum		16**	2
Burial 21	Cementum		17**	2
		Tissue Average	**15****	**3****
		Standard Dev	**2****	
Burial 21	Dentin[1]		19	2
Burial 21	Dentin[1]		19	2
Burial 21	Dentin[2]		14	2
Burial 21	Dentin[2]		14	2
		Tissue Average	**17**	**3**
		Standard Dev	**3**	
Burial 7	Enamel		21	2
Burial 7	Enamel		19	2
Burial 7	Enamel		23	2
Burial 7	Enamel		18	2
		Tissue Average	**20**	**2**
		Standard Dev	**3**	
Burial 7	Cementum		13	2
Burial 7	Cementum		13	2
Burial 7	Cementum		14	2
Burial 7	Cementum		14	2
		Tissue Average	**13**	**1**

		Standard Dev	**1**	
Burial 7	Dentin[1]		15	2
Burial 7	Dentin[1]		12	2
Burial 7	Dentin[2]		13	2
Burial 7	Dentin[2]		15	2
		Tissue Average	**14**	**2**
		Standard Dev	**1**	
Burial 12	Enamel		16	2
Burial 12	Enamel		15	2
Burial 12	Enamel		20	2
Burial 12	Enamel		21	2
		Tissue Average	**18**	**3**
		Standard Dev	**2**	
Burial 12	Cementum		15	2
Burial 12	Cementum		12	2
Burial 12	Cementum		12	2
Burial 12	Cementum		13	2
		Tissue Average	**12**	**1**
		Standard Dev	**1**	
Burial 12	Dentin[1]		12	2
Burial 12	Dentin[1]		19	2
Burial 12	Dentin[2]		15	2
Burial 12	Dentin[2]		14	2
		Tissue Average	**15**	**3**
		Standard Dev	**3**	

Appendix C: Supporting Statistics

Table C.1: Results of oneway analysis of variance conducted on enamel $\delta^{18}O$ values obtained from Fidler Mounds individuals.

	Sum of Squares	df	Mean Square	F	Significance
Between Individuals	741.56	11	67.41	15.32	0.000
Within Individuals	153.99	35	4.4		
Total	895.54	46			

Table C.2: Results of oneway analysis of variance conducted on dentin $\delta^{18}O$ values obtained from Fidler Mounds individuals.

	Sum of Squares	df	Mean Square	F	Significance
Between Individuals	219.04	11	19.91	3.6	0.002
Within Individuals	193.82	35	5.54		
Total	412.87	46			

Table C.3: Results of oneway analysis of variance conducted on cementum $\delta^{18}O$ values obtained from Fidler Mounds individuals

	Sum of Squares	df	Mean Square	F	Significance
Between Individuals	400.02	11	36.37	9.79	0
Within Individuals	130	35	3.714		
Total	530.01	46			

Table C.4: Results of two-sided T-Tests performed on cementum and enamel $\delta^{18}O$ data taken from individuals interred at Fidler Mounds

Individual 10B	Tissue	Data points	Mean	SD	SME
	Enamel	4	10	0.57	0.29
	Cementum	2	3	0.64	0.45

Levene's Test for Equality of Variences	F	Sig
Equal variances assumed	0	1
Equal variances not assumed		

T-test for Equality of Means						95% Confidence interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error difference	Lower	Upper
Equal variances assumed	12.85	4	0	6.55	0.51	5.14	7.96
Equal variances not assumed	12.29	1.868	0.008	6.55	0.53	4.09	9.01

Individual 11	Tissue	Data points	Mean	SD	SME
	Enamel	4	14	0.13	0.65
	Cementum	4	12	1.21	0.61

Levene's Test for Equality of Variences	F	Sig
Equal variances assumed	5.30	0.061
Equal variances not assumed		

T-test for Equality of Means						95% Confidence interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error difference	Lower	Upper
Equal variances assumed	3.28	6	0.017	2	0.61	0.51	3.49
Equal variances not assumed	3.28	3.068	0.045	2	0.61	0.08	3.92

Individual 12	Tissue	Data points	Mean	SD	SME
	Enamel	4	18	2.80	1.40
	Cementum	4	13	1.72	0.86

Levene's Test for Equality of Variences	F	Sig
Equal variances assumed	4.85	0.07
Equal variances not assumed		

T-test for Equality of Means						95% Confidence interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error difference	Lower	Upper
Equal variances assumed	3.10	6	0.02	5.10	1.65	1.08	9.12
Equal variances not assumed	3.10	4.98	0.03	5.10	1.65	0.87	9.33

