EXPLORING THE POTENTIAL OF STRONTIUM ISOTOPE ANALYSIS TO DETECT ARCHAEOLOGICAL MIGRATION EVENTS IN SOUTHERN ONTARIO, CANADA

By

© Megan A. Bower

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Department of Archaeology, Faculty of Humanities and Social Sciences
Memorial University of Newfoundland

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Abstract

This dissertation examines the potential of strontium isotope analysis to detect archaeological migration events in southern Ontario, Canada. It is the first study of strontium isotope analysis of white-tailed deer teeth conducted in Canada, with previous research making use of stable isotope analysis and archaeological and ethnohistorical evidence to investigate mobility. Southern Ontario has a rich archaeological record with a long history of mobility studies making it an ideal setting in which to investigate the potential of this method.

In pursuit of this, the range of variation in bioavailable $^{87}Sr/^{86}Sr$ values in southern Ontario was established to create an isotopic baseline. Three models detailing the range of variation in $^{87}Sr/^{86}Sr$ values were created: a proxy model using previously published $^{87}Sr/^{86}Sr$ values of geological substrates; a theoretical model using previously published equations to establish potential bioavailable $^{87}Sr/^{86}Sr$ values; and an experimental model using white-tailed deer teeth recovered from archaeological sites in southern Ontario.

Three hundred and twenty one samples of core enamel from 104 white-tailed deer teeth recovered from 31 different archaeological sites in southern Ontario were prepared for strontium isotope analysis to characterize the bioavailable strontium. Sites were located in traditional Huron-Wendat and Neutral territory dating from A.D. 75-1651. The underlying geology in the region dates to the Palaeozoic era (~542MYA to 251MYA) and contains limestone, sandstone, dolomite and shale with trace amounts of other rocks and minerals (e.g., arkose). A variety of types of sediment and soil overlay the bedrock

including sand, clay, silt, gravel, and glacial till dating to the Quaternary period (2.6MYA to present) while elevation ranges from 49 to 542 meters above sea level. The amount of variation within and between white-tailed deer teeth was also examined with serial samples analyzed from multiple lophs on the same tooth, as well as from different types of teeth (e.g., first, second and third molars) from the same individual.

Strontium isotope analysis was found to be of limited utility to investigate mobility within groups originating from southern Ontario (e.g., the Huron-Wendat and Neutral) with minimal variation present. However, distinction between populations from different geographic areas (e.g., Northern Iroquoians, Iroquoians, Europeans, Algonquians) remains feasible. Similarly, the strontium isotope composition within white-tailed deer teeth is relatively homogenous making them a viable sample for strontium isotope analysis. However, small differences between types of teeth were noted suggesting that white-tailed deer behaviour and seasonality are influential. Cultural factors such as white-tailed deer acquisition and type of site (e.g., village, hamlet) also impact strontium isotope analysis and should be considered in any study making use of this method.

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Any errors within this manuscript are mine and mine alone.

Dedication

This dissertation and any work resulting from it are dedicated to the memory of Glen W. Smith without whom it would not have been possible. We miss you.

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Chapter One: Introduction

Population movement is a significant aspect of life on Earth. Not only does it dictate the physical environment that an individual is exposed to on an everyday basis but it is also a central aspect of social life (Anthony 1997:30). As such, movement influences a number of phenomena, including subsistence, health, socio-political organization, economics, demography, gender roles, ideology, and identity. This has led archaeologists to identify it as an important avenue of study with a large body of literature devoted to its exploration.

This is particularly true for southern Ontario, Canada, which represents a unique opportunity for researchers interested in past mobility patterns. With a rich archaeological record and a large number of documented archaeological sites associated with several indigenous populations, such as the Huron-Wendat and the Neutral, researchers have been investigating movement in this region for decades (e.g., Wright 1966; Ramsden 1988; Snow 1995; Hart 2001; Creese 2011). This prior research has suggested that movement was a regular occurrence right up until A.D. 1649-1651. Phenomena such as post-marital residence patterns, population origins, mortuary practices and economic activities (e.g., acquiring resources for trade) have all been suggested as motivating factors for movement; however, debate as to their extent in Northern Iroquoian populations has spurred researchers to search for alternative methods of investigation.

These alternative methods include both direct and indirect approaches. For example, archaeologists have hypothesized about the occurrence of movement using indirect methods such as ethnohistoric records, discontinuities in artifact construction and style, changes in settlement patterns, and unique mortuary practices (e.g., Heidenreich 1971; Brumbach 1975; Damkjar 1982; Trigger 1987; Ramsden 1988; Bamann et al. 1992; Crawford and Smith 1996; Birch 2010; Hart 2012). Similarly, bioarchaeologists have made use of techniques such as non-metric traits and craniometrics (e.g., Molto 1983; Dupras and Pratte 1998; Rost 2011). Recently, isotope analyses of elements such as strontium, oxygen, lead, and sulphur have been used to answer questions focused on past population movement. However, these methods are fraught with limitations, leading researchers to call for clarification on what occurred, specifically in southern Ontario (Pfeiffer et al. 2014).

Existing research on mobility in this area has been restricted to using ancient DNA, differences in diet based on carbon and nitrogen isotope values, and archaeological interpretation of differences in settlement patterns and artifacts (Schwarcz et al. 1985; Finlayson 1985; Ramsden 1988; Damkjar 1990; Hart 2012; Pfeiffer et al. 2014). Although attempts have been made to use oxygen isotope analysis to investigate mobility in this area (e.g., Schwarcz et al. 1991; Morris 2015), a number of concerns have been raised as to the way that these data have been acquired and interpreted (Morris 2014). Supplementing these existing interpretations with isotopic analyses of elements such as strontium can aid in understanding the extensive population movement that characterized life in southern Ontario in the Middle and Late Woodland Periods (i.e., from A.D. 1000 onwards).

It is this desire for clarification that has prompted the exploration of strontium isotope analyses in southern Ontario. However, in order for this technique to be used to its maximum potential, a number of conditions need to be met. One of these is the establishment of a local isotopic baseline that characterizes the isotopic composition of the environment of the study area. It is this topic that is the subject of this dissertation.

1.1 Research objectives

This research is a pilot study investigating the feasibility of using strontium isotope analysis to identify archaeological migration events in southern Ontario, Canada, by establishing the range in variation in bioavailable strontium. This is accomplished by conducting strontium isotope analysis on white-tailed deer teeth recovered in archaeological contexts from southern Ontario, Canada. Two additional models created using previously published research are also presented: one using previously published $^{87}Sr/^{86}Sr$ values from geological material and the second using mathematical equations to predict theoretical bioavailable $^{87}Sr/^{86}Sr$ values. This research also investigates the amount of variation in $^{87}Sr/^{86}Sr$ values within and between white-tailed deer teeth. Specifically, the goals for this research include:

1. Establish whether strontium isotope analysis is an appropriate method to investigate mobility and associated topics in past populations in southern Ontario.
2. Develop a proxy model of variation in $^{87}Sr/^{86}Sr$ values using previously published $^{87}Sr/^{86}Sr$ values from geological material and a theoretical model of $^{87}Sr/^{86}Sr$ values in southern Ontario using previously published mathematical equations.
3. Create an isotopic baseline for bioavailable strontium isotopes in southern Ontario using faunal remains recovered from archaeological sites in the area.
4. Identify the extent of intra-species variation in $^{87}Sr/^{86}Sr$ values obtained from enamel of white-tailed deer recovered in the area.
5. Investigate the potential for the influence of seasonality on local $^{87}Sr/^{86}Sr$ values in white-tailed deer.
6. Consider the relationship between strontium isotope analysis, culture and the environment and how they work together to provide observed bioavailable strontium isotope data.

1.2 Overview of this dissertation

This dissertation is divided into nine chapters. The first chapter provides an overview of the research and details the research questions and objectives. Chapter Two discusses the biogeochemistry of strontium in the environment and in living creatures (i.e., the geosphere and biosphere). A focus is placed on the geology, soils and sediment, water, flora and fauna indigenous to southern Ontario, Canada. The third chapter considers the creation of an isotopic baseline and theoretical modeling in mapping the variation in $^{87}Sr/^{86}Sr$ values, presenting two theoretical models for strontium in southern Ontario. One of these is created using a previously established simulation based on mathematical modeling in ArcGIS (Bataille 2014) and the other is created using previously published strontium data from geological sources. The fourth chapter considers how mobility has been approached in archaeology and discusses the different theoretical approaches that have been used to inform analyses in southern Ontario throughout time. Chapter Five gives details on the archaeological record in southern Ontario, focusing specifically on the Northern Iroquoian populations of the Huron-Wendat and Neutral. Chapter Six provides an overview of the methods and samples that were used to create the isotopic baseline making use of white-tailed deer teeth, including the physical sampling procedures as well as mass spectrometry, while Chapter Seven presents the results from the strontium isotope analyses conducted on archaeological faunal material. Chapter Eight considers the data obtained and places them into the archaeological context. Finally, Chapter Nine presents the conclusions drawn from this research, as well as the identified limitations associated with this work and avenues of future research.

Chapter Two: Strontium Biogeochemistry

In 1965, Brill and Wampler (in Pollard 2011) introduced a new application for isotope analysis to archaeology. Researchers came to realize the potential of this new application and quickly expanded on the original concept (e.g., van der Merwe and Vogel 1978; DeNiro and Epstein 1981) including J.E. Ericson (1985). Using a sample population of Chumash Indians from the Santa Monica Mountains in California near the coast of the Pacific Ocean, Ericson (1985) successfully demonstrated the potential of strontium isotope analysis to investigate mobility in a mobile hierarchical society with ambilocal marriage patterns. Although there are several complicating environmental and cultural factors, researchers recognized the potential of the method and studies making use of strontium isotope analysis around the world are now common (e.g., Ezzo et al. 1997; Price et al. 2006; Slovak et al. 2009; Kusaka et al. 2012; Buzon and Simonetti 2013; Giblin et al. 2013; Gregoricka 2013a, b; Kinaston et al. 2013; Font et al. 2015; Scherer and Wright 2015).

This chapter provides a brief background of strontium isotopes in the biogeosphere. An overview of strontium isotope chemistry is presented before a discussion on how strontium interacts with the environment and in mammalian tissues. Specific topics such as geology, sediment, water, flora and fauna are considered with a focus placed on southern Ontario. A general summary of white-tailed deer (*Odocoileus virginianus)*, their biology, and ecology is provided before finishing the chapter with an acknowledgement of the influence that mixing systems wield on bioavailable strontium isotopes.

2.1 Strontium geochemistry

Strontium, which has an atomic number of 38, is a divalent alkaline earth element with an ionic radius of 1.13Å (Radosevich 1993:271; Ezzo 1994; Bentley 2006). It has four naturally occurring isotopes, ^{84}Sr (0.5%), ^{86}Sr (9.9%), ^{87}Sr (7.0%), and ^{88}Sr (82.5%) (Faure and Powell 1972), as well as one additional isotope, ^{90}Sr, that occurs as a result of fission reactions (Comar et al. 1957; Capo et al. 1998). Of these naturally occurring isotopes, all are stable; however, ^{87}Sr is a radiogenic isotope resulting from the decay of ^{87}Rb. In archaeological applications, researchers make use of ^{87}Sr relative to ^{86}Sr, notated as $^{87}Sr/^{86}Sr$, to study provenance and mobility, and the concentrations of elemental strontium relative to calcium in the reconstruction of paleodiet (e.g., Sr/Ca) (but see Knudson et al. 2010).

As noted, ^{87}Sr is a radiogenic isotope that is the result of the radioactive β decay of ^{87}Rb, which has a half-life of 48.8 billion years (Capo et al. 1998; Benson et al. 2006; Benson et al. 2008:913) and a decay constant (λ) of 1.42 x10^{11} year^{-1} (Capo et al. 1998:199). As ^{87}Rb decays, it produces ^{87}Sr, as can be seen in the following equation where $^{87}Sr_0$ is the original amount of ^{87}Sr at t=0, $^{87}Rb_0$ is the original amount of ^{87}Rb at t=0 while t represents time.

$$^{87}Sr = {}^{87}Sr_0 + {}^{87}Rb_0 - {}^{87}Rb_0 e^{-\lambda t}$$

(Bentley 2006:137)

As such, the amount of ^{87}Sr in a mineral and thus its $^{87}Sr/^{86}Sr$ value is a function of the initial amounts of strontium and rubidium, and the age of the mineral of interest (i.e., time) (Bentley 2006; Benson et al. 2008).

These two controlling factors, age and original mineral composition, depend on the type of rock under consideration (Price et al. 2002). For example, increased rubidium concentrations can be found in potassium minerals such as muscovite, biotite, alkali feldspars (orthoclase and microcline), clays (illite) and evaporates (sylvite, carnalite) (Capo et al. 1998:199), as well as micas (Ericson 1985:505). These minerals would have higher $^{87}Sr/^{87}Rb$ ratios as they have more initial rubidium available for decay. Similarly, older rocks (>10 million years) will have more ^{87}Sr resulting from the decay of ^{87}Rb and therefore higher $^{87}Sr/^{86}Sr$ values than younger rocks (<1-10 million years) (Graustein 1989; Capo et al. 1998; Price et al. 2002).

In addition to the decay of rubidium, trace elements such as strontium are incorporated into the crystalline structure of the minerals that compose bedrock during their formation. This can occur via four different methods: impurities, adsorption onto growing crystal surfaces, occlusion in lattice defects, and solid-solution substitution for a major element of the mineral (Banner 1995). Typically, these processes occur during mineral precipitation from fluid solutions; however, aspects such as weathering and recrystallization complicate this process (Banner 1995).

Most rocks contain a few hundred parts per million of strontium (Turekian and Kulp 1956), resulting from both the original amount of strontium in a mineral as well as from the decay of rubidium. However, not all types of rock contain the same amount of strontium (Katzenberg 1984:9). For example, in sedimentary rocks, limestone generally contains more strontium than shale (Turekian and Kulp 1956).

In general, $^{87}Sr/^{86}Sr$ values from geological samples vary naturally with documented values as low as 0.700 and higher than 0.800 (Veizer and Compston 1975; Price et al. 2002). Within this range, researchers have noted certain trends. For example, bedrock composed of materials such as sandstone, shale and granite, which initially contain higher Rb/Sr concentrations, should have higher $^{87}Sr/^{86}Sr$ values assuming that the rock is old enough for significant decay of ^{87}Rb to ^{87}Sr (Capo et al. 1998; Beard and Johnson 2000). Clays should also exhibit higher strontium values (Stueber et al. 1972; Knudson et al. 2012). Conversely, basaltic lava, marble, and limestone have low Rb/Sr values (Beard and Johnson 2000:1050) and thus lower $^{87}Sr/^{86}Sr$ ratios. For example, limestones from the Palaeozoic era (~542MYA to 251MYA), such as those found in southern Ontario, typically have $^{87}Sr/^{86}Sr$ values of approximately 0.708 (Stueber et al. 1972). Similarly, deposits of gypsum and rock salt, indicative of the Palaeozoic ocean, should also have $^{87}Sr/^{86}Sr$ values of approximately 0.708 (Peterman et al. 1970).

Therefore, different types of bedrock have $^{87}Sr/^{86}Sr$ values, depending on their mineral composition and age (Hodell et al. 2004; Frei and Frei 2011). These minerals erode by either natural or chemical processes, releasing strontium isotopes into the environment (Allaway 1989; Capo et al. 1998; Bern et al. 2005). It is important to note that not all minerals weather at the same time, which can change the strontium value from a single rock over time. Furthermore, different minerals in the same rock can weather at different rates; a single rock can have a range of $^{87}Sr/^{86}Sr$ values depending on their mineral composition (Price et al. 2002). For example, continental rocks such as granite have more variation in their mineral composition than ocean basalts (Ericson 1985:506) meaning that ocean basalts have a narrower range of $^{87}Sr/^{86}Sr$ values. This has implications for the characterization of local $^{87}Sr/^{86}Sr$ values as the local strontium available for integration into the biosphere can change throughout time.

It is important to note that despite the influence of time on $^{87}Sr/^{86}Sr$ values, they do not change in the smaller spans of time that concern archaeologists (Sealy et al. 1995; Beard and Johnson 2000; Benson et al. 2008). These differences in original rubidium and strontium concentrations and age result in variation that is dependent on geology. This variation is incorporated unchanged into the food chain via the local sediment and water of a location thus providing the opportunity to distinguish between different geographic locations (assuming that they have different geological settings).

2.2 Strontium biochemistry

Isotope analyses of mammals are based on the premise that "you are what you eat and drink" (Evans et al. 2012:754), which is, in the case of strontium, linked to the local geology of an area. Strontium isotopes originate in the local bedrock and make their way via weathering and atmospheric deposition into the local food chain before ending up in mammalian tissues. However, strontium isotope absorption into animal tissues can be complex. A brief overview of strontium in mammals is provided, including a section considering the differences between strontium and calcium concentrations, and their use in paleodietary investigations, before focusing on strontium in enamel, and a short section on dentine and bone.

Strontium isotopes released from bedrock make their way into animal tissues via water, sediment and plants, aggregating primarily in the crystalline lattice of apatite

($Ca_{10}[PO_4]_6[OH]_2$) in teeth and bone (Burton and Wright 1995; Dahl et al. 2001; Pasteris et al. 2004; Bentley 2006; Lakhkar et al. 2013) with minimal influence on the organization of the apatite crystals (Huang et al. 2015). Similar to barium and lead, strontium atoms substitute for calcium during nutrient uptake, excretion, and internal distribution in crystal genesis (Ericson 1985; Nielson 1986:437; Schweissing and Grupe 2003a). This is possible because strontium closely resembles calcium with a similar ionic radius, electron configuration and ionization energy of +2 (Radosevich 1993:271; Ezzo 1994; Oliveira et al. 2012).

Unlike calcium, strontium has historically been viewed as having minimal metabolic function (Nielson 1986; Lambert and Weydert-Homeyer 1993; Burton and Wright 1995); however, recently it has been shown that its consumption as strontium ranelate increases bone density (Mentaverri et al. 2012; Lakhkar et al. 2013; Fernandez et al. 2014). Despite this possible influence on bone development, calcium is incorporated preferentially over strontium atoms (Elias et al. 1982; Lakhkar et al. 2013). This could be because a mild distortion in the crystalline lattice is created when strontium is incorporated due to its larger ionic radius (Inoue 1981; Oliveira et al. 2012). Therefore discrimination against strontium by epithelial cells (Radosevich 1991) occurs in the intestine and renal systems (Wallach and Chausmer 1990:236). Any unabsorbed strontium, approximately 80% of the total strontium consumed by an individual (Burton and Wright 1995), is excreted in urine through the kidneys (Lakhkar et al. 2013). However, strontium absorption is influenced by age with some suggestion that subadults do not discriminate against strontium as well as adults and therefore exhibit higher concentrations of strontium (Katzenberg 1984; Oliveira et al. 2012).

The food items that animals eat have higher strontium concentrations and, by association, higher Sr/Ca values than the animals themselves (Burton and Wright 1995). This discrimination against strontium, or biopurification of calcium, can be seen in the food chain and results in differences between trophic levels (Elias et al. 1982; Katzenberg 1984; Blum et al. 2000). Therefore, plants have higher strontium concentrations relative to calcium than herbivores, while herbivores have more strontium than carnivores (Comar et al. 1957; Elias et al. 1982; Nielson 1986:437; Lambert and Weydert-Homeyer 1993; Burton and Wright 1995; Blum et al. 2000).