Individual 15	Tissue	Data points	Mean	SD	SME
	Enamel	4	12	2.66	1.33
	Cementum	4	10	0.95	0.48

Levene's Test for Equality of Variences	F	Sig
Equal variances assumed	3.36	0.12
Equal variances not assumed		

T-test for Equality of Means						95% Confidence interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error difference	Lower	Upper
Equal variances assumed	1.15	6	0.29	1.63	1.41	-1.83	5.08
Equal variances not assumed	1.15	3.76	0.32	1.63	1.41	-2.40	5.65

Individual 17	Tissue	Data points	Mean	SD	SME
	Enamel	4	13	1.59	0.92
	Cementum	4	12	1.84	0.92

Levene's Test for Equality of Variences	F	Sig
Equal variances assumed	0.03	0.88
Equal variances not assumed		

T-test for Equality of Means						95% Confidence interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error difference	Lower	Upper
Equal variances assumed	1.41	5	0.22	1.88	1.33	-1.55	5.30
Equal variances not assumed	1.44	4.08	0.21	1.88	1.30	-1.50	5.25

Individual 19	Tissue	Data points	Mean	SD	SME
	Enamel	4	18	1.86	0.93
	Cementum	4	12	1.40	0.70

Levene's Test for Equality of Variences	F	Sig
Equal variances assumed	0.15	0.71
Equal variances not assumed		

T-test for Equality of Means						95% Confidence interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error difference	Lower	Upper
Equal variances assumed	4.99	6	0.002	5.83	1.17	2.97	8.68
Equal variances not assumed	4.99	5.57	0.003	5.83	1.17	2.91	8.73

Individual 7	Tissue	Data points	Mean	SD	SME
	Enamel	4	20	1.97	0.99
	Cementum	4	14	0.54	0.27

Levene's Test for Equality of Variences	F	Sig
Equal variances assumed	5.90	0.051
Equal variances not assumed		

T-test for Equality of Means						95% Confidence interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error difference	Lower	Upper
Equal variances assumed	6.40	6	0.001	6.55	1.02	4.05	9.05
Equal variances not assumed	6.40	3.44	0.005	6.55	1.02	3.52	9.58

Individual 9	Tissue	Data points	Mean	SD	SME
	Enamel	4	23	1.50	0.74
	Cementum	4	18	4.07	2.04

Levene's Test for Equality of Variences	F	Sig
Equal variances assumed	4.57	0.076
Equal variances not assumed		

T-test for Equality of Means						95% Confidence interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error difference	Lower	Upper
Equal variances assumed	2.491	6	0.047	5.40	2.17	0.10	10.71
Equal variances not assumed	12.29	3.79	0.071	5.40	2.17	-0.76	11.56

Individual Fill A	Tissue	Data points	Mean	SD	SME
	Enamel	4	15	0.62	0.31
	Cementum	4	11	1.76	0.88

Levene's Test for Equality of Variences	F	Sig
Equal variances assumed	4.79	0.71
Equal variances not assumed		

T-test for Equality of Means						95% Confidence interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error difference	Lower	Upper
Equal variances assumed	4.71	6	0.003	4.40	0.94	2.11	6.69
Equal variances not assumed	4.71	3.74	0.011	4.40	0.94	1.73	0.64

Individual FillB	Tissue	Data points	Mean	SD	SME
	Enamel	4	19	1.77	0.88
	Cementum	4	12	1.29	0.64

Levene's Test for Equality of Variences	F	Sig
Equal variances assumed	0.48	0.51
Equal variances not assumed		

T-test for Equality of Means						95% Confidence interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error difference	Lower	Upper
Equal variances assumed	6.27	6	0.001	6.85	1.09	4.18	9.52
Equal variances not assumed	6.27	5.49	0.001	6.85	1.09	4.11	9.59

Individual FillLRC	Tissue	Data points	Mean	SD	SME
	Enamel	4	12	4.30	2.15
	Cementum	5	9	2.05	0.92

Levene's Test for Equality of Variences	F	Sig
Equal variances assumed	3.512	0.10
Equal variances not assumed		

T-test for Equality of Means						95% Confidence interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error difference	Lower	Upper
Equal variances assumed	1.28	7	0.24	2.76	2.16	-2.35	7.86
Equal variances not assumed	1.18	4.09	0.30	2.76	2.34	-3.68	9.19