Researchers have used these trophic level differences in trace elements to investigate paleodiet (e.g., Toots and Voorhies 1965; Brown 1974; Elias et al. 1982; Ezzo 1994 but see Sealy and Sillen 1988). However, the relationship between diet and strontium concentrations is not straightforward, and is complicated by physiology (Montgomery et al. 2007), relationships between trace elements (Nielson 1986; Wallach and Chausmer 1990; Lambert and Weydert-Homeyer 1993; Radosevich 1993; Fernandez et al. 2014), geography (Sillen and Kavanagh 1982; Montgomery 2010), health (Katzenberg 1984; Montgomery 2010; Mentaverri et al. 2012), age (Derise and Ritchey 1974; Sillen and Kavanagh 1982; Wallach and Chausmer 1990; Oliveira et al. 2012) and cultural practices such as food acquisition and preparation (Ezzo 1994; Price et al. 1994; Burton and Wright 1995; Wright 2005). Furthermore, strontium absorption can be impacted by various factors such as what is being consumed in addition to strontium. For example, lactase, vitamin D, lysine, and arginine all increase strontium absorption (Comar et al. 1957; Nielson 1986:438; Vilaca et al. 2014). Similarly, foods that minimize calcium uptake, such as fibre and phytate, encourage strontium absorption (Lambert and Weydert-Homeyer 1993 but see Nielson 1986). Conversely, diets with lots of calcium and protein suppress strontium absorption (Lambert and Weydert-Homeyer 1993; Burton and Wright 1995), as does the consumption of dairy (Comar et al. 1957; Ezzo 1994). Finally, Blum and colleagues (2000) documented variation at different trophic levels suggesting that individual metabolism influences strontium uptake and multiple samples from each trophic level (e.g., herbivore, carnivore) are required. For example, Katzenberg (1984) notes that pregnancy can influence $^{87}Sr/^{86}Sr$ values in females compared to males and non-pregnant females.

After absorption, strontium atoms move through the body via ion exchange on the apatite surface, heteroionic substitution, and resorption, and deposition during bone growth and remodelling in Haversion canals (Comar et al. 1957; Lakhkar et al. 2013). However, the amount of strontium differs between types of bone (cancellous versus cortical), as well as at different sites (Oliveira et al. 2012; Lakhkar et al. 2013 but see Pemmer et al. 2013). Strontium is also deposited in tooth enamel during its formation (i.e., amelogenesis). Modern humans have concentrations that range between 50 and 300 ppm (Vaughan 1981; Montgomery 2010) with mammals, such as white-tailed deer, exhibiting similar strontium concentrations of approximately 51 to 252 ppm (Price et al. 1985). Mammalian tissues never exceed 1000 ppm (Radosevich 1993:283) because tissue strontium concentrations will plateau with excessive strontium consumption (Starkey

1964; Lambert and Weydert-Homeyer 1993; Dahl et al. 2001; Montgomery 2010; Lakhkar et al. 2013). Enamel tends to have lower strontium concentrations than bone (Schweissing and Grupe 2003a) with mean concentrations between 180.1 and 285.6 ppm (Derise and Ritchey 1974).

Generally, strontium residence time in the body is between 800 to 1600 days with a 10% retention rate after 400 days (Rundo et al. 1964; Dahl et al. 2001; Barenholdt et al. 2009). However, different factors impact residence time such as age, sex, health, pregnancy and lactation, and differential remodelling in bone (e.g., deep cortical bone versus surface bone) (Vaughan 1981; Sillen and Kavanagh 1982; Nielson 1986; Radosevich 1993; Dahl et al. 2001; Pemmer et al. 2013; Huang et al. 2015).

Different tissues will reflect the $^{87}Sr/^{86}Sr$ values ingested during specific times of life as a result of tissue development and remodelling. Once formed in childhood, enamel is a dense, kinetically stable, avascular tissue (Montgomery 2010) composed primarily (~96%) of inorganic calcium phosphate by weight, ~3% water and ~1% organic matter (Hillson 1986) with an unchanging chemical composition (Ezzo et al. 1997) and evenly distributed strontium concentrations within a single tooth (Brudevold and Soremark 1967; Montgomery 2002 but see Kang et al. 2004). It has been documented in rats, however, that different teeth can contain various amounts of strontium (Oliveira et al. 2012).

The strontium isotope composition incorporated during the multistep process of mineralization reflects that of the plasma in an individual's blood at the time of mineralization (Nielson 1986; Dahl et al. 2001; Montgomery 2010). This, in turn, is dictated by the strontium isotope composition of an individual's diet. The strontium isotope composition of enamel will therefore reflect the geological area where that individual was obtaining their food during tooth development. By comparing the $^{87}Sr/^{86}Sr$ values in enamel to local environmental strontium isotope signatures at the deposition or burial location, researchers can infer whether or not an individual has moved away from the location where they grew up.

Teeth mineralize at different times of an individual's life (Hillson 1986), with some developmental variation noted (Reid and Dean 2006). In mammals, the process of enamel formation is called amelogenesis and it occurs in two phases: matrix production and maturation (Suga 1982; Ungar 2010). During these stages, ameloblasts, which are enamel secreting cells, move from the inner portion of what will eventually be the tooth outwards, leaving a trail of proteins, minerals, and water (i.e., the matrix) (Suga 1982). These ameloblasts continue to deposit the enamel matrix appositionally in crystallites until the cuspal enamel is completed, at which point they move down vertically over the sides of the tooth in an overlapping fashion, similar to shingles on a roof (Ungar 2010:20). This leads to unequal enamel thickness across the tooth (Stevens et al. 2011). Once matrix secretion is completed, the second phase, maturation, starts. The ameloblasts absorb the organic matrix and water from the developing enamel, and mineral surrounds the crystallites, maturing them. This takes longer than the first stage, comprising two thirds of the overall development time (Smith 1998). However, this process does not follow the matrix secretion pattern, making serially sampling in some species difficult, as it does not happen in a linear fashion but rather all at once (Smith and Tafforeau 2008) in multiple different directions (Balasse et al. 2002). The ameloblasts then secrete a thin organic layer over the newly formed tooth, which is shed when the tooth erupts through the gum line (Ungar 2010:22).

Enamel mineralization is dependent upon the species under consideration with differences in cusp formation, morphology and eruption sequences. For example, the average rate of enamel secretion tends to be similar within a taxon; however, the length of the secretion period can be variable as a result of phenomena such as body size, metabolism, and brain size (Smith and Tafforeau 2008). Additionally, the shape of a tooth is determined by how the matrix secreted by the ameloblasts at the epithelium and the mesenchyme interacts with other matrix proteins and minerals at that location (Ungar 2010:23). This, in turn, is dictated by the function of the tooth (Rensberger 2000). These differences have been the basis of a number of studies that are concerned with evolution (e.g., Teaford et al. 2000; Ungar 2010).

Montgomery (2010:326) suggests that targeting $^{87}Sr/^{86}Sr$ values in teeth with shorter mineralization patterns allows for investigation of residence during a specific time in life or with multiple samples, the reconstruction of residential mobility sequences. The use of multiple samples to reconstruct mobility has been applied to a single tooth as well as several teeth from the same individual for different elements including carbon, oxygen and strontium (Balasse et al. 2003). Serially sampling enamel has been used to address questions about seasonal movement and diet, livestock herding practices, and the reconstruction of movement in migratory species. By taking horizontal strips of bioapatite perpendicular to the direction of growth of the tooth, researchers have traced movement in animals such as sheep, cows, steenbok, mammoth and caribou (e.g., Balasse et al. 2002; Pellegrini et al. 2008; Britton et al. 2009; Metcalfe and Longstaffe 2012; Buchan et al. 2015). Metcalfe and Longstaffe (2012) and Blumenthal and colleagues (2014) investigated not only variation along the vertical axis of a tooth, but also horizontally within a tooth, sampling close to the pulp chamber of a tooth and moving outwards.

Issues with taking incremental samples, however, include that there is no way to accurately isolate a discrete period of time because of how enamel forms (Balasse et al. 2002). Therefore, any samples that are taken represent an average of the strontium isotopes consumed by an individual over an indeterminate amount of time (Blumenthal et al. 2014). Additionally, there is a general assumption that seasonal changes will manifest in a sinusoidal curve, which may or may not be accurate (Metcalfe and Longstaffe 2012). Finally, despite the success reported by Metcalfe and Longstaffe (2012) for their horizontal sampling of enamel, they report technical difficulties in obtaining these data, resulting in the paucity of data obtained using this method.

Dentine, which composes the interior portion of a tooth, is composed primarily of inorganic calcium phosphate (70-75%) with some organic material, specifically Type I collagen, (~20%) and minimal water (5-10%) present (Brudevold and Soremark 1967; Hillson 1986; Kang et al. 2004). There are different types of dentin (e.g., primary, secondary and reparative or tertiary), determined by structural differences resulting from age, disease and type of tooth (Marshall et al. 1997). Similar to bone, dentine is porous with one-micrometer diameter tubules and smaller crystallites (<100 nm long, Hillson

1986). These tubules represent the tracks that odontoblastic cells left during their journey from the dentin-enamel junction or cementum to the pulp chamber (Marshall et al. 1997). It forms at the same time as enamel during childhood (Hillson 1986) and as such, enamel and dentine have similar strontium isotope compositions in life that are evenly distributed throughout the tissue (Budd et al. 2000; Bentley 2006) although dentine has a higher strontium concentration than enamel (Beard and Johnson 2000). Dentine also has a higher organic component than enamel, has access to a continuous blood supply, and a reduced crystal size making it more porous like bone (Kohn et al. 1999; Budd et al. 2000; Scott 2008:267). Unlike bone, primary dentine does not remodel and is of epithelial origin (Hillson 1997; Fincham et al. 1999).

Bone is composed of both inorganic (65-70%) and organic (24-26%) parts (Brudevolde and Soremark 1967). The organic component of bone is predominantly composed of Type I collagen with non-collagenous proteins, lipids and polysaccharides (Veis 1984; Ambrose and Norr 1993). These collagen molecules are arranged in fibrils with inorganic crystals of bioapatite ($Ca_{10}(PO_4)_6(OH)_2$) found throughout (Miller 1976). Both carbonate (CO_3) and phosphate (PO_4) can be obtained from these inorganic crystals although phosphate is more common relative to carbonate. Bone is metabolically active as it undergoes remodelling throughout life, slowly changing its chemical composition throughout time if there are changes in diet or environment (Sealy et al. 1995; Beard and Johnson 2000; Bentley 2006). Although remodelling rates depend on the element and type of bone under consideration (Vaughan 1981; Sealy et al. 1991; Ezzo 1994; Manolagos 2000; Teitelbaum 2000 but see Parfitt 2002), bones typically reflect an average of the $^{87}Sr/^{86}Sr$ values consumed over the ten to twenty-five years before death (Vaughan 1981; Sealy et al. 1995; Manolagos 2000). As such, bone contains the strontium isotope composition from foods and water consumed later in life, acting as an ion reservoir with factors such as remodelling, calcium intake, age, and health impacting strontium residence time (Montgomery 2010).

As a result of this remodelling, when an individual moves from one location to another, the chemical composition of their bones eventually changes to reflect their new residence (Ezzo et al. 1997; Schweissing and Grupe 2003b). By comparing the strontium isotope ratio in an individual's bone to that in their enamel, an indication of whether movement has occurred can be obtained (Price et al. 2000; Bentley 2006). A note of caution, however, is that different $^{87}Sr/^{86}Sr$ values can be obtained from the same bone (see Wallach and Chausmer 1990:236; Sealy et al. 1995; Dahl et al. 2001). Similarly, it may be that remodelling can release old strontium isotopes and then re-incorporate them without including any of the new strontium isotope ratios (Priest and Van de Vyver 1990).

It is important to note that unlike with lighter isotopes such as oxygen, fractionation in vivo as a result of biological processes is not a complicating factor in strontium isotope analysis (Graustein 1989; Sealy et al. 1991; Blum et al. 2000; Flockhart et al. 2015). Fractionation refers to the differences observed between the isotope ratios of dietary components and the tissues of the consumer (Schoeninger and Moore 1992). ^{87}Sr and ^{86}Sr are physically and chemically identical (Benson et al. 2008:913) with minimal mass differences (Sealy et al. 1995:292). Furthermore, the high temperature required for fractionating strontium atoms due to their large mass is not present in biological processes (Price et al. 1994). Finally, researchers correct for any mass-dependent fractionation during mass spectrometry using normalization of non-radiogenic isotope values (e.g., $^{88}Sr/^{86}Sr = 8.37521$) and any fractionation that does occur is too small to be measured with today's available technology (Ericson 1985; Graustein 1989; Capo et al. 1998; Beard and Johnson 2000; Bentley 2006; Montgomery 2010). Therefore, the ratio of strontium isotopes remains unchanged as they move through the environment.

Bioarchaeologists can use the $^{87}Sr/^{86}Sr$ values in tissues, specifically teeth and bone, to comment on mobility in past populations. By comparing the strontium isotope composition in tooth enamel, which does not change throughout life, to that of the local environment, hypotheses about where an individual obtained their food and water as a child can be made (e.g., Buzon and Simonetti 2013; Kenoyer et al. 2013; Ortega et al. 2013). Similarly, comparisons between bone and tooth enamel, or the local environment, are possible. If a difference exists between either these tissues or the tissue and the environment, movement is inferred as having occurred.

2.2.1 Diagenesis

A complicating factor in establishing whether or not a difference is present between biological tissues and the environment is diagenesis. Diagenesis, or the post-mortem alteration of the chemical composition of tissues (Katzenberg 1992), complicates analyses as it can result in data that reflect the burial environment rather than the tissue's original biogenic signature. Ericson (1985) first acknowledged diagenesis as a limitation for strontium isotope analysis with his landmark study that outlined the potential of strontium isotope analysis for archaeological investigations. However, he argues that despite the occurrence of diagenesis, strontium isotope analysis still has value and can be mitigated with proper sample preparation. Despite some debate about its influence originally (e.g., Schoeninger 1979; Pate and Brown 1985), it is now generally accepted that diagenetic alteration needs to be considered in one way or another. For example Price and colleagues (2001) suggest that since diagenetic alteration will always reflect a local signature, any foreign signature is significant. As such, they argue "diagenesis does not cause us to misidentify locals as immigrants" (Price et al. 2001:597). However, foreign signatures can be masked by local diagenetic material, leading foreign individuals to be classified as local, when this is not the case.

Diagenesis is a function of a variety of different factors. These include temperature, porosity, and the density of the sample tissue (Wang and Cerling 1994). For example, Nelson and colleagues (1986) discuss how groundwater can precipitate diagenetic secondary calcite and facilitate an exchange of ions, exchanging strontium ions from the water with the strontium from the sample. Similarly, bone is more apt to be diagenetically altered based on its porosity, relative to tissues such as tooth enamel (see below). Unfortunately, there is no natural environment that will not exert an influence on remains after deposition; rather, the extent of its influence is of import.

Diagenesis has been found to occur in a number of different ways. These include geochemical and microbial processes (Grupe et al. 1989; Grupe et al. 2000) that result in the exchange or adsorption of ions from their surrounding deposits and/or increased crystallinity (Wang and Cerling 1994). Nelson and colleagues (1986) characterize these processes as: 1) secondary minerals filling in pores; 2) recrystallization or remineralisation of apatite; 3) direct exchange with strontium in the original apatite crystals and 4) absorption onto the surfaces or in micro cracks in the original apatite crystals. These processes all compromise the original biogenic signature in tissues such as bone, dentine and enamel.

The occurrence of diagenesis can be dependent on what tissue is being sampled (e.g., bone, dentine and enamel). Furthermore, these processes can affect tissues unequally. For example, the amount of alteration can vary from tooth to tooth or within a single bone or tooth (Wang and Cerling 1994; Hedges et al. 1995). Although all three tissues can be preserved in archaeological contexts, bone is typically the most susceptible to diagenesis, followed by dentine and then finally enamel.

Bone is more susceptible to diagenetic change than dentin or enamel due to bone's greater porosity (Brudevold and Soremark 1967; Ericson 1985; Lee-Thorp and van der Merwe 1990; Price et al. 1994a; Koch et al. 1997; Budd et al 2000; Price et al. 2002; Hoppe et al. 2003). Furthermore, bone apatite can become unstable after death as a result of degradation, resulting in ionic substitution that does not change the physical structure of the tissue (Smith and Tafforeau 2008). Of bone's components, bone carbonate is more apt to be diagenetically altered relative to bone phosphate (Kolodny et al. 1983; Wang and Cerling 1994). This is because of the strength of the bonds between elements in each molecule making the bonds in CO_3 more susceptible to breaking. However, bone phosphate is more prone to enzymatic alteration (Sharp et al. 2000). Finally, bone contains more organic material than either dentine or enamel, which contributes to its susceptibility to diagenesis (Brudevold and Soremark 1967; Smith and Tafforeau 2008). As the organic portion degrades, porosity increases leading to diagenesis (Hedges 2002).

Similar to bone, dentine is more apt to be diagenetically altered when compared to enamel as a result of its more porous structure. The tubules found in dentine act as channels that allow for the transfer of ions and increase overall porosity (Kohn et al. 1999; Budd et al. 2000; Hoppe et al. 2003) thus leading to diagenesis.

Of the three tissues, enamel, with its low porosity of approximately 1% with large crystal sizes and minimal organic component, is less likely to be diagenetically altered (Wang and Cerling 1994; Budd et al.2000; Chiaradia et al. 2003; Hoppe et al. 2003; Lee-Thorp and Sponheimer 2003; Copeland et al. 2010). However, despite its innate resistance to diagenetic alteration, enamel can still be impacted by diagenesis with its biogenic signature compromised (Montgomery et al. 2000; Schoeninger et al. 2003; Sponheimer and Lee-Thorp 2006). This can occur either by chemical alteration of the apatite and/or physical contamination by secondary materials (Kohn et al. 1999). This is particularly true for surface enamel (Ericson 1985, Grupe et al. 1997; Budd et al. 2000). Schoeninger and colleagues (2003) found evidence that the presence of diagenetic material is dependent on the portion of tooth sampled (i.e., core tooth enamel versus exterior tooth enamel) with differences of one to five per mil present between the two areas. Similarly, Sponheimer and Lee-Thorp (2006) found that up to 50% of carbonate in fossil enamel could be diagenetic. As such, tooth enamel can be differentially diagenetically altered (Schoeninger et al. 2003:17).

As the influence of diagenesis was recognized and acknowledged, researchers developed methods in order to minimize its influence. However, there is no consensus as to whether a single method can effectively negate its influence (Sealy et al. 1991; Price et al. 1992; Grupe et al. 1999; Hoppe et al. 2003). For example, it was suggested that pre-treatment of samples with weak acid may be able to mitigate the effects of diagenetic material (Sillen 1986, 1989; Sealy et al. 1991; Price et al. 1994a; Sillen and Sealy 1995; Nielsen-Marsh and Hedges 2000). This method, proposed by Sealy and colleagues (1991), has been endorsed by Price and colleagues (1994a, 1994b) and subsequently dismissed by Budd and colleagues (2000). This could be because those methods that involve submersion of samples in weak acid have had mixed success in their application (Bentley 2006:165). Similarly, Ezzo and colleagues (1997) and Price and colleagues (1994a) successfully applied Sillen's (1991) methodology, however, Horn and colleagues (1994) and Beard and Johnson (2000) were unable to duplicate this accomplishment. Additionally, Price and colleagues (1994a) reported success for their unique method of minimizing the influence of diagenesis in "many hundreds of samples" (Price et al. 1994a:321); however, Knudson and Buikstra (2007) found the same method to be ineffective. Hoppe and colleagues (2003) conclude that not only does pre-treatment of samples using weak acid not remove all diagenetic strontium in bone, leaving up to 80% of diagenetic strontium behind, the process of soaking bone in acid may even recrystallize some of the dissolved secondary carbonate strontium. The effectiveness of these protocols depends on the nature of the post-depositional alteration that has occurred. For example, they tend to work well if the diagenetic material is highly soluble, such as can be found in carbonate-rich burial environments (i.e., when diagenetic material may be less soluble than biogenic material).

In enamel specifically, Budd and colleagues (2000) note that even though small diagenetic changes can occur on the exterior surface of enamel, that portion of the tooth can easily be removed via mechanical abrasion. Schoeninger and colleagues (2003) suggest that removing the surface 0.5mm of enamel succeeds in removing most diagenetic material. Budd and colleagues (2000) also suggest that 95% of diagenetic strontium can be removed from tooth enamel with pre-treatment of weak acid. Sponheimer and Lee-Thorp (2006) second this, stating that the diagenetic material is usually secondary carbonate or is highly soluble that can be removed with 0.1M acetic acid.

Another issue with diagenesis is identification of when it has occurred. As was discussed, debate exists as to whether it is possible to remove diagenetic material. As such, researchers have developed techniques in order to establish whether the data that are obtained represent the biogenic signature and not a diagenetic one. For example, similar to Price and colleagues (1994a), Copeland and colleagues (2010) analyzed both modern and archaeological samples of enamel in order to identify diagenesis. If there was a difference in strontium concentrations, they concluded that diagenetic material was present. Kohn and colleagues (1999) used a similar strategy, considering rare earth elements. If there are increased rare earth elements in archaeological samples relative to modern samples, diagenesis is assumed to be a concern. Other researchers have also used measurement of trace elements such as uranium, aluminum and manganese as indicators for diagenesis (e.g., Price et al. 1994a; Price et al. 2000, Knudson et al. 2012). Another comparative technique involves comparing the strontium signatures from different types of samples such as dentine and enamel. Because of their structure, different tissues have different susceptibilities to diagenetic alteration. Assuming that those tissues that are more likely to be altered diagenetically have, in fact, been altered, one compares the two samples.

Alternatively, Schoeninger and colleagues (2003) suggest screening enamel using cathodoluminescence to identify places that are less diagenetically altered and sampling from these locations. Cathodoluminescence (CL) is a process where high-energy electrons in a sample are excited and emit photons in the visible range as result. These photons reflect different colours depending on the chemical composition of the sample. For example, rare earth elements, whose presence indicates diagenetic material, will turn various colours (e.g., pink, violet, red, etc.) while uncontaminated enamel will reflect blue light (Mitchell et al. 1997; Segalen et al. 2008). Samples of enamel approximately one to eight millimeters thick are polished and carbon coated before being subjected to CL spectroscopy analysis (Segalen et al. 2008). Samples for isotope analysis should be removed from areas that reflect blue light. Researchers are slowly adopting this method for identification of diagenetic material (e.g., Fischer et al. 2012; Lebon et al. 2014).

Despite the negative aspects associated with diagenesis, in studies that aim to characterize local strontium isotope baselines, diagenesis can be construed as a positive aspect rather than a negative one. Since the goal of an isotopic baseline is to identify the local environmental strontium signature and diagenetic material originates from the local environment, the diagenetic material reflects the local environmental strontium. However, this is only valid in areas where the addition of modern anthropogenic strontium has not occurred. Otherwise, archaeological samples affected by diagenesis will provide modern strontium values, which could be drastically different from those present in the past leading to misinterpretation of what constitutes a local isotope signature. Furthermore, without knowing how much of the sample is diagenetic versus biogenic, it is not possible to know how much diagenetic material is being measured. Therefore, the sample could reflect a mixture of both local diagenetic and possibly foreign biogenic material.

2.3 Strontium in the environment

Although based on a simple premise, that of comparing the $^{87}Sr/^{86}Sr$ values obtained from an individual’s tissues to that of the environment, strontium isotope analysis is not necessarily this straightforward with different environmental factors such as geology, sediment, elevation, climate and seasonality, proximity to the ocean, glacier movement, and human activities (e.g., pollution, agriculture) all influencing strontium isotope variation in the environment.

2.3.1 Geology

In order for strontium isotopes to be useful as indicators of paleodiet or place of residence, there needs to be quantifiable geological variation in strontium isotope compositions as the local strontium isotopes primarily come from the weathering of bedrock (Bern et al. 2005; Frei and Frei 2011). In southern Ontario, there are a number of different types of bedrock that formed at various times and are composed of numerous minerals and lithologies. Although Ontario is divided into three distinct geological and physiological regions, the study area falls within the Grenville Province, which is approximately 1.0 to 1.6 billion years old (Baldwin et al. 2000). The Grenville Province, which forms the southeast margin of the Canadian Precambrian Shield, consists of a 400-kilometer wide belt that stretches 1600 kilometers from the Atlantic Ocean to Lake Huron (Marcantonio et al. 1990). It is composed primarily of granite (66%), sedimentary rocks (20%), and volcanics (7%), (Chesworth and Evans 1982: Table 2).

At its base, southern Ontario is composed of Precambrian bedrock that is buried underneath sedimentary rocks from the Cambrian, Ordovician, Silurian and Devonian periods below the Trent-Severn Waterway with Precambrian (Neo- to Meso- Proterozoic) migmatitic rocks and gneisses, mafic to ultramafic plutonic rocks, felsic plutonic rocks derived gneisses and migmatites and metavolcanic and metasedimentary rocks above the Trent-Severn waterway (Ontario Geological Survey 1991). Bedrock composed of shale, limestone, dolostone, siltstone, arkose, and sandstone can be found superficially in the principal study area with granite, granite pegmatite, basalts, quartz, marine carbonate and volcanic rocks distributed just outside of it (see Ontario Geological Survey 1991). These geological variations have been categorized into different geological formations (see Figure 2.1 and Table 2.1).

2.3.2 Sediment and soil

Once released from the bedrock, strontium isotopes pass unchanged into the sediments and soils of a location. Sediments and soils are derived from bedrock and so the local sediments and soils should reflect the local geology (i.e., the parent material).

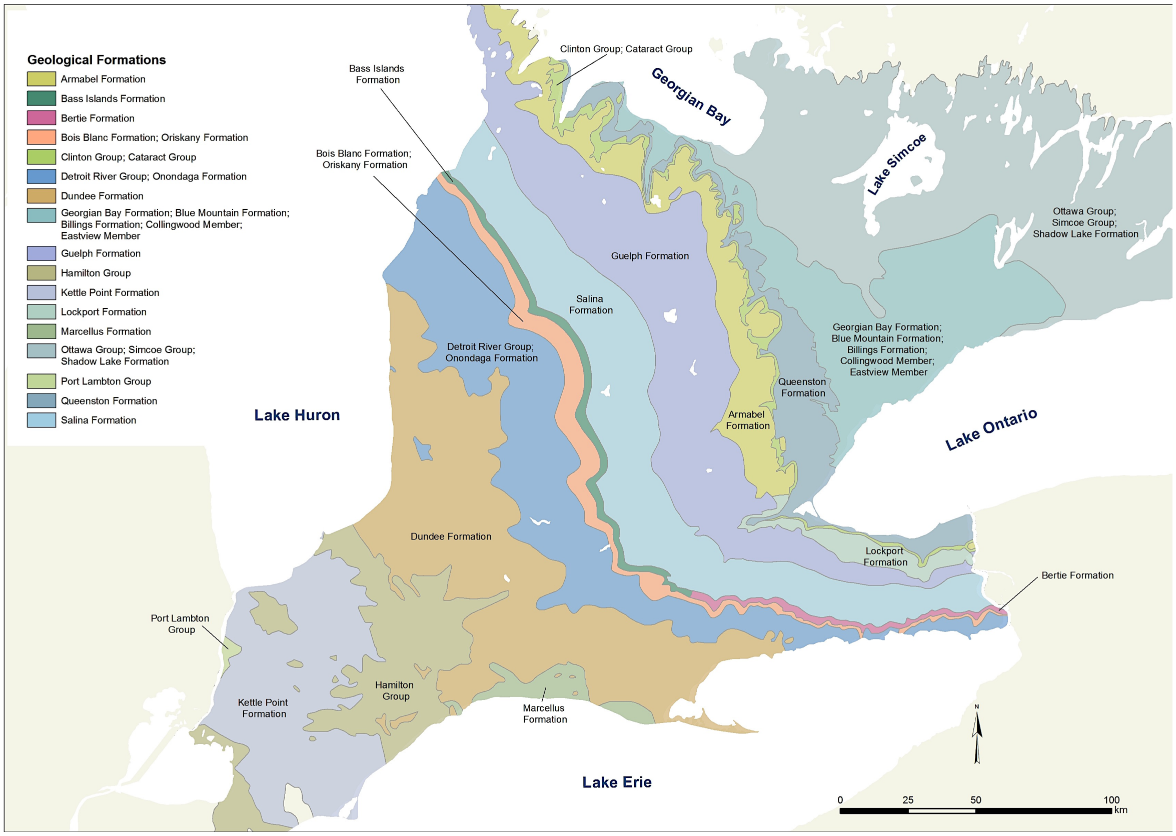

Figure 2.1 Map depicting the geological formations present in southern Ontario, Canada. Map created using ArcGIS and data from an open source ArcGIS database.

However, a variety of factors affect the local strontium isotope composition in the sediments and soils, complicating this seemingly straightforward relationship. These include the mechanisms involved in sediment and soil movement, as well as other miscellaneous factors such as environmental influences and the addition of anthropogenic strontium.

Of particular importance in strontium isotope analysis is the movement of sediments and soils. Sediments and soils can be moved in many ways, including via both natural (e.g., erosion, natural disasters, water movement) and anthropogenic phenomena (e.g., construction). On a larger scale, phenomena such as glaciers can drastically change

Table 2.1 Geological formations and their underlying geology and ages in southern Ontario. Data are taken from Map 2544 produced by the Ontario Geological Survey (1991) and Chesworth and Evans (1982: Table 3).

Age	Geology	Formation
Mississippian (~359 to 318MYA)	Shale	Port Lambton Group
Upper Devonian (~385 to 359MYA)	Shale, dolomite	Kettle Point Formation
	Shale	Long Rapids Formation
Middle Devonian (~397 to 385MYA)	Shale, limestone	Hamilton Group
	Limestone, dolomite, shale	Marcellus Formation
	Limestone, sandstone	Dundee Formation
	Dolomite, limestone	Detroit River Group
	Limestone, dolomite, shale	Onondaga Formation
	Limestone, dolomite, shale	Williams Island Formation
	Limestone, dolomite, shale	Murray Island Formation
	Limestone, dolomite, shale	Moose River Formation
	Limestone, dolomite, shale	Kwataboahegan Formation
Lower Devonian (~416 to 397MYA)	Limestone, dolomite	Bois Blanc Formation
	Sandstone, dolomite	Oriskany Formation
	Sandstone, dolostone, limestone	Stooping Formation
	Sandstone, dolostone, limestone	Sextant Formation
Upper Silurian (~422 to 416MYA)	Dolomite	Bass Islands Formation
	Limestone, dolostone, shale, sandstone, gypsum, salt	Bertie Formation
	Dolomite, gypsum, salt, shale	Salina Formation
	Limestone, dolostone, shale, sandstone, gypsum, salt	Kenogami River Formation
Middle and Lower Silurian (~443MYA to 422MYA)	Dolomite	Guelph Formation
	Dolomite, limestone	Lockport Formation
	Dolomite	Amabel Formation
	Sandstone, shale, dolostone and siltstone	Clinton Group

Table 2.1 continued.

Age	**Geology**	**Formation**
Middle and Lower Silurian (~443MYA to 422MYA)	Sandstone, shale, dolostone and siltstone	Cataract Group
	Sandstone, shale, dolostone and siltstone	Thornloe Formation
	Sandstone, shale, dolostone and siltstone	Earlton Formation
	Sandstone, shale, dolostone and siltstone	Wabi Group
	Sandstone, shale, dolostone and siltstone	Attawapiskat Formation
	Sandstone, shale, dolostone and siltstone	Ekwan River Formation
	Sandstone, shale, dolostone and siltstone	Severn River Formation
Upper Ordovician (~460 to 443MYA)	Shale, dolomite	Queenston Formation
	Shale, limestone, dolostone, siltstone	Georgian Bay Formation
	Shale	Blue Mountain Formation
	Shale, limestone, dolostone, siltstone	Billings Formation
	Limestone, dolomite	Collingwood Mb
	Shale, limestone, dolostone, siltstone	Eastview Mb
	Shale, limestone, dolostone, siltstone	Liskeard Group
	Shale, limestone, dolostone, siltstone	Red Head Rapids Formation
	Shale, limestone, dolostone, siltstone	Churchill River Group
	Shale, limestone, dolostone, siltstone	Bad Cache Rapids Group
Middle Ordovician (~471 to 460MYA)	Limestone, dolostone, shale, arkose, sandstone	Ottawa Group
	Limestone, dolostone, shale, arkose, sandstone	Simcoe Group
	Dolomite, shale	Shadow Lake Formation
	Limestone, dolostone, shale, arkose, sandstone	Chazy Group
	Limestone, dolostone, shale, arkose, sandstone	Rockcliffe Formation
Lower Ordovician (~488 to 471MYA)	Dolostone, sandstone	Beekmantown Group

local sediment and soil composition. When glaciers move, they churn up local sediments and soils moving them from place to place, depositing foreign sediments/soils in new locations and removing local sediments/soils. Consequently, this changes the local $^{87}Sr/^{86}Sr$ values in sediment and soil from those ratios derived from the local geology to a foreign value (Galy et al. 2010). Additionally, glacier movement can remove all of the sediment and soil from a location, leaving only bedrock behind, as well as mixing any remaining soils and sediments together, changing local $^{87}Sr/^{86}Sr$ values in sediment/soil from the expected values derived from local bedrock to ones that are very different with the deposition of foreign sediments, soils, and glacial till.

Various factors dictate the movement of glaciers and subsequent sediment movement (see MacLachlan 2011). In Ontario, glacier movement was irregular with both advances and retreats across the province occurring up to 12,000 years B.P. during the last major glacial stade (Baldwin et al. 2000). The Laurentide Ice Sheet surged up and down the area, depositing glaciofluvial complexes throughout the province before retreating and leaving a sandy and silt till in southern Ontario (Baldwin et al. 2000). As such, the sediment and soils may not accurately reflect the bedrock that lies underneath it. For example, Steele and Pushkar (1973:336) found that samples in their study reflected the $^{87}Sr/^{86}Sr$ values of the glacial till rather than the local bedrock. However, in southern Ontario specifically, the influence of local bedrock is still visible (Chesworth and Evans 1982). For example, in areas where Palaeozoic rocks predominate, such as below the Trent-Severn waterway, soils are characteristically luvisols whereas brunisols and podzols dominate those areas where Precambrian rocks are the principal substrate

(Chesworth and Evans 1982; Katzenberg 1989). Luvisol soils are typically developed in the presence of calcareous parent material in a humid, cool climate while brunisol soils are more general and can be found in a variety of locations. Finally, podzol soils are typically found in cold climates in acidic parent materials (Chesworth and Evans 1982:25-26). As such, although glacial movement impacted local sediments and soils, the influence of the underlying bedrock is also evident.

Small-scale miscellaneous influences can also impact $^{87}Sr/^{86}Sr$ values in local sediments and soils, although to a lesser extent. For example, sediments and soils at different places in the same location can have varying $^{87}Sr/^{86}Sr$ values (Sillen et al. 1998) with inconsistencies at different levels (Radosevich 1993; Blum et al. 2000:91; Poszwa et al. 2004). Deeper levels have $^{87}Sr/^{86}Sr$ values that resemble the underlying bedrock (Probst et al. 2000; Frei and Frei 2011:336) while the surface levels contain $^{87}Sr/^{86}Sr$ values from organic materials (Aberg 1995) and strontium isotopes deposited by wind and water (Comar et al. 1957:487; Blum et al. 2000:91; Benson et al. 2008:917). Gosz and Moore (1989) suggest that rainwater can wash foreign strontium isotopes that have been atmospherically deposited onto plant leaves down into the sediment and soil. Similarly, Comar and colleagues (1957) suggest that the actions of burrowing animals can influence $^{87}Sr/^{86}Sr$ values in local sediments and soils, creating opportunities for mixing between different levels. This means that a range of variation can exist in the sediment and/or soil in a single area depending on the depth of the sediment and/or soil that is sampled and where the sample is obtained.

Another small-scale influence on local soil ^{87}Sr/8^{6}Sr values is the addition of anthropogenic strontium via fertilizer or irrigation. Research has suggested that foreign ^{87}Sr/^{86}Sr values can be introduced as a result of agricultural activities (Negrel and Deschamps 1996; Bohlke and Horan 2000; Negrel et al. 2004; Evans et al. 2010; Frei and Frei 2011; Evans et al. 2012). Agriculture has been present in southern Ontario for hundreds of years with the addition of fertilizer in modern contexts. This can complicate strontium isotope analysis, particularly when samples originate from a modern context rather than an archaeological one.

In Ontario, sediments and soils are relatively young as they were formed during the Quaternary period (2.6 million years ago to present). They are composed of a variety of different sediment and soil types (e.g., sand, clay, gravel, silt and diamicton or poorly sorted glacial till) with deposits of coarse- and fine-textured glaciomarine deposits, coarse- and fine-textured glaciolacustrine deposits, glaciofluvial deposits, and ice-contact stratified deposits and glacial till (i.e., diamicton) (Ontario Geological Survey 2008). These are composed primarily of calcite, dolomite, and illite in southern Ontario below the Trent-Severn waterway (Chesworth and Evans 1982). Their distribution reflects the movement of the glaciers across the province, principally in the Wisconsinan period (Chesworth and Evans 1982).

2.3.3 Water

Strontium is found not only in the local bedrock and sediment/soil of an area but also in its water, which can contribute small amounts of strontium to local organisms (although not as much as bedrock and sediments and/or soils). Strontium in water can come from a number of sources, including bedrock, sediment/soil and glacial deposits, as well as atmospheric deposition (e.g., precipitation, dust deposition) and anthropogenic sources (e.g., fertilizer), with mixing from several sources regularly occurring (Stueber et al. 1972; Graustein 1989; Blum et al. 1994). In bounded bodies of water, such as lakes and ponds, strontium is also obtained from the rivers and tributaries flowing into the lake or pond (Faure et al. 1967). As such, lakes and ponds represent a mixture of strontium from a number of sources, homogenizing them into an average value (assuming a fairly quick mixing rate).

Strontium resulting from fluid-rock interactions during mineral dissolution and precipitation is usually the primary source of $^{87}Sr/^{86}Sr$ values in water (Stueber et al. 1972; Banner 1995; Christian et al. 2011; but see Graustein and Armstrong 1983). However, not all minerals in bedrock weather and precipitate at the same rate (Probst et al. 1992; Bain et al. 1998). Therefore, $^{87}Sr/^{86}Sr$ values in run-off water may not reflect the average $^{87}Sr/^{86}Sr$ value of the bedrock it runs over (Graustein 1989). For example, Steele and Pushkar (1973) found differential leaching of strontium in the same sheet of bedrock depending on the type of mineral. Specifically, they found that calcium carbonate in shale was dissolved before the shale itself, influencing local $^{87}Sr/^{86}Sr$ values (Steele and Pushkar 1973). Katzenberg (1989:10) also notes that limestone, which is prevalent in southern Ontario, contributes minimal strontium to water. As such, water running over a combination of rocks including limestone may not reflect the $^{87}Sr/^{86}Sr$ values of the limestone.

A wide range of isotopic variation has been recorded in natural waters (Banner 1995). For example, in areas where water runs over plagioclase feldspars, $^{87}Sr/^{86}Sr$ values will be relatively low compared to areas with potassium feldspars and micas (McNutt et al. 1984; Franklyn et al. 1991). This wide range is visible both between different bodies of water as well as within them. A single river can run over different types of bedrock, exhibiting different $^{87}Sr/^{86}Sr$ values (Ryu et al. 2008). For example, Steele and Pushkar (1973) provide a case study showing that although part of a river had $^{87}Sr/^{86}Sr$ values that reflected the underlying bedrock, another section of the same river did not. Benson and colleagues (2003) also document a similar phenomenon (but see Negrel et al. 2004). This complicates strontium isotope analysis in water and any attempts to document local environmental variation.

Furthermore, seasonality has the potential to complicate $^{87}Sr/^{86}Sr$ values in water. With the melting of snow and ice increasing the amount of water during spring, and evaporation of water during summer, as well as wet seasons such as those during monsoon seasons, flow rates and the amount of water will change seasonally, thereby potentially changing how and where strontium isotopes are obtained. For example, with more water flowing during snowmelts, the area covered with water will increase and more bedrock can contribute to its strontium isotopic composition. Also with increased flow rates, water will travel faster and further, carrying strontium from one location to another. This is a phenomenon explored by Aubert and colleagues (2002), who found that with high water flow rates, higher radiogenic isotope ratios (i.e., higher $^{87}Sr/^{86}Sr$ values) were observed in streams relative to times when water flow was lower. Flow rates will change weathering rates. Conversely, with drought, water will not cover as much bedrock, nor will it travel the same distance. Furthermore, drought encourages dust creation enabling for atmospheric transportation of material containing strontium. However, it should be noted that this would not be overly influential in overall $^{87}Sr/^{86}Sr$ values.

It is unknown as to the extent of the influence that seasonality may yield, with researchers suggesting that it is both significant and not, or sometimes both depending on location (Eastin and Faure 1970; Stueber et al. 1972; Graustein 1989; Bickle et al. 2003; Jin et al. 2011; Douglas et al. 2013; Wei et al. 2013). For example, Eastin and Faure (1970) found that in one river, $^{87}Sr/^{86}Sr$ values in a river changed seasonally from 0.71160 to 0.70880; however, in a second river in the same state, no influence was noted. Similarly, Yang and colleagues (1996) found that the St Clair, Detroit, and Niagara rivers did not exhibit variation in $^{87}Sr/^{86}Sr$ values; however, the lower St. Lawrence did despite the fact that all four rivers together comprise a single freshwater river system: the Great Lakes-St. Lawrence system.

Elevation has also been suggested to influence strontium isotopes in water, with higher weathering rates noted at higher elevations (Bentley 2006:144). Additionally, as water runs downhill, the opportunity arises for a variety of materials containing different strontium isotopes to be incorporated (i.e., the water at the top of a hill will contain strontium isotopes from the peak of the hill whereas water at the bottom of a hill can potentially contain a mixture of strontium isotopes from both the top of the hill and the bottom). This could also result in a number of different $^{87}Sr/^{86}Sr$ values in a single river as documented by Tricca and colleagues (1999) in the Vosges Mountains and the river Rhine.

It is important to note that although a lot of variation in strontium in aquatic environments has been recorded, this is not the case for the ocean. Strontium in water is correlated with salinity (Banner 1995; Negerl and Casanova 2005), with the ocean acting as a reservoir for strontium and other elements. It has both a slow mixing rate (10^3 years) and a long residence time (2×10^7 years) (DePaolo and Ingram 1985; Aberg 1995; Capo et al. 1998). This means that it will not reflect the basement bedrock (Faure et al. 1967) but rather will have a uniform value ($^{87}Sr/^{86}Sr$= 0.70924 +/-0.00003; Veizer 1989). However, this is not a primary concern for southern Ontario during the time period this research is concerned with as it is located inland away from the ocean.

Strontium values ranging from 0.7036 to 0.7384 in Canadian streams have been reported (Brass 1976; Wadleigh et al. 1985). In Ontario specifically, values range from $^{87}Sr/^{86}Sr$ =0.70869 to 0.71646 (see Table 2.2). Although southern Ontario experiences all four seasons, minimal seasonal data on $^{87}Sr/^{86}Sr$ values are available. It is important to note that these studies have been conducted on surface water rather than groundwater, which can potentially have a different strontium isotope value. Again, although strontium in water represents a contributing source of $^{87}Sr/^{86}Sr$ values, it is not the most influential source.

2.3.4 Flora

$^{87}Sr/^{86}Sr$ values pass from the sediment and soils and, to a lesser extent, from the water of an area into local plants without fractionating (Capo et al. 1998; Benson et al.

Table 2.2 Previously published $^{87}Sr/^{86}Sr$ data for surface water in Ontario, Canada.

Body of water	$^{87}Sr/^{86}Sr$	n	St. Dev.	Study
Albany River	0.71575	1		Wadleigh et al. 1985
Detroit River	0.70947	1		Yang et al. 1996
Harricana River	0.71646	1		Wadleigh et al. 1985
Hudson Bay	0.70928	4	0.00025	Faure et al. 1967
Moose River	0.71323	1		Wadleigh et al. 1985
Niagara River	0.70934	2	0.00001	Yang et al. 1996
Ottawa River	0.71097	1		Yang et al. 1996
St. Clair River	0.70942	1		Yang et al. 1996
St. Lawrence River	0.70946	1		Wadleigh et al. 1985
St. Lawrence River	0.70964	12	0.00038	Yang et al. 1996
Thames River	0.70869	1		Yang et al. 1996

2006). In this way, strontium enters the food chain (Aberg 1995). Plants can also obtain strontium via atmospheric deposition. For example, Graustein and Armstrong (1983) found that upwards of 75% of the strontium isotope composition in plants from New Mexico originated from the atmosphere. Therefore, plants reflect $^{87}Sr/^{86}Sr$ values from the various sources around them, and as such provide an average of the local bioavailable strontium within their proximity (Benson et al. 2006).

However, complicating factors such as root depth and species can influence strontium values in plants (Allaway 1989:474; Gosz and Moore 1989; Aberg 1995; Capo et al. 1998; Poszwa et al. 2004). For example, plants with deeper roots may have different $^{87}Sr/^{86}Sr$ values than those with a shallower root system because they incorporate $^{87}Sr/^{86}Sr$ values that are correlated with soil depth. These differences can exist between plants of the same or different species (Poswa et al. 2004), depending on each individual plant's root system. Furthermore, different parts of the same plant can have varying strontium isotope ratios (Comar et al. 1957; Nielson 1986; Radosevich 1993; Poszwa et al. 2004). This has implications for sampling plants with the intention of characterizing local $^{87}Sr/^{86}Sr$ values and plant consumption.

In southern Ontario, there are a variety of different plants that will incorporate the local environmental $^{87}Sr/^{86}Sr$ values, both indigenous plants and cultigens. Although both of these are suitable for isotope analysis, the cultigens are of interest because they would have been grown in a restricted area dictated by humans. Similarly, archaeologists have recovered the remains of cultigens at archaeological sites throughout southern Ontario.

However, the addition of anthropogenic strontium is a concern with cultigens. Practices such as irrigation and the application of fertilizer in agriculture can introduce foreign $^{87}Sr/^{86}Sr$ values that will affect that of the plant (Negrel and Deschamps 1996; Bohlke and Horan 2000; Negrel et al. 2004; Evans et al. 2010; Frei and Frei 2011; Evans et al. 2012). Not only will the application of fertilizer change the local strontium isotope signature, but Allaway (1989) also suggests that it encourages plant roots to grow deeper, incorporating different strontium isotopes. This is not a concern with those plants that were not cultivated.

This being said, indigenous populations in southern Ontario such as the Huron-Wendat and Neutral did not fertilize or irrigate their fields with elaborate irrigation systems that would have introduced foreign $^{87}Sr/^{86}Sr$ values (Trigger 1987:34-36). There is ethnographic evidence that they may have added ash to the sediment before planting their crops (Trigger 1987), but this ash resulted from the burning of the trees that were already in the area, which would not introduce foreign values.

Local indigenous populations were cultivating a number of different crops when the Europeans arrived in the 17th century, including maize and beans. Both of these have long histories of use, *Zea mays* (maize) was introduced to the local environment around A.D. 550, (Monckton 1992; Crawford and Smith 1996; Crawford et al. 1997). Maize has a fibrous root system that grows as deep and as wide as 0.6 m (Keller and Bliesner 2000). It requires an average of 7.0 mL of water daily for optimal growth (Mishra and Cherkauer 2010). Maize was an important dietary staple with isotopic, osteological and ethnographic evidence for its consumption by local populations in the past (Pfeiffer and King 1983; Schwarcz et al. 1985; Moncton 1992; Katzenberg et al. 1995; Bower 2011). Similarly, beans (*Phaseolus vulgaris*) were an integral dietary component for past populations (Schwarcz et al. 1985; Katzenberg et al. 1995; Harrison and Katzenberg 2003). Introduced to the area around A.D. 1100 (Yarnell 1976), beans contain more strontium than meat or maize (Nielson 1986; Burton and Wright 1995) thus potentially contributing more dietary strontium. They have a growth season of approximately 80 days and a root system that is concentrated around the topsoil level but can penetrate as low as one meter depending on nutrient availability (i.e., whether the soil contains nitrogen deeper in the ground) (Guo et al. 2002). It is important to note that not only would humans be consuming these plants but animals could graze from both active and abandoned fields, incorporating local bioavailable strontium isotopes into their bodies (Benson et al. 2003 but see Morris 2015 and Pfeiffer et al. 2016).

Other plants in the area that may have been consumed by humans and animals include nuts, berries, seeds and tree bark (Trigger 1987; Katzenberg 1989; Crawford and Smith 1996; Crawford et al. 1997). These edible plants are prevalent in the area and there is evidence for their consumption at different archaeological sites (e.g., Hidden Spring

[ASI 2010]). However, some of these food items, such as acorns and tree bark, were often viewed as being “famine foods” or foods that were consumed when the crops failed in Huron-Wendat society (Trigger 1987:36). As such, their consumption would be limited to times of stress.

With their unique $^{87}Sr/^{86}Sr$ values dictated primarily by the local geology and soils, plants will incorporate the local bioavailable strontium in the environment and contribute to the strontium isotope composition of human and animal tissues. Understanding where plants obtain their strontium allows for insight as to where strontium in animals originates and therefore their mobility, as well as their utility in mapping local bioavailable strontium in an area.

2.3.5 Fauna

Animals ingest strontium from their food. Their tissues therefore reflect strontium from multiple sources including plants and, in the case of carnivores, other animals, providing an average of the bioavailable strontium in the local environment. The $^{87}Sr/^{86}Sr$ value of an animal’s tissues depends on its diet and home range (catchment characterization and definition) (Ericson 1985; Price et al. 2002). For example, animals with larger catchment areas typically exhibit more variation as they consume resources from a wider geographic range and therefore $^{87}Sr/^{86}Sr$ values from different geological substrates (e.g., migratory animals such as caribou). On a local scale, animals that are opportunistic and eat a wide range of foods with heterogeneous $^{87}Sr/^{86}Sr$ values will have strontium coming from more sources and therefore more potential variation.

Researchers have suggested that non-migratory animals with small home ranges are good indicators of local bioavailable strontium values for the characterization of local environments (Price et al. 2002; Evans et al. 2010); however, what species provides the most accurate reflection of an environment's bioavailable strontium isotope composition is situation-specific. Local factors such as what species are available and the cultural use of these species needs to be considered. There are a number of animals in southern Ontario that are appropriate for strontium isotope analysis for mapping local bioavailable strontium isotopes in past and present contexts. These include non-domesticated animals such as white-tailed deer, which form the basis of this study.

White-tailed deer (*Odocoileus virginianus*) are found throughout North America in forested areas with fresh water (Ungar 2010:157). They are one of the most adaptable cervids, found from the Canadian Shield to South America (Dobbyn et al. 1994; Morris 2015:178). As adults, they are approximately 4.5-6.5 feet tall and weigh between 50 and 350 pounds (Gilbert 1990:158) with males growing about 40% larger than females (Sauer 1984 in Van Deelan et al. 2000). Fawns have a gestation period of approximately 200 days and are typically born in late May or early June in pairs but the birth of a single fawn or triplets have been documented (Governo et al. 2006). Fawns are weaned by six weeks old and accompany their mothers in their quest for food afterwards (Morris 2015:180). The modern population in Ontario numbers approximately 400,000 deer (Ontario Ministry of Natural Resources 2013) and they can live up to ten years, although this is rare (Hoskinson and Mech 1976).

White-tailed deer home ranges are dictated by their biological sex. Males tend to have larger home ranges than females (approximately 142ha vs. 45ha respectively) (Beier and McCullough 1990), possibly as a result of social differences. However, the size of their ranges change seasonally as both sexes tend to have smaller home ranges in the winter (Lesage et al. 2000:1935, Table 3). For example, the winter home range of the average white-tailed deer, which is located no more than 38 kilometers away from their summer home range, is approximately 26 hectares (Hoskinson and Mech 1976). Females return to the same summer and winter home ranges year after year whereas males return to the same summer home range but wander more freely in the winter, occasionally changing home ranges (Armstrong et al. 1983; Beier and McCullough 1990; Nelson and Mech 1999). Typically, white-tailed deer take the same migration route between their winter and summer territories; however, not all deer migrate and some will stay in the same area all year (Nelson and Mech 1999; Horsley et al. 2003). This is more common in areas without constant winter snow cover such as in southern Ontario (Larson et al. 1978; Horsley et al. 2003). Fawns will stay with their mothers, who have small home ranges, during tooth development. Therefore, $^{87}Sr/^{86}Sr$ values in white-tailed deer teeth should reflect the relatively small geographic areas that female white-tailed deer inhabit.

Deer require 3,600 to 9,900 calories a day (depending on their size), 13-16% of which is protein, and require calcium and phosphorus for healthy bone growth (French et al. 1956). They consume local vegetation such as acorns, fruits and leafy browse (Weckerly and Nelson 1990:534), although individual variation in diet is expected. Dietary differences based on sex have been documented with females exhibiting more selectivity (Beier 1987; Beier and McCullough 1990; but see Weckerly and Nelson 1990). Beier and McCullough (1990) suggest that metabolic differences allow males to subsist on foliage that is of lower nutritional quality but more abundant. However, given the choice, deer will select those plants with greater nutritional value, with a suggestion that easily digestible plants will be consumed first (Morris 2015:178).

Variation in dietary components resulting from seasonality in North America, is minimal as deer consume a similar balance of carbohydrates, protein and calcium year round (Beier and McCullough 1990; Weckerly and Nelson 1990; but see Morris 2015). Rather, the percentage of specific food items eaten may change, with more grazing occurring during the spring than any other time of year (Morris 2015:180). In the fall, high-energy foods such as fruit, mushrooms and maize are preferred (Morris 2015:181). White-tailed deer tend to consume twigs from shrubs and small trees year round (French et al. 1956; Dumont et al. 1998). $\delta^{13}C$ values, which allow for investigation of whether an individual is consuming C_4 plants, such as maize, or C_3 plants, such as grass or twigs, for archaeological deer range from -22.4+/-1.0‰ to -11.9 +/-1.2‰ (Katzenberg 1989; 2006; Pfeiffer et al. 2014; Pfeiffer et al. 2016) while $\delta^{15}N$ values, which provide an indication of an individual's trophic level and protein consumption, cluster around 6.4+/-0.8‰ to 5.9 +/-0.9‰ (Katzenberg 1989; 2006; Pfeiffer et al. 2014; Pfeiffer et al. 2016). These suggest that these animals consumed local terrestrial C_3 and non-leguminous plants. White-tailed deer may have been chased away from agricultural fields by women living nearby (Trigger 1987) resulting in the carbon isotope data indicating consumption of C_3 plants rather than maize. In addition to the change in specific diet items, the rate of consumption changes, as deer increase their food intake in the spring after winter has decreased their body fat and muscle reserves (Morris 2015:180).

White tailed deer have an elliptical jaw with three premolars and three molars (see Figure 2.2) designed for grinding vegetation resulting in large surface areas (Van Deelan et al. 2000). The molars, which contain two lophs, exhibit a double infundibulum (a depression shaped like a funnel in the middle that is filled with cementum and capped with enamel), except for M3, which has an additional loph (Ungar 2010:158). In general, incisors erupt first with the permanent incisors present by age one, followed by the molars around one year, five months old. These develop until about two years of age. The premolars erupt last around the age of nineteen months (see Gilbert 1990 for a summary). The amount of wear on deer teeth is commonly used as an estimate of the age of a deer (Severinghaus 1949) with subtle differences noted between sexes (Van Deelan et al. 2000).

Their teeth form in different seasons with the third molar developing six months after the first molar (Severinghaus 1949). Therefore, by sampling both the first and third

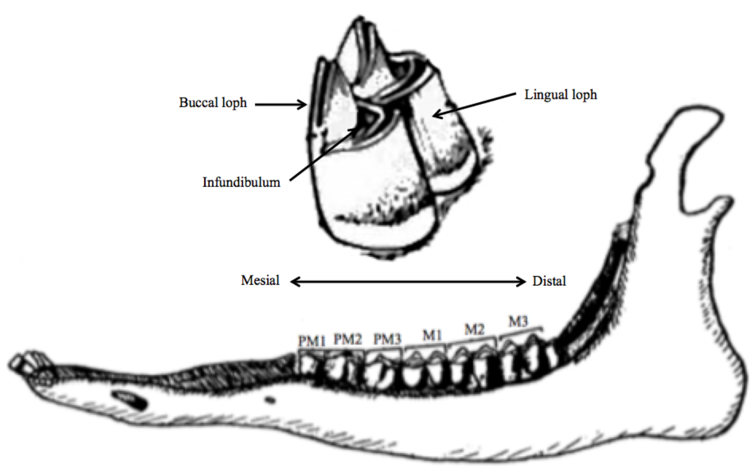

Figure 2.2 Adult white-tailed deer mandible illustrating the location of the three premolars and three molars. Terms of direction (mesial, distal, buccal and lingual) as well as the location of the infundibulum are indicated. Adapted from Severinghaus (1949, Figure 1).

molar in a single deer maxilla or mandible, some indication of seasonal differences in strontium isotope signatures should be possible. Morris (2015:215) explored this idea for oxygen isotope analysis, noting the influence of seasonal climate change on $\delta^{18}O$ values both between molars and within a single tooth. She found that $\delta^{18}O$ values in enamel decreased as samples were taken from the occlusal surface towards the cemento-enamel junction or CEJ (i.e., the enamel located near the base of the crown) of a tooth. Similarly, permanent mandibular M1 teeth exhibited higher $\delta^{18}O$ values relative to the second mandibular molar and third mandibular molars. She hypothesized that these higher values reflect the warmer spring climate that was present when the first molar was developing (Morris 2015:215); however, this could also reflect weaning, which takes place six weeks after birth (Morris 2015:180).

Despite the availability of literature on dental eruption, information on dental mineralization for white-tailed deer is sparse. Using radiography, Morris (2015) documented the sequence of enamel mineralization in white-tailed deer mandibles (see Figure 2.3). Morris found that the first permanent mandibular molar starts to form in utero, with a complete crown visible eight weeks after birth. Both the distal and mesial lophs (i.e., cusps closer to the back of the jaw and cusps closer to the front of jaw) appear to develop from the apex of the crown at the occlusal surface to the CEJ at the same rate (see appendix J in Morris [2015]). The second permanent molar starts forming once the first permanent molar is complete two months after birth and is complete between five and six months of age. The mesial loph of the second molar appears to develop shortly before the distal loph. The third permanent molar starts mineralizing after the second

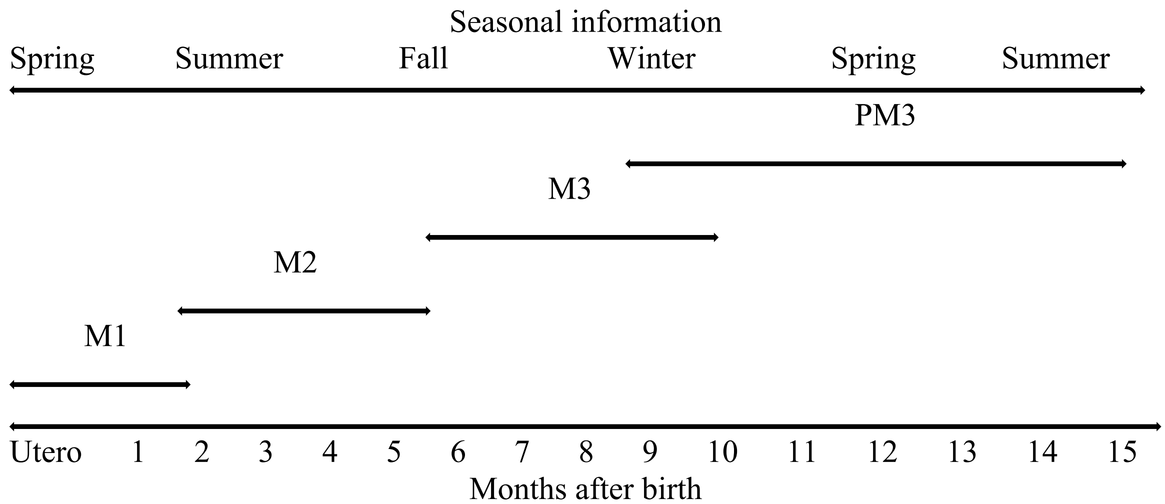

Figure 2.3 Mineralization sequence for permanent mandibular teeth in white-tailed deer. Data obtained from Morris (2015:203).

permanent molar is completely mineralized and finishes between nine and ten months after birth. According to the radiographs in Morris (2015), the middle loph of M3 starts developing first, followed by the distal loph with the mesial loph finishing mineralizing last. The premolars start to form at the age of nine months and are completed by the age of 15 months (Morris 2015:203). No radiographic information on maxillary tooth development is currently available; however, there is little difference in the development of mandibular and maxillary teeth (Severinghaus 1949).

Deer were an important resource for local indigenous populations in southern Ontario and their remains are abundant at archaeological sites. Not only were they a primary source of protein but they also provided skins for essential items such as clothing and blankets. Deer meat was primarily consumed as a stew, boiled with maize (Tooker 1964; Trigger 1987), while bones may have been boiled to extract marrow or grease (Morris 2015:243). Additionally, deer brain may have been used in the process of tanning hides, necessitating the boiling of the deer head to liquefy the brain. Groups such as the Huron-Wendat engaged in hunting trips to acquire white-tailed deer, skinning them on location and bringing home the meat (Trigger 1987; Pfeiffer et al. 2016). Alternatively, the deer were obtained and butchered at the site itself, providing an abundance of archaeological remains for sampling (see Appendix B for an overview of sites where this may have occurred). Morris (2015:229) and Pfeiffer and colleagues (2016) suggest that hunting would have occurred in the forest or along local watersheds, away from open and/or cleared lands. Overall, the relative abundance of white-tailed deer at archaeological sites, their repeated use of a defined home range, their limited lifespan, and their consumption of local plants and water (giving them an average of the local bioavailable strontium) makes this species an attractive option for determining bioavailable strontium isotope compositions across Ontario.

2.4 Sources of strontium isotopes

From the above discussion, it is clear that strontium isotope ratios to characterize the environment are rarely obtained from a single source. Rather, the environment can be better characterized as a mixing system with different sources for both the input and output of strontium isotope values (Bentley 2006). The simplest mixing system assumes only two sources, such as geological and atmospheric strontium (Blum et al. 2000); however, both inputs (e.g., atmosphere, weathering) and outputs (e.g., stream water, groundwater, intermediate reservoirs like biosphere and sediment/soil) need to be considered (Bentley 2006).

This means that the local strontium isotope composition in an area is the result of strontium isotopes from a variety of sources and therefore the local bioavailable strontium, or strontium that is available for exchange, can differ from those of the local bedrock (Sillen et al. 1998; Price et al. 2002; Bowen and West 2008). It is therefore advisable to consider the composition of bioavailable strontium rather than strictly looking at that of geological strontium composition (Price et al. 2002; Bataille 2014). This can be accomplished with the sampling of faunal remains, plants, water and sediments taken from the local area (Hodell et al. 2004; Evans et al. 2010; Frei and Frei 2011; Laffoon et al. 2012). However, Graustein (1989:494) suggests that preliminary characterization of the local geology in an area to explore the potential of strontium isotope analysis would be beneficial. In other words, if there is geological variation in an area, further investigation of the potential of strontium isotope analysis is warranted.

Mixing models also apply to the isotope composition of animal and human tissues. An individual does not typically eat a single food item but rather a mixture of different foods. Burton and Wright (1995) investigated this phenomenon, characterizing the Sr/Ca values for different diets. Consumption of different foods and water from different places results in variation in the strontium isotope composition in mammalian tissues. This is why strontium obtained from archaeological fauna have been recommended for mapping local strontium variation in an area as they provide an average of local values rather than a single value (Price et al. 2002). This will be discussed in further detail in the following chapter (Chapter Three: Predicting and mapping strontium isotope variation).

2.5 Summary

Strontium is a naturally occurring element with five documented isotopes. In archaeological investigations of mobility, $^{87}Sr/^{86}Sr$ is measured to provide an indication of an individual's place of origin. This is possible as $^{87}Sr/^{86}Sr$ varies according to the local geological composition. Strontium varies naturally in bedrock according to the original amount of rubidium, strontium and the age of the mineral being considered. This variation is passed from the geology into the local sediments, plants and water before ending up in the mineralized tissues of living creatures. Strontium has similar properties to calcium enabling its incorporation into biological organisms.

However, there are numerous factors that complicate this process. For example, the incorporation of strontium into living creatures is individualized, with numerous factors dictating its absorption including age, physiology, metabolism, health, diet and cultural practices. Additionally, environmental aspects dictate the release of strontium through weathering and atmospheric deposition. Local considerations such as sediment and soil movement, seasonality, differential weathering, unique growing patterns in plants, and animal behaviour all impact local bioavailable strontium isotopes. As such, the environment is best represented as a mixing model, with numerous sources contributing strontium available for consumption. This muddles strontium isotope analysis and introduces difficulties when creating isotopic baselines. However, techniques have been introduced to minimize the influence of these issues, specifically for mapping bioavailable isotopes, as will be seen in the next chapter.

Chapter Three: Predicting and Mapping Strontium Isotope Variation

In order to provide context for $^{87}Sr/^{86}Sr$ values obtained from human remains, a baseline reference map of local strontium values for an area must be available. There are several ways of obtaining $^{87}Sr/^{86}Sr$ values, including theoretical approaches (e.g., Beard and Johnson 2000; Bataille 2014), proxy approaches and sampling the local environment of the research area (e.g., Price et al. 2002; Hodell et al. 2004; Bentley and Knipper 2005; Hedman et al. 2009; Evans et al. 2010; Frei and Frei 2011; Laffoon et al. 2012; Frei and Price 2012; Hegg et al. 2013). In this chapter, how isotopic baselines have been created in the past is considered before models predicting the $^{87}Sr/^{86}Sr$ values that should be visible in southern Ontario are presented. This is done using both a strictly theoretical model that considers the age and type of the bedrock, as well as a proxy model that uses previously published strontium data for types of rock matrices that are present in southern Ontario.

3.1 Mapping variation in $^{87}Sr/^{86}Sr$ values

Establishing baselines for strontium isotope analysis has represented a challenging endeavour for archaeologists. Numerous factors introduce complications into the goal of establishing past mobility patterns using strontium isotope analysis. Despite this, researchers have established protocols that enable for the documentation of strontium isotopic variation in the environment.

One of these is the direct measurement of $^{87}Sr/^{86}Sr$ values from environmental samples. Maps depicting local strontium values have been created using local surface water either on its own (e.g., Frei and Frei 2011) or in conjunction with other local environmental samples such as sediments, soils, and plants (e.g., Hodell et al. 2004; Frei and Price 2012; Laffoon et al. 2012; Frei and Frei 2013; Willmes et al. 2014). However, these methods can be time consuming and costly, and so using these techniques at a large scale can be impractical. Additionally, significant heterogeneity in the $^{87}Sr/^{86}Sr$ values of rocks, plants, sediments, and soils in a local area has been documented, creating a wide range of $^{87}Sr/^{86}Sr$ values in a single region (Price et al. 2002).

In order to mitigate this concern, researchers recommend using local flora (Copeland et al. 2016) or fauna recovered in the study area (Price et al. 2002; Evans et al. 2010). Local animals consume resources from a number of sources, similar to humans. As such, their remains act as an averaging mechanism in a heterogeneous environment and any strontium data recovered from their remains should more closely reflect that of humans in the same area. This technique has successfully been used in various parts of the world to create local isotopic baselines for the investigation of past migration events (e.g., Bentley and Knipper 2005; Hedman et al. 2009; Evans et al. 2010; Hegg et al. 2013). However, questions about the best type of faunal sample to use for this purpose remain.

For example, both modern (e.g., Stojanowski and Knudson 2011; Hartman and Richards 2014) and archaeological (e.g., Bentley and Knipper 2005; Hedman et al. 2009) faunal remains have been used in the creation of these maps. However, concerns about using modern samples to answer archaeological questions have been raised (Madgwick et al. 2012). Complications such as the anthropogenic addition of strontium to the modern environment via pollution or fertilizer need to be considered as they have been shown to change local strontium values (Bohlke and Horan 2000; Jiang 2011; Christian et al. 2011;

Maurer et al. 2012). Therefore, modern environmental samples provide strontium isotope ratios that may differ from those in the past. Comparing archaeological specimens to maps created using modern samples may lead to inaccurate conclusions.

Furthermore, sample selection needs to be considered carefully on a case-by-case basis. What may represent a suitable animal for isotopic baseline creation at one location may not necessarily be appropriate for another. Similar to people, animals move from place to place, incorporating $^{87}Sr/^{86}Sr$ values from different locations. For example, strontium isotope analysis has been used to identify past herding and pasture practices (e.g., Bentley et al. 2003; Thornton et al. 2011; Aiglstorfer et al. 2014) and movement of migratory animals (e.g., Britton et al. 2009; Price et al. 2015). Use of such animals to characterize local strontium isotope ranges is thus inappropriate. Therefore, cultural practices that may influence local animal behaviour, as well as animal ecology need to be considered.

Additionally, researchers need to be aware of variation in growth rates of enamel both within and between teeth. Enamel incorporates strontium from the local environment as it forms. If a tooth grows over the course of many months in an area where seasonal differences in strontium values are present, these can be incorporated into the enamel resulting in different values within a single tooth and between teeth (Balasse et al. 2002). Similarly, if an animal moves between areas with different geological substrates and sediments/soils while their enamel is forming, their teeth will contain different $^{87}Sr/^{86}Sr$ values depending on what area they were living on while that tooth, or section of tooth, was developing (Britton et al. 2009). Therefore, if the potential for these differences exists, samples must be taken from the same part of the same tooth so as to enable comparison. In this way, variation in growth rate represents a potential complicating factor for strontium isotope analysis making use of faunal teeth.

One of the ways to ensure that the strontium data that are obtained reflect local values is to create a predictive model with which to compare experimentally obtained data. Using theoretical modeling or pre-existing research (e.g., strontium data from groundwater or streams, sediments, soils, and geological bedrock) can provide an indication of the accuracy of the local $^{87}Sr/^{86}Sr$ values and whether they accurately represent the local area (Bentley et al. 2004). As such, two predictive models were created: one using theoretical equations and ArcGIS established by Bataille (2014) and the other using previously published strontium data.

3.2 Theoretically modeling $^{87}Sr/^{86}Sr$ values

Predicting variation in local environmental strontium values using the composition of local bedrock geology is not a new concept. In 1977, Faure, who summarizes the basic theory underlying strontium isotope variation in geological materials, proposed two equations describing strontium isotope variation in mantle and crustal rocks. These equations are the basis for all current $^{87}Sr/^{86}Sr$ models today, such as the one proposed by Beard and Johnson (2000), which makes use of multiple linear regression to provide a theoretical strontium value for an area. With consideration of the influence that age has on strontium values in bedrock, they predicted strontium values for the continental United States. However, there are issues associated with this approach. For example, Bataille (2014:12) notes that this method is best for areas with minimal geological complexity, as it requires a large number of strontium analyses to ensure statistical robusticity. Additionally, their model assumed bedrock weathering as the sole source of strontium, without considering additional sources of strontium, such as those deposited from the atmosphere or those of anthropogenic origins (e.g., fertilizer). Furthermore, they looked exclusively at the age of the bedrock in the United States, rather than both the age and rock type. A unified framework that considers both factors (age and rock type) together appears to provide a more accurate model (Bataille 2014).

Bataille (2014) later expanded upon the model proposed by Beard and Johnson (2000), using ArcGIS to create a model capable of predicting strontium isotope distribution globally using both rock type and age. Making use of geospatial data on surficial and bedrock geology, rock geochemistry, hydrology, climate and aerosols, he created several models that consider the environment as a mixing system. In other words, rather than creating a model for geological strontium values, Bataille (2014) considers bioavailable strontium values, which should more closely reflect those values found in animal and human tissues.

Using the model created by Bataille (2014), the following strontium values in Table 3.1 (bedrock) and Table 3.2 (sediments/soils) for southern Ontario were obtained. Specifically, equation (1) in Bataille (2014:89) for silicate and carbonate rocks was used:

$$({}^{87}Sr/{}^{86}Sr)_b = 0.701 + ({}^{87}Rb/{}^{87}Sr)_{parent}(e^{\lambda(t1-t2)} - 1) + ({}^{87}Rb/{}^{86}Sr)_{rock}(e^{\lambda t2} - 1)$$

where $({}^{87}Rb/{}^{87}Sr)_{parent}$ refers to the ${}^{87}Rb/{}^{86}Sr$ of the parent material, $({}^{87}Rb/{}^{86}Sr)_{rock}$ is the ${}^{87}Rb/{}^{86}Sr$ of the modern rock type, t_1 = 3000Ma (when crustal differentiation occurred) and t_2 the age of the modern rock in millions of years (i.e., when the rock was deposited).

Table 3.1 Predicted $^{87}Sr/^{86}Sr$ values for bedrock in southern Ontario calculated using equation one for silicate and carbonate rocks in Bataille (2014).

Geological period	**Bedrock geology**	**Predicted $^{87}Sr/^{86}Sr$**
Mississippian	Shale	0.72003
Early Ordovician	Sandstone	0.71434
Early Ordovician	Limestone	0.71043
Middle Ordovician	Arkose	0.71434
Middle Ordovician	Dolomite	0.71069
Middle Ordovician	Limestone	0.70954
Middle Ordovician	Sandstone	0.71441
Middle Ordovician	Shale	0.72389
Late Ordovician	Dolomite	0.71107
Late Ordovician	Limestone	0.70989
Late Ordovician	Shale	0.72432
Late Ordovician	Siltstone	0.71604
Ordovician	Sandstone	0.71451
Ordovician	Shale	0.72432
Early Silurian	Dolomite	0.71044
Early Silurian	Sandstone	0.71423
Early Silurian	Shale	0.72315
Early Silurian	Siltstone	0.71563
Middle Silurian	Dolomite	0.71036
Late Silurian	Dolomite	0.72043
Late Silurian	Sandstone	0.71410
Late Silurian	Shale	0.72260
Silurian	Sandstone	0.71423
Early Devonian	Dolomite	0.71069
Early Devonian	Limestone	0.70968
Early Devonian	Sandstone	0.71406
Middle Devonian	Dolomite	0.71060
Middle Devonian	Limestone	0.70963
Middle Devonian	Shale	0.72241
Upper Devonian	Shale	0.72159
Devonian	Sandstone	0.71406
Devonian	Shale	0.72241

Table 3.2 Predicted $^{87}Sr/^{86}Sr$ values for sediment and soil in southern Ontario calculated using equation one for silicate and carbonate rocks in Bataille (2014).

Geological Period	Sediment type	Predicted $^{87}Sr/^{86}Sr$ value
Illinoian	Clay	0.71146
Illinoian	Sand	0.71146
Illinoian	Till	0.71145
Sangamon	Sand	0.71146
Sangamon	Clay	0.71146
Early Wisconsinan	Clay	0.71146
Early Wisconsinan	Silt	0.71147
Early Wisconsinan	Sand	0.71146
Early Wisconsinan	Till	0.71145
Middle Wisconsinan	Till	0.71145
Middle Wisconsinan	Glaciolacustrine	0.71145
Middle Wisconsinan	Silt	0.71147
Middle Wisconsinan	Sand	0.71146
Middle Wisconsinan	Peat	0.71145
Late Wisconsinan	Sand	0.71146
Late Wisconsinan	Silt	0.71147
Late Wisconsinan	Till	0.71145
Late Wisconsinan	Clay	0.71146

The mean absolute error of predictions is 0.000249 for the silicate and carbonate model (Bataille 2014:93). This was used in conjunction with the specified values located in Appendix A. An important note is that the type of rock under consideration determines $(^{87}Rb/^{87}Sr)_{parent}$. Silicate rocks are assumed to have a magma source whereas carbonate rocks are calibrated using $^{87}Sr/^{86}Sr$ value of seawater throughout time.

An assumption with this model is that sedimentary rock age is dictated by deposition. However, the components of sedimentary rocks can be recycled and so the deposition age of a sedimentary rock may not accurately reflect the actual age of the rock's components (Bataille 2014:120). In other words, the components of the rock may be older than the age of the rock's deposition, thus the $^{87}Sr/^{86}Sr$ values could be higher than estimated in the rock. Furthermore, there is an assumption of geological homogeneity, with all the minerals in a single rock weathering at the same, constant rate, which may or may not be accurate. $^{87}Sr/^{86}Sr$ values can also vary at different scales, and as this model is designed for large-scale applications whereas the current research has a regional focus, issues regarding the rock units are a concern. Additionally, it is assumed that modern rocks will obtain their $^{87}Sr/^{86}Sr$ from the rocks that they are derived from, with all rock types originating from the same parent material, which may not be correct. Finally, the carbonate model makes use of the $^{87}Sr/^{86}Sr$ value in seawater from the time period of interest. These values come from other research focusing on the $^{87}Sr/^{86}Sr$ seawater curve (e.g., Denison et al. 1998; Zachos et al. 1999; Cramer et al. 2011), and are thereby subject to a different set of methodological and theoretical concerns.

3.3 Proxy modeling $^{87}Sr/^{86}Sr$ values

The second predictive model for $^{87}Sr/^{86}Sr$ values was developed using previously published data. With a literature review of the strontium data that are available, primarily culled from geological studies that are concerned with Rb/Sr dating, values from similar bedrock types and ages to those in southern Ontario but originating from around the world have been obtained (Table 3.3). Subdivisions of each geological period into Early, Middle and Late have been provided whenever possible. Similarly, strontium values have been separated based on bedrock type (e.g., limestone, sandstone, etc.); however, some studies have not divided strontium values by specific bedrock types but rather combined them and as such, those values are reported as published (e.g., “dolomitic limestone” instead of “dolomite” and “limestone”). Furthermore, only whole rock matrix values were used as they provide an overall average for the entire rock rather than for just a specific

Table 3.3 Previously published mean $^{87}Sr/^{86}Sr$ values for bedrock types dating to the Ordovician, Silurian and Devonian periods that have been documented in southern Ontario.

Geological period	Bedrock geology	Mean $^{87}Sr/^{86}Sr$	n	St. Dev.	Country	Reference
Mississippian	Shale	0.73818	5	0.00525	United States	Steele and Pushkar 1973
Early Ordovician	Dolomite	0.70910	8	0.0003	China	Wenhui et al. 2006
Middle Ordovician	Dolomite	0.70862	6	0.00028	United States	Min Yoo et al. 2000
Middle Ordovician	Dolomite	0.70858	5	0.00020	Canada	McNutt et al. 1987
Middle Ordovician	Limestone	0.70880	1	-	China	Jiang et al. 2001
Middle Ordovician	Limestone	0.70835	2	0.00003	China	Wenhui et al. 2006
Middle Ordovician	Limestone	0.70826	1	-	Canada	Brand 2004
Middle Ordovician	Limestone, shale	0.70842	3	0.0001	Canada	Brand 2004
Late Ordovician	Dolomite	0.7080	1	-	Canada	Holmden 2009
Late Ordovician	Limestone	0.70810	1	-	China	Jiang et al. 2001
Late Ordovician	Shale	0.71077	1		Canada	Brand 2004
Late Ordovician	Shale, siltstone, limestone	0.71012	1	-	Canada	Brand 2004
Ordovician	Limestone	0.70808	2	0.00015	United States	Stueber et al. 1987
Ordovician	Shale	0.73434	1	-	United States	Stueber et al. 1987
Ordovician	Shale, sandstone	0.70807-70810	NA	NA	United States	Clark et al. 2004
Early Silurian	Dolomite, limestone	0.70818	2	0.00018	United States	Chenery et al. 2010
Early Silurian	Sandstone	0.71292	1	-	United Kingdom	Chenery et al. 2010
Early Silurian	Sandstone	0.7111	1	-	United States	Sunwall and Pushkar 1979
Early Silurian	Shale	0.70862	1	-	Australia	Compston et al. 1962
Early Silurian	Siltstone	0.71108	2	0.00098	United Kingdom	Chenery et al. 2010
Middle Silurian	Dolomite	0.70845-0.70910	NA	NA	Canada	Coniglio et al. 2003
Late Silurian	Salt	0.70870	1	-	Canada	Qing et al. 1998
Late Silurian	Shale	0.71110	1	-	United States	Bottino and Fullhar 1966
Silurian	Dolomite	0.70898	6	0.00058	United States	Stueber et al. 1987
Silurian	Limestone	0.70859	4	0.00021	United States	Stueber et al. 1987
Silurian	Sandstone	0.71138	9	0.00058	China	Cai et al. 2001
Early Devonian	Dolomite	0.70801	2	0.00011	Canada	Mountjoy et al. 1992

Table 3.3 continued.

Geological period	Bedrock geology	Mean $^{87}Sr/^{86}Sr$	n	St. Dev.	Country	Reference
Early Devonian	Limestone	0.70839	1	-	United States	Gao 1993
Early Devonian	Limestone	0.70853	1	-	United States	Denison et al. 1997
Early Devonian	Sandstone	0.71169	2	0.00036	United Kingdom	Chenery et al. 2010
Middle Devonian	Dolomite	0.70842	9	0.00024	Canada	Mountjoy et al. 1992
Middle Devonian	Dolomite	0.70800	3	0.00004	Canada	Teare 1990
Middle Devonian	Dolomite	0.70857	3	0.00054	Canada	Qing and Mountjoy 1994
Middle Devonian	Limestone	0.70780-0.70810	NA	NA	Canada	Qing 1998
Middle Devonian	Limestone	0.70610	4	0.00142	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.73450	20	0.01249	United States	Whitney and Hurley 1964
Upper Devonian	Dolomite	0.7085	1	-	Canada	Mountjoy and Halim-Dihardja 1991
Upper Devonian	Dolomite	0.70945	4	0.00021	Canada	Mattes and Mountjoy 1980
Upper Devonian	Dolomite	0.70951	1	-	Canada	Sharp et al. 2002
Upper Devonian	Dolomite	0.70850	1	-	Canada	Mountjoy et al. 1992
Upper Devonian	Limestone	0.70820	1	-	Belgium	DeJohnghe et al. 1989
Upper Devonian	Limestone	0.70828	1	-	United States	Brand 2004
Upper Devonian	Shale, limestone	0.70803-0.71064	NA	NA	United States	Clark et al. 2004
Upper Devonian	Shale	0.72000	1	-	Australia	Bofinger et al. 1970
Devonian	Dolomite	0.71055	1	-	United States	Stueber et al. 1987
Devonian	Dolomitic limestone	0.70860	1	-	United States	Steele and Pushkar 1973
Devonian	Limestone	0.70832	1	-	United States	Stueber et al. 1987
Devonian	Sandstone	0.71230	1	-	Ireland	Knudson et al. 2012
Devonian	Sandstone	0.70971	2	0.00084	United States	Stueber et al. 1987
Devonian	Shale	0.73908	3	0.01139	United States	Stueber et al. 1987

mineral. This is because a single rock can be composed of numerous minerals rather than being homogenous. Finally, these compiled values represent an average of those data available. See Appendix A for all of the data in their original form.

Although minimal, there have been some studies on strontium conducted in Canada specifically (see Figure 3.1). For example, Brand (2004) obtained strontium values from three different geological formations in Ontario. In southern Ontario specifically, he reports a strontium value of 0.71077 for the Georgian Bay formation (Brand 2004:32). According to Armstrong and Dodge (2007), the Georgian Bay formation is dated to the Upper Ordovician in the Palaeozoic era. It is composed primarily of grey-green to dark grey shale, siltstone and limestone (Dodge and Armstrong 2007:5). It is located on the shore of Lake Ontario, covering the area from Oshawa, south to Toronto and north to Uxbridge (Ontario Geological Survey 1991) and is near both traditional Neutral and Huron-Wendat territory.

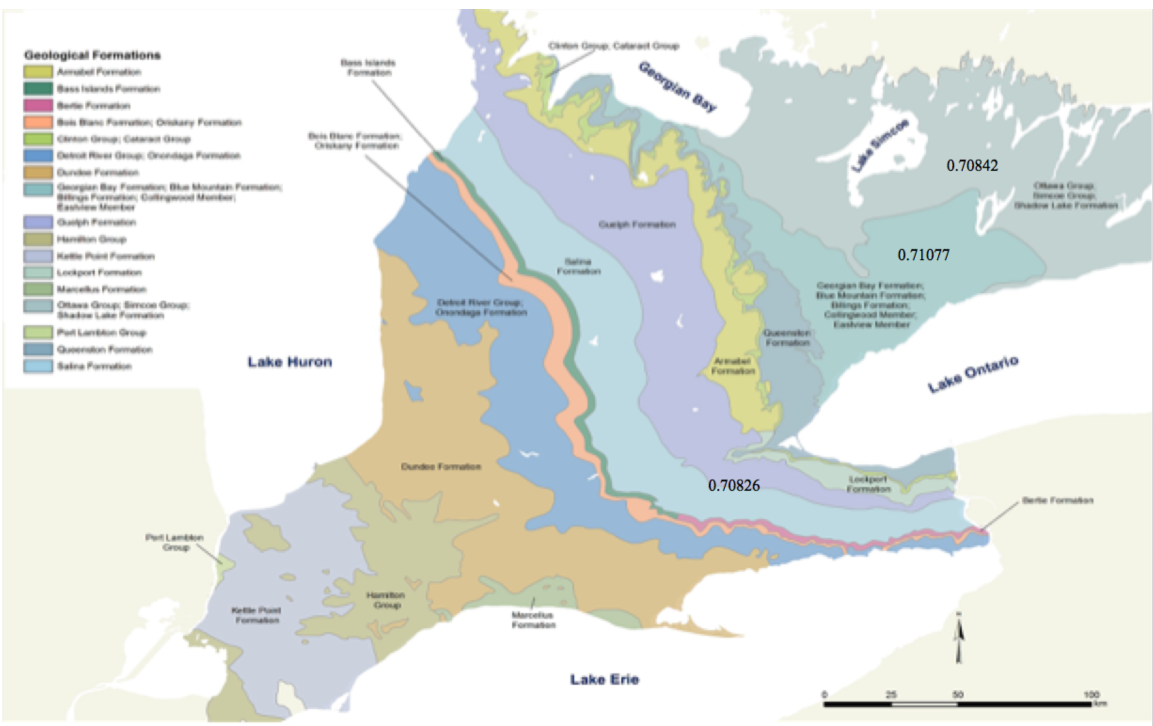

Figure 3.1 Previously published $^{87}Sr/^{86}Sr$ values for geological formations in southern Ontario. Data from Brand (2004) and McNutt and colleagues (1987). Map created using ArcGIS and data from an open source ArcGIS database.

Brand (2004) also reports strontium values for the Cobourg formation ($^{87}Sr/^{86}Sr$=0.70826) and the Verulan formation ($^{87}Sr/^{86}Sr$=0.70856, 0.70831 and 0.70839), both of which are lower than what was obtained using the predictive model. The Verulan formation is part of the Simcoe Group and is located in the Lake Simcoe area around Georgian Bay (Ontario Geological Survey 1991), in traditional Huron-Wendat territory. It is composed of a mixture of limestone and grey-green calcareous shale and is a Middle Ordovician feature (Armstrong and Dodge 2007:4). The Cobourg formation also dates to the Middle Ordovician and is composed primarily of limestone. It is a part of the Trenton formation, found in southwestern Ontario (Haeri-Ardakani et al. 2013) in traditional Neutral territory. McNutt and colleagues (1987) also investigated $^{87}Sr/^{86}Sr$ values in the Trenton Formation; however, they focused on dolomite in the formation. They found a mean $^{87}Sr/^{86}Sr$ value of 0.70858 using five whole rock matrix samples taken in Essex, Ontario (McNutt et al. 1987).

Similar to the theoretical model, there are limitations associated with the creation of a proxy model. Bedrock is not homogenous and can be composed of multiple different minerals. A similar type of rock (e.g., granite, limestone) may contain different proportions of individual minerals, influencing the strontium isotope composition. For example, Devonian sandstone was recorded as having two distinct $^{87}Sr/^{86}Sr$ values: 0.71230 (n=1) in Ireland (Knudson et al. 2012) and 0.70971 +/-0.00084 (n=2) in the Illinois basin, United States of America (Stueber et al. 1987). It may be that different mineral inclusions are present in the samples, impacting their $^{87}Sr/^{86}Sr$ values and complicating the use of geological samples for the creation of isotopic baselines.

Related to this, a single location can be composed of different layers of bedrock. Depending on where the sample for analysis was taken from, different minerals may be included (or excluded) for analysis, impacting the resulting $^{87}Sr/^{86}Sr$ value. Although the mean value might mask some of the lower values present in the rock, this reflects what can occur in the natural environment.

Whole rock $^{87}Sr/^{86}Sr$ values are rarely the focus of study. Rather they are supplementary to the primary research goal (e.g., establishing $^{87}Sr/^{86}Sr$ curves, Rb/Sr dating), thereby limiting the number of samples taken in each study. Although some databases exist that have compiled $^{87}Sr/^{86}Sr$ values for specific types of bedrock (e.g., EarthChem Portal), unfortunately none for those present in southern Ontario have been included yet. This results in a lengthy literature review process, providing small numbers of potentially biased samples thus limiting statistical analyses.

Finally, both the predictive model and previously published values are subject to analytical error. In the case of the predictive model, it tends to underestimate the $^{87}Sr/^{86}Sr$ value, on average, by +/-0.000249, while in the previously published values, error is dependent on each individual study. For example, a wide range of standard deviations is present ranging from 0.00525 (Mississippian shale, Steele and Pushkar 1973) to 0.00003 (Middle Ordovician limestone, Wenhui et al. 2006). These will result in a range of values characterizing a single type of bedrock, some of which are quite large. This is not unusual with Hoppe and colleagues (1999) noting standard deviations in the third decimal place for $^{87}Sr/8^{6}Sr$ values obtained from modern rodents collected from an area with homogeneous geology. Therefore, the differences visible between the observed $^{87}Sr/^{86}Sr$

values from geological samples and the predicted $^{87}Sr/^{86}Sr$ bioavailable values could be resulting from the error associated with each of their unique originating studies.

3.4 Summary

Overall, archaeological faunal specimens, with careful consideration of their species ecology and potential influence from cultural activities, represent the best opportunity for creating an isotopic baseline for answering questions within archaeology. Predictive models, created either by theoretical modeling using equations or by conducting a literature review of strontium values that have been previously published for environments (e.g., bedrock, aquatic) that are similar to the study area, allow for corroboration of experimentally obtained $^{87}Sr/^{86}Sr$ values. Based on the predictive models created for southern Ontario, $^{87}Sr/^{86}Sr$ values for bedrock should fall between $^{87}Sr/^{86}Sr$= 0.7080 and $^{87}Sr/^{86}Sr$= 0.73434. However, it should be kept in mind that these models are theoretical only, as each has its own set of limitations and assumptions. Furthermore, strontium isotope analysis is influenced by local environmental factors, such as those discussed in Chapter Two, which impact $^{87}Sr/^{86}Sr$ values.

Chapter Four: Theoretical Perspectives on Mobility

Archaeology in southern Ontario has been of interest for many years in both formal and informal academic contexts. For example, in the 19th century antiquarians became interested in artifacts of indigenous origins (Birch and Williamson 2015:6). This subsequently led to formal archaeological excavations, which established the Northern Iroquoians as a distinct population (Parker 1922; Wintemberg 1928; Ritchie 1944) and gave rise to an abundance of research in the area.

As archaeology developed into an academic pursuit in southern Ontario, different theoretical approaches developed alongside it. These different approaches will be explored in this chapter, with a focus placed on how mobility has been approached in archaeology as a whole before a discussion of the theoretical archaeological frameworks that have been used to interpret past Northern Iroquoian populations in southern Ontario is presented.

4.1 Mobility in archaeology

Mobility has been of interest to archaeologists for quite some time; however, it has not been always an accepted avenue of explanation. An overview of how mobility has been viewed in archaeology as a discipline throughout time is provided, with an examination of the acceptance that specific theoretical paradigms have had implementing mobility theory (or lack thereof), starting with cultural historicism before discussing processualism and post-processualism.

4.1.1 Cultural historicism

Culture historical archaeology was heartily endorsed in the late 19th century as an alternative to cultural evolutionism and remained a popular theoretical approach until the advent of processualism in the 1960s. Refined by researchers who worked primarily with historical societies (Adams et al. 1978), culture history was concerned with the identification of cultural groups and ethnicity, and made use of material culture that was restricted both geographically and temporally (Cameron 1995:106; Erlandson 2010). Cultural historicism posits that as long as a researcher has enough data, patterns and interpretation will emerge (Lock 2009). As such it is viewed as being a one-way street, moving from data to interpretation (Lock 2009) with a single hypothesis used to explain any observations (Rouse 1986:16). As a result of the emphasis on history, a common application of cultural historicism is to consider modern societies and project their material culture backwards in time in order to gain insight about their origins (Erlandson 2010:193).

Cultural historians viewed migration and diffusion as valid explanations for change in material culture. Diffusion is invoked to explain slow or large-scale culture change (Adams 1978; Chapman and Hamerow 1997), while migration is used to explain rapid culture change (Adams 1978; Cameron 1995:106). Movement is identified using discontinuities in the archaeological record. For example, it is assumed that mobility is responsible for any discontinuity in material culture, particularly with the discovery of a similar artifact in a different geographic location (Erlandson 2010). Rouse (1986:16) suggests that one of the reasons that mobility was favoured as an explanation in cultural historic archaeology was because of the continuing colonization of previously colonized territories that occurred at this time.

Central to the tenets of culture historicism is the idea of ethnicity, which is perceived as being a discrete variable that can be identified in the archaeological record using material culture. Using this concept, in the early 20th century Kossinna (1911; 1928; 1932) proposed the idea of defined geographical cultural areas that directly correspond with specific ethnicities, using material culture to support his hypotheses. V. Gordon Childe (1925) later took this concept, modified it and expanded it to describe migration and diffusion as the primary means of interaction between prehistoric populations in Europe. Unfortunately, he did not make a distinction between diffusion and migration despite the fact that Tylor (1871) had earlier defined the differences between them. However, migration quickly became a common explanation in cultural historical archaeology, particularly when its utility in nationalism and the creation and maintenance of national identity were recognized. With this recognition came the adoption of cultural historic perspectives in government policies. For example, the Nazi party of Germany used a cultural historic approach as justification for World War II (Harke 1998). Similarly, theories of mobility were used to support Apartheid in South Africa (Harke 1998) and sporadically in Russia to encourage the development of a national identity (Harke 1998; Frachetti 2011).

Eventually, the weaknesses associated with cultural historicism resulted in its marginalization and with it, the study of mobility. Cultural historicism was viewed as being “idealistic” (Bulbeck 2008:48) and “intrinsically subjective” (Lock 2009:76). It required researchers to view material culture as static and unchanging throughout time (Burmeister 2000:540) and it assumed that cultures migrate (Adams 1978; Cook and

Schurr 2009:344). Finally, the archaeological identification of ethnicity is fraught with methodological concerns (Burmeister 2000; Zakrowski 2011).

Likewise, as a result of the tendency to use mobility as an explanation whenever researchers could not adequately explain cultural phenomena, migration theories resulted in far-fetched conclusions that were eventually discredited (Cook and Schurr 2009; Erlandson 2010). This is unsurprising, as migration theories at this time were “simply ad hoc and somewhat mechanical explanations for anomalous site or trait distributions” (Adams et al. 1978:487). Unfortunately, material culture is not static and it is not cultures that migrate, but people (Anthony 1990). Similarly, the argument that particular ethnic groups display a specific type of material culture is misleading (Bader 2012:213). Complicating this further was the separation between theory and method in mobility studies at the beginning of the 20th century, which limited the utility of theories of mobility in archaeological investigation (Anthony 1990:896). Finally, the association between cultural historicism and nationalism with the pro-Nazi propaganda of World War II prompted researchers to distance themselves from cultural historicism.

Despite the issues associated with the uncritical application of mobility as an explanation in cultural historicism, Chapman and Hamerow (1997) believe the processualist claim that cultural historicists did not consider process in migration models is unjustified. They state that the identification of migration in past populations using cultural historicism required explanation of cultures both before and after the change. By identifying the source of the change, cultural historicists were, in effect, considering process in migration models; it was just not explicitly defined (Chapman and Hamerow

1997). Additionally, certain elements of cultural historicism have persisted in contemporary studies, including the current focus on ethnicity and the difficulties associated with the archaeological identification of other "group forming identities" such as profession, religion, political tendency, class, and sexuality (Bader 2012:214). Similarly, the historical approach to linguistics and archaeological research has been retained. For example, Fortunato (2011:99) calls for the use of an explicitly historical approach when making use of cross-cultural data for comparison purposes. Similarly, McConvell (2010) notes that migration trees in linguistics work backwards, identifying similarities and differences in languages in order to establish where they diverged from the original proto language. With the return of the study of mobility, it may be that further aspects of cultural historicism will also make a re- appearance in modern studies.

4.1.2 Processualism

In the 1960's, the issues associated with culture historicism spurred the adoption of a new theoretical framework called the New Archaeology or (later) processualism. First suggested by Lewis Binford (1962; 1965), who was inspired by W.W. Taylor's *A Study of Archaeology* (1948), processualism advocates the use of inductive reasoning with explicit and scientific methods in order to explain culture change (Chapman and Hamerow 1997; Lock 2009). It emphasizes phenomena such as population growth, internal social differentiation and environmental change, and rejects mobility as an explanation for these phenomena from a reductionist standpoint (Chapman 1997; Lock 2009). This caused a number of studies to focus on the internal rather than external causes of demographic expansion (Erlandson 2010). Unlike cultural historicism, the use of hypothesis testing and rejection in processualism enabled the use of statistics and computational modelling (Lock 2009). The belief associated with this school of thought is that “archaeological research should be driven by anthropological, ecological, and evolutionary theory rather than explicitly historical approaches” (Erlandson 2010:194).

This emphasis on positivist approaches resulted in a “retreat from migrationism” (Adams et al. 1978) between 1960 and 1980, as it was believed that theories of mobility did not conform to the established canons of science. This is because such concepts fall short of causal explanation, lacking sound methods or theories (Adams et al. 1978:502; Burmeister 2000:539). For example, cultural historicism assumed that linguistic, ethnic and cultural distributions coalesced, an incorrect assumption that was viewed as being simplistic by processualists (Adams et al. 1978:502). Additionally, models of migration were based on the concept that cultures were bounded, homogenous and normative, which is not acceptable in processualism (Chapman and Hamerow 1997). They were also perceived as being intertwined with inaccurate chronology and depictions of culture. The weaknesses inherent in the theoretical conception of culture were believed to be the fault of migration models (Chapman and Hamerow 1997). Additionally, the discovery of evidence supporting alternative hypotheses to explain cultural phenomena other than mobility in cultural historical models contributed to the decrease of the popularity of mobility as an explanation (Rouse 1986:17). Rouse (1986) also suggests that the influence of developments in anthropology and other social sciences encouraged archaeologists to re-evaluate their approach to population movement. Finally, it was realized that there is no standard terminology for mobility (Anthony 1990) nor is there a definitive method of identifying it archaeologically as "clear-cut evidence of... migration is frequently lacking in the archaeological record" (Trigger 1968:29). Therefore, it comes as no surprise that when models of culture change were rejected, the concept of mobility was rejected with them (Adams et al. 1978; Chapman and Hamerow 1997) in a process that Anthony (1990) has compared to tossing the baby out with the bathwater.

Other reasons for the neglect of mobility in processualism include Harke's (1998) argument that the problem of mobility is a problem with attitude. For example, British archaeology subscribed to an "immobilist" perspective (Hawkes 1987 in Harke 1998) that minimizes research on mobility. Harke (1998) argues that this is a reflection of the history of Britain because it is isolated from mainland Europe and did not experience a number of migrations identifiable in other areas of Europe. Similarly, Rouse (1986:16-18) notes the importance of what he terms "cultural bias" in the perception of mobility, suggesting that there is a direct correlation between modern cultural perceptions of movement and the acceptance of population movement as an explanation in archaeology. Harke (1998) and Rouse (1986) note the effects of post-war decolonization, insularity and the development of a welfare state in the dismissal of research on mobility. Similar to Rouse (1986), Chapman (1997) also discusses the influence of attitude on the general acceptance of mobility as a whole, believing that the individual experiences of researchers reflect the social and political changes that occurred at the time. For example, Chapman (1997) discusses the potential impact of generational experience, or the idea that people who are born during the same time period will have similar culture and social experiences, and therefore will have similar reactions and worldviews (Chapman

1997:14). As such, archaeologists who were active in the 1960's would have had some awareness of World War II and wished to distance themselves from anything resembling justification for the actions of the Nazis during that time.

However, some researchers are puzzled by the outright rejection of mobility by processualists. Chapman and Hamerow (1997) suggest that there was no reason why processualists could not have worked mobility into existing models as an external variable. Similarly, Anthony (1990:585) suggests that migration is a predictable process that is influenced by aspects such as trade, transportation and social organization and as such it is feasible to investigate it from a processualist perspective. Additionally, Burmeister (2000) uses a combination of processual and post-processual techniques to propose a model for mobility in Europe. Specifically, he uses processualism to illustrate that material culture can have more than one level of meaning (Burmeister 2000b:560).

As a result of the general neglect of migration-based explanations for archaeological phenomena, Anthony suggests that the theoretical aspects of mobility had been ignored (1990:899). Burmeister concurs, stating that archaeological research focusing on this topic is inadequate with few exceptions (2000:552). However, notwithstanding the poor reputation of mobility in processualist archaeology, researchers were considering mobility and publishing on the topic during this time period (Clarke 1968; Adams et al. 1978; Rouse 1986). Rao (1998) notes that a worldwide interest in mobility was prevalent from 1970 to 1999 while Rouse (1986) states that during the "retreat from migration", several innovations in mobility studies were proposed. Champion (1990) argues that processualists never entirely rejected migration, something also noted by Snow (1995) in his migration theory for the Northern Iroquoians. Rather, processualists rejected migration that was not easily explained (Anthony 1997:21). This is evidenced by Binford's (1980; 1982; 1983) work with his distinction between group and individual movements, and research on foraging versus collecting. Additionally, the acceptance of optimal foraging theory in ecological archaeology promoted theoretical consideration of mobility. Therefore, processualists did not entirely reject mobility (Champion 1990; Snow 1995; Anthony 1997); rather it was just not a common avenue of study.

4.1.3 Post-processualism

In the 1980's, a group of archaeologists expressed concern with the explicitly scientific approach endorsed by processualist archaeology (Hodder 1991). Instead of a sole focus on quantitative variables, there was an increased desire to study the qualitative aspects of human life represented in the archaeological record (Lock 2009). It was believed that material culture should be viewed as active and meaningful, with the agency of the individual, culture and history taken into consideration rather than a strictly utilitarian perspective (Hodder 1985). This resulted in the creation of what Hodder (1985) called post-processual or interpretive archaeology. Post-processual archaeology is a generic term for a wide range of archaeological approaches that have a similar fluid aspect in the relationships between data, interpretation and the individual (Lock 2009). Interpretive archaeologists take umbrage with processualism's positivist stance and promotion of universal laws (Chapman and Hamerow 1997), and advocate a reflexive approach that considers how "we as archaeologists think about the past, identify and scrutinize these factors that influence our thinking, and examine the implications of the way we structure our thinking about interpretations of the past" (Smith 1995:29). It does not agree with the processualist position that older methods and theories are invalid (Hodder and Hutson 2003) and attempts to make archaeology more accessible to people who are not archaeologists (Shanks and Tilley 1989).

In accordance with the belief that culture historicism was not wholly uncritical, concepts that were discarded by processualist archaeology, such as migration, are re-emerging as valid research topics. It is now recognized that mobility is a complex global phenomenon that requires understanding of gender, culture, identification, class and intent (Harzig and Hoerder 2009). As such, consideration of theories such as agency, gender and identity theory, social network theory and world systems theory in post-processual studies of mobility is now common (e.g., Anthony 1990; Anthony 1997; Milroy and Milroy 1997; Burmeister 2000; Cobb 2005; Goldstein 2005; Harzig and Hoerder 2009; Kok 2010; McConvell 2010).

Social network theory posits that individuals create and maintain personal networks or communities as a method of providing a meaningful framework to resolve everyday problems (Milroy and Milroy 1997). It permits interaction between groups without necessarily establishing a power dynamic between them (Goldstein 2005:25). As such, social networks can either encourage and enable mobility or discourage and prevent it. For example, information obtained through a social network can encourage an individual to leave a less desirable location or to remain in an area that is more desirable than the surrounding places. Similarly, goods that enable travel can be obtained through social networks while debts can prevent one from leaving an area (or vice versa, encouraging an individual to leave in a hurry).

In Anthony's (1990) pivotal article on mobility theory, he emphasizes the importance of social networks and the flow of information in the decision to move. Various researchers have since acknowledged the utility of social networks in mobility studies (e.g., Milroy and Milroy 1997; Goldstein 2005; Harzig and Hoerder 2009; Kok 2010). Harzig and Hoerder (2009:80) suggest that social networks influence most aspects of everyday life as individuals live in the "context of other human beings." This is visible in the application of social network theory in linguistic studies, as language is a primary means through which individuals relate to one another. Additionally, social network theory is common in linguistic studies of mobility that are concerned with the style of language rather than its form or function (e.g., Milroy and Milroy 1997; McConvell 2010). This is because language can function as a symbolic means of asserting speaker-identity and belongingness, similar to archaeology's quest for the symbolic meanings of material culture (Milroy and Milroy 1997).

However, when considering the influence of social network theory in mobility studies, it is important to include scale. Social network theory is a micro-scale process that concentrates on small group interactions without considering the socio-political structure of larger groups (Milroy and Milroy 1997). As such, it should be used with caution when applied in models of human mobility in the past (i.e., one must ensure that the scales are comparable). However, Fix (1999) suggests that network theory can provide a link between micro- and macro-scale processes. Furthermore, social network theory cannot provide concrete evidence for the motivation behind mobility in the origin areas (Kok 2010), necessitating careful consideration when it is used in interpretation of human activity in the past. Nevertheless, despite Anthony's (1990) emphasis on the importance of social network theory, he suggests focusing on the process of mobility rather than the motivation behind it, thus circumventing Kok's (2010) concern.

In an attempt to understand motivation and migration, researchers can also consider agency. Based on ideas proposed by Bourdieu and Giddens, agency can be defined as the "sum of actions, choices, and strategies for achieving the goals of individuals or groups within a society" (Goldstein 2005:18). Agency reflects an aspiration to counter the concept that human behaviour is externally determined, and instead acknowledges that people typically act with purpose and that these actions alter the external world (Dornan 2002:304). Agency can be expressed either intrinsically or extrinsically (Goldstein 2005:18). In mobility studies, concepts such as habitus (i.e., socialized norms that influence behaviour), and its influence on material culture and architecture, have been identified as helpful (e.g., Burmeister 2000; Goldstein 2005). Furthermore, agency perspectives consider a society as a composite rather than as a homogenous group (Goldstein 2005), promoting an integrative perspective in the study of mobility. Despite a uniform agreement that agency enables the individual or group to play an active role in their environment, researchers have debated about standardized definition and application (Dornan 2002), reminiscent of the dilemma that has plagued mobility studies. This is not necessarily problematic nor has it limited the application of agency in archaeology, however, with researchers using aspects of material culture as indicative of agency (Bolduc 2011).

A number of parallels can be seen between general trends in archaeological theory and how the study of the Northern Iroquoians has been approached in Ontario archaeology. During the era of cultural historicism, migration was freely accepted as an explanation for the origins of the Northern Iroquoians and dominated the theoretical sphere at that time (Snow 1995). However, with the advent of processualism, the major theoretical paradigm changed from migration to the Ontario Iroquois Tradition proposed by Wright (1966). The latter *in situ* theory became popular and studies focused on artifacts and the insight that they could provide on life in the past. This denunciation of the migration hypothesis reflects the rejection that processualism advocated with respect to migration as a research topic in general.

It was not until well after the adoption of post-processualist theories by some researchers that Snow (1995) once again proposed migration as an explanation for the origins of the Northern Iroquoians. Today, researchers acknowledge the impact that mobility has in the area and continue to debate the extent of its influence. They have expanded their research areas to consider post-processual aspects such as social identity and kinship, social networks and agency at both a local and regional scale in addition to continuing to study the more traditional artifact (e.g., ceramics) and settlement patterns. Therefore, theoretical development in Ontario closely reflects that which occurred with mobility in archaeology as a whole.

4.2 Archaeological frameworks in southern Ontario

Different theoretical frameworks have been used to interpret the archaeology of past populations in southern Ontario. These frameworks have both cultural and chronological components, and address different aspects of archaeology in the region. However, these are not static. As the discipline of archaeology has evolved, so have the interpretive frameworks that have been used to interpret past populations. This reflects the changing theoretical paradigms and methodological orientations and developments that have been popular in archaeology.

Prior to 1944, one of the topics archaeologists were concerned with was the function of artifacts and focused on identifying their utility. This functionalist approach corresponded with a shift to a more systematic approach in archaeology as a whole (Smith 1990:280). Archaeologists adopted migration as the major theoretical paradigm during this time. In the case of the Northern Iroquoians, this was based solely on ethnohistoric records, such as the notes left by Jesuit missionaries (e.g., The Jesuit Relations 1896-1901, 73 volumes), with minimal consideration of archaeological evidence (Trigger 1978). It was not until later that the two sources of evidence – archaeological and ethnohistoric accounts – were combined to create a more comprehensive image of life in the past (Smith 1990). However, even with this combination, a theoretical paradigm concerned with migration persisted with a general acceptance that the Northern Iroquoians moved into the area, displacing local Algonquin groups (Smith 1990).

After 1944, archaeological concern shifted from artifact utility to generating a chronology of types (e.g., ceramics), which led to a change in the dominant theoretical paradigm. During this time, an *in situ* development for the Northern Iroquoians became widely accepted, as can be seen in MacNeish's (1952) *Iroquois Pottery Types* where he proposed a chronological sequence detailing the *in situ* cultural evolution of the Huron-Wendat. MacNeish's research suggested a longer Northern Iroquoian occupation than previously thought and was the first to apply dates to the Northern Iroquoian presence in Ontario (Smith 1990:283). The creation of this sequence allowed subsequent researchers to place their studies within a larger context by comparing the pottery recovered at different sites to the chronology established by MacNeish (1952). Additionally, this publication created a reference database for those pottery styles that were considered to be local versus foreign, enabling for consideration of interactions between different indigenous groups. This stimulated interest in chronology and ceramics, changing the primary methodological orientation in southern Ontario archaeology from one of artifact function to one concerned with style and chronology (Smith 1990).

While an *in situ* hypothesis was generally accepted, some degree of regional movement in the area was also recognized. One of MacNeish's primary arguments was that the Huron-Wendat moved north into their traditional territory ("Huronia") in the Georgian Bay/Lake Simcoe area from their original location in the region around modern-day Toronto. However, Ridley (1952a, 1952b) published two papers during this same time period that contradicted this idea, suggesting instead a southern movement based on the differences noted in ceramics between pre- and post-European contact in what he termed “LaLonde” sites. It was not until J. Wright’s (1966) publication, *The Ontario Iroquois Tradition*, that these two competing hypotheses were resolved. In this, Wright (1966) synthesized current research at the time and suggested two groupings in the Northern Iroquoian population – a northern and southern population – both of which arose from a single homogenous group, that he called the Middleport Horizon.

Wright’s (1996) publication heralded a change in the major archaeological theoretical paradigm, which moved from an *in situ* development focus to one concerned with the cultural-historical Ontario Iroquoian Tradition through the use of methods that focused on fine-grained chronology, ecology, settlement patterns and attributes (Smith 1990:280). This resulted in an archaeological interest in small-scale interactions, such as the events occurring at a single site (e.g., Finlayson 1985; Naismith Ramsden 1989; Damkjar 1990; Ramsden 2009). There was also an interest in refining the chronology suggested by Wright (1966), with studies using ceramic attribute analysis rather than typological analysis. For example, Ramsden (1977) focused on ceramic variation at numerous sites, using ceramic attribute analysis in order to argue that Huron-Wendat populations were constantly shifting and village composition changed as a result of processes such as fission, coalescence, alliances and migration.

This ushered in an era in Ontario archaeology where the focus of research was on sites at a local scale rather than the broader perspectives espoused by earlier studies. Subsequent researchers were interested in the movement of individual villages, or parts of villages, through space and time (e.g., Ramsden 1979; Birch and Williamson 2015), as well as considering sites that are not villages but rather seasonally occupied sites and special purpose sites (e.g., Pendergast 1974; Pihl and Thomas 1997; Robertson 2004; Bursey 2006). Furthermore, different methods have become commonplace, including osteology (Rost 2011; Spence 2011; Spence and Wilson 2015) and isotope analyses (Schwarcz et al. 1985; Katzenberg et al. 1993; Katzenberg et al. 1995; Harrison and Katzenberg 2003; Van der Merwe et al. 2003; Bower 2011; Pfeiffer et al. 2014; Pfeiffer et al. 2016), which have enriched our understanding of the Northern Iroquoians in southern Ontario and beyond.

It is interesting that this preoccupation with establishing chronological sequences, such as that found in past publications (e.g., MacNeish 1952,) continues today. For example, researchers are still interested in reconstructing sequences of events at a local scale, focusing on either the movement of entire villages from location to location (e.g., Fitzgerald 1982; Birch and Williamson 2015; Birch and Williamson 2015b) or the introduction and subsequent use of artifacts (e.g., Michelaki et al. 2013). A more subtle chronological influence can be found in researchers' tendency to organize their research according to general broad time periods based on cultural characteristics (e.g., Ellis and Ferris 1990). Some of the time periods that have been used can be found in Table 4.1. It should be noted that this is not a complete list. Furthermore, researchers have identified cultural complexes within these broad time periods. For example, within the Early Woodland, researchers refer to the Meadowood (800 B.C. – 400 B.C.) and Middlesex (450 B.C. – 0 B.C.) complexes (Spence et al. 1990). Similarly, the beginning of the Late Woodland period is often split into the Glen Meyer complex in the west and the Pickering complex in the east.

Table 4.1 Chronological time periods in southern Ontario archaeology. Data taken from Ellis and Ferris (1990), Ferris and Spence (1995) and Ferris (1999).

Time Period	Date
Palaeo Indian	11,300 B.C. to 10,200 B.C.
Archaic	8,000 B.C. to 2,600 B.C.
Early Woodland	800 B.C. to 0 B.C.
Middle Woodland	500-400 B.C. to A.D. 500-700
Transitional Woodland	A.D. 500-700 to A.D. 900-1000
Late Woodland	A.D. 900-1000 to A.D.1400
Terminal Woodland	A.D.1400- A.D. 1700

However, these categories are problematic for a number of practical and theoretical reasons. For example, these time periods are not uniformly accepted and researchers provide different start and end dates (e.g., Wright 1966; Ellis and Ferris 1990; Warrick 2000) or acknowledge some periods while not others (e.g., van der Merwe et al. 2003). Similarly, these time periods can be, and have been, subdivided further. For example, van der Merwe and colleagues (2003:246) divide the Late Woodland into three distinct periods: early Late Woodland (A.D. 900-1300), middle Late Woodland (A.D. 1300-1400) and late Late Woodland (A.D. 1400-1650). This division is similarly reflected in the comprehensive volume on southern Ontario archaeology edited by Ellis and Ferris (1990), with separate chapters devoted to the early, middle and late Late Woodland period.

There are a number of assumptions built into this preoccupation with chronology that affect any interpretations. First, Wright's (1966) publication, which forms the basis of many of these categories, is grounded in culture-history, with the aim of organizing populations into distinct cultural and ethnic groups based on their material culture. This is a holdover from MacNeish (1952), who proposed fixed ethnic territories for the Northern

Iroquoians. Unfortunately, these cultural divides are unrealistic in many aspects because, as Ramsden (1977) notes, population movement was constant with people continuously in flux creating a dynamic, shifting social landscape. It is this aspect that makes strontium isotope analysis, with its ability to investigate migration events in past populations, such an attractive potential method for this area.

This propensity towards movement is inherent in the socio-political organization of local indigenous groups such as the Huron-Wendat. It has been argued that the primary socio-political unit was the longhouse (Heidenreich 1971:123; Varley and Cannon 1994), giving families the flexibility to travel where they wished. For example, Ramsden (2009) posits that a family who wished to pursue their interest in the fur trade left the Benson site while a more traditional faction stayed behind. Therefore, the basic socio-political organization is designed to allow flexibility and mobility, allowing individuals to travel from place to place and not reside just within a single cultural area but to facilitate movement between them.

This creates difficulties because as people travel, they bring things with them, both physical objects and abstract concepts including religious and cultural practices. As Burmeister (2000) notes, adherence to the familiar is not just a preference, but instead is psychologically ingrained. People take their past with them when they move and are apt to adhere to the familiar in a new setting, particularly within their home. As such, attempting to isolate and divide specific cultures and time periods based on material culture in a population that is characterized by movement is problematic.

Furthermore, those groups that are known as the Huron-Wendat and Neutral today may not have existed as they are portrayed in European writing prior to A.D. 1300. These are the groups that were observed by European visitors in the 17th century during a time of socio-political and economic change. Projecting the presence of these specific bounded groups as they were during European contact backwards through time can be complicated. Although the people themselves have inhabited this region for hundreds of years, how they have occupied the space has changed. Therefore, to apply a chronological sequence created using a culture-historical approach with its focus on defined culture areas means accepting a number of problematic assumptions about past populations in the region and their culture (as inferred from archaeological and ethnohistoric evidence).

This is evidenced in the various debates that exist as to the origins of the Northern Iroquoians, such as the question of migration versus *in situ* origins (as discussed above) or the Pickering conquest debate. The Pickering conquest hypothesis was originally suggested by Wright (1966; 1992) and Wright and Anderson (1969) and later supported by Finlayson (1998) to explain the sudden similarities in pottery manufacture between geographically disparate groups in A.D. 1300 during the Uren cultural horizon. Pickering refers to a geographically contained group of Northern Iroquoians who lived in the southeast at the same time as individuals in the west, who were part of what is traditionally known as the Glen Meyer horizon. Wright posits that the Pickering groups moved into the area occupied by the Glen Meyer Early Iroquoians in a bloody conquest and captured local villages, resulting in the ceramic homogeneity visible in the archaeological record during the Uren horizon (A.D. 1300-1330). However, other researchers dispute this, suggesting that there was no conquest but rather trade and diffusion spreading from the east (Wright 1986; Spence 1994; Pearce 1996; Warrick 2000:441-443).

Therefore, using a chronological sequence that is based on the idea of separate ethnic territories is fraught with issues. This may explain why there is some ambiguity as to the start and end dates of the cultural and time divisions seen in Table 4.1, which are based on cultural developments. Given the frequency with which individuals moved, bringing their distinctive cultural practices with them, as well as the changing cultural contexts, there is bound to be overlap between areas, thus blurring the lines between the chronological divisions. Some researchers have acknowledged this in the past 20 years, with the suggestion that these categories are more of a “hindrance than a help to interpretation” (Spence 1994:8). The division of different groups may be arbitrary lines drawn on a spatial and/or chronological continuum, resulting in the uncertain start and end dates of specific time periods and cultural complexes. It is unfortunate that this preoccupation with ethnic territories throughout space and time has persisted and continues to influence research today (Hart 2012:128).

Despite the problems associated with classifying indigenous populations, ethnohistoric records have documented the presence of several distinct groups in southern Ontario at the time of European contact in the 17th century. These include the Northern Iroquoians: the Huron-Wendat, the Petun-Tionnante, the Neutral, and the Erie (see Figure 4.1). For some of these groups, particularly the Huron-Wendat, a wealth of ethnohistoric records written by European visitors documenting their everyday life are available, representing a unique opportunity for researchers.

These documents are invaluable and have provided useful context for archaeological investigations. However, it must be noted that these records are rife with biases. These documents are written records of the observations made by male Europeans, often traders, explorers and missionaries, who visited the indigenous populations during the contact era. European contact was a time of change not necessarily a drastic change in the traditional lifestyle, but rather elaboration of current practices (Trigger 1987:427). Given the dramatic loss in population, increase in conflict as a result of the fur trade, and the pre-existing fluid socio- political structure of local indigenous groups, it is probable that the events documented by Europeans were new variations on older traditions. Furthermore, the Europeans themselves were biased and would project their own perspectives onto their observations. The Europeans were experiencing a new way of life in a foreign language with their own objectives and orders. They had preconceived notions of what was appropriate and what was not. For example, Jean de Brebeuf is a Jesuit missionary who lived in Canada from A.D. 1625 until A.D. 1629, returning in A.D. 1633 and staying until his death in A.D. 1649. He witnessed the creation of the Ossossane ossuary and provides us with much of what we know about the mortuary practices of the Huron-Wendat. Yet he places the Huron-Wendat on a level just above that of “beasts” (JR 1896-1901 10:211) and would therefore view their practices through a similarly biased lens. An additional issue is that the missionaries were often describing events that occurred in a single village. If mortuary ritual differed from nation to nation, application of their observations to the entire confederacy would be inappropriate. As such, it is not suitable to treat ethnohistoric records as accurate throughout time and space.

Evidence for this can be found in the archaeological record. For example, Brebeuf notes the commingling of remains within ossuaries, and although archaeological evidence for this process has been documented at some ossuaries (e.g., Kidd 1953; Churcher and Kenyon 1960; Pfeiffer 1980), it is not visible in others (e.g., Jerkic 1975; Williamson et al. 2003:157). Furthermore, ossuary structure has changed throughout time, switching from a community or family based event in the Early Iroquoian period to the highly ceremonial nation-wide function observed by Brebeuf during the contact era (Johnston 1979; Trigger 1987:138; Sutton 1988; Williamson and Steiss 2003; Robertson 2004:95; Birch and Williamson 2015:152). This could reflect the creation of the confederation and a need to solidify the alliances necessary for its maintenance.

Brebeuf also notes the inclusion of grave offerings in ossuaries; however, there has been minimal recovery of grave offerings in pre-European contact ossuaries (Jamieson 1981; Trigger 1987:147; Ramsden 1990b). As noted, with European contact and the establishment of the fur trade, Huron-Wendat culture was able to flourish and become more elaborate (Trigger 1987:426). It should therefore come as no surprise that some of this elaboration of previously established practices occurred in their mortuary systems. Ethnohistoric documents can therefore provide an indication of what was occurring during a specific time in the specific place that they were written, through a male European viewpoint.

4.4 Summary

Mobility has been a topic of great interest in southern Ontario for decades. The local indigenous populations in the region were relatively mobile and archaeological research has considered this mobility accordingly. This is reflected in the theoretical paradigms that have held sway in southern Ontario over the past century, as well as in the general theoretical trends of archaeology as a whole (e.g., the rise and fall of the popularity of mobility as a theoretical paradigm).

Chapter Five: Archaeological Context

Researchers have compiled many of the existing ethnohistoric records on the Northern Iroquoian populations into synthetic ethnographies, some combining archaeological, ethnohistoric, and traditional knowledge (e.g., Wright 1963; Tooker 1964; Heidenreich 1971; Trigger 1987; Sioui 1999). Keeping in mind the caveats discussed in Chapter Four associated with archaeological chronologies and cultural divides, as well as the reliability of ethnohistoric sources, a brief summary of those Northern Iroquoian groups pertinent to this research, the Huron-Wendat and the Neutral is presented in this chapter.

It should be noted that the Northern Iroquoians are different from the Iroquois, or *Haudenosaunee*, with whom they share common cultural and linguistic aspects but differ in several key aspects including mortuary practices, material culture, kinship and clan organization (Steckley 2007; Warrick 2007; Birch 2010; Birch and Williamson 2015:4). The *Haudenosaunee* were a confederation of five Iroquoian speaking groups (Seneca, Cayuga, Onondaga, Oneida and Mohawk) who lived in what is now the United States. In contrast, the Northern Iroquoians, who are the focus of this research, consisted of the Huron-Wendat, the Petun-Tionnante, the Neutral and the Erie, lived in modern-day Canada, called British North America in the 17th century (see Figure 5.1).

5.1 The Huron-Wendat

The Huron-Wendat were a Northern Iroquoian confederacy composed of four or five Iroquoian speaking groups, occasionally referred to as nations, who lived in southern

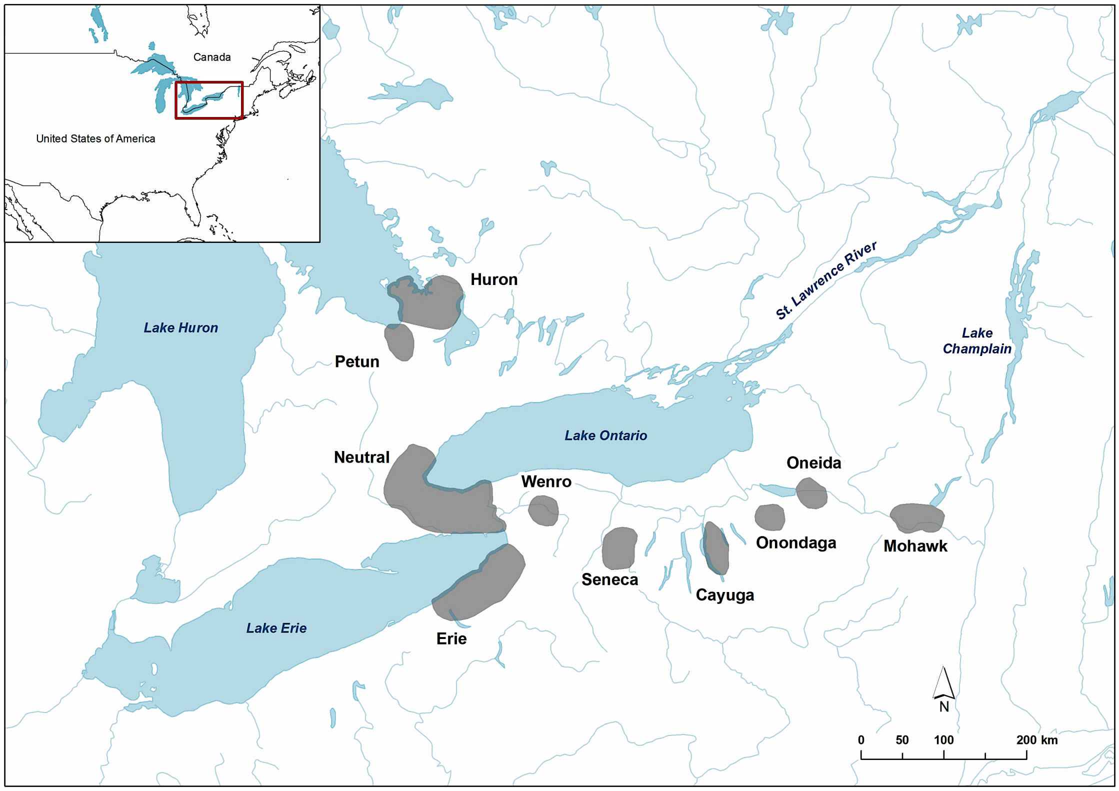

Figure 5.1: Locations of Northern Iroquoian and Iroquois populations during the period of early European contact in the 17th century.

Ontario during the 17th century (Ramsden 1990b). These groups included the *Attinniaoenten* (People of the Bear), who lived the furthest east in traditional Huron-Wendat territory, *Arendaenronnon* (People of the Lying Rock) in the west, *Atahontaenrat* (People of the Deer) and *Ataronchronon* (People of the Bog), both of whom lived in between the *Arendaenronnon* and *Attinniaoenten*. Occasionally, the *Hatingeennonniahak* (Makers of Cords for nets), who lived north along the shores of Lake Huron, are included as a separate nation in the confederacy. It is hypothesized that the *Attinniaoenten* were the original inhabitants in traditional Huron-Wendat territory along the north shore of Lake Ontario, while the other nations moved into the area later for protection (Heidenreich

2011). This confederacy lasted for approximately fifty years (Ramsden 2006:28), before the Huron-Wendat were dispersed by the *Haudenosaunee* in A.D. 1649.

Prior to European contact, the Huron-Wendat are believed to have numbered between 20,000 and 25,000 people; however, after a series of depopulation events (e.g., epidemics) their population dropped to approximately 9,000 individuals (Warrick 2008). They lived in 18 to 25 villages, located near a source of fresh water and sandy soils preferred for growing crops. Occasionally, these villages were occupied year round and palisaded for protection (but see Ramsden 1988); at other times they were special purpose sites or seasonally occupied for specific activities such as fishing or agriculture (e.g., Pendergast 1974; Pihl and Thomas 1997; Robertson 2004). Typically, these villages would be occupied for a maximum of 20 years (Heidenreich 1963), after which the village would be abandoned and the village inhabitants would establish a new village nearby. This pattern has been attributed to several factors including practical, economic and spiritual/religious reasons (Ramsden 1977; Heidenreich 1971:214; Birch and Williamson 2015).

The socio-political structure of the Huron-Wendat in the 17th century has traditionally been visualized as having four levels: the household or longhouse, the village, the nation and the confederacy. Of these, the household can be viewed as the primary unit of organization, consisting of an extended family related by lineage living in a longhouse (Varley and Cannon 1994:91). This is followed by the village, which incorporated the smaller household units (Birch 2012) and was governed via daily village council meetings (Tooker 1964:42-43). Village councils were composed of the older men in the community from each longhouse and were headed by the village chiefs (those men who were the most qualified from a specific lineage) (JR 1896-1901 10:232; Heidenreich 1971:79; Birch 2012). The third tier of organization, the nation, was composed of villages located within a specific region (Ramsden 1977:2). Similar to the villages, nations were also governed by a council, composed of the chiefs from each village in the nation (JR 1896-1901 10:231). After A.D. 1300, the nations united and became a confederacy (Ramsden 1977:2) and moved into the geographic locations they occupied at the time of European contact. It is at this point that the term “Wendat”, meaning “islanders” came into use (Trigger 1987:27, Steckley 2007). One final aspect of socio-political organization that can be found in Huron-Wendat society is the presence of clans. Clans were mostly ceremonial constructs based on lineage that cut across the other socio-political boundaries and encouraged solidarity within the confederacy (Heidenreich 1971:78; Trigger 1987:154).

The Huron-Wendat were horticulturalists who cultivated maize (*Zea mays*), beans (*Phaseolus vulgaris*), squash (*Cucurbit* sp.) and sunflowers (*Helianthus annus*) for both sustenance and trade (Trigger 1987; Monckton 1992). Of these, maize has been proposed as being the most important, constituting approximately half of the Huron-Wendat diet during the Late Woodland Period (Monckton 1992:xii, 92) with 6-11% of their diet composed of deer meat (Turner and Santley 1979). Trigger (1987:38) states that this maize was often consumed as a thin soup made of corn meal, occasionally with fish, meat or squash. Maize was also important during the weaning process (Tooker 1964). For example, children were often fed maize water if their mother died prior to weaning

(Tooker 1964). This hypothesis is supported by isotope data, which indicates consumption of C_4 plants in small children (Katzenberg 1993). This reliance on maize was supplemented by hunting animals such as white-tailed deer (*Odocoileus virginianus*), black bear (*Ursus americanus*), beaver (*Castor canadensis*) and other mammals in addition to fishing freshwater species such as burbot (*Lota lota*), lake trout (*Salvelinus namaycush*), salmon (*Oncorhynchus gorbuscha*) and yellow walleye (*Sander vitreus*) (van der Merwe et al. 2003) and gathering local flora (e.g., berries and nuts). In addition to cultivating and hunting for food, the Huron-Wendat would also collect surplus resources for trading purposes.

White-tailed deer were hunted for food and skins, as well as for trading purposes. They were viewed as a utilitarian item with their skins used for clothing and blankets and their bones modified for tools. They are common in southern Ontario with local indigenous populations attributing them minimal ideological significance. An exception to this is the antlers, which symbolized justice and authority (Sioui 2011:209). Research has suggested that hunting territories of six to thirteen square miles per village were sufficient to obtain enough deer skins for clothing and blankets depending on white-tailed deer population densities (Gramly 1977; Turner and Santley 1979; Webster 1979).

Hunting white-tailed deer was a social activity where groups of men from a village would participate in driving deer towards a barrier where they could more easily be killed (Biggar 1922-1936). These drives were timed to coincide with times of high deer densities such as during autumn or late winter (Webster 1979). After a hunt, parts of the animal could be left behind (e.g., the meat) after the carcasses were skinned (Trigger

1981). As such, unmodified skeletal remains such as teeth would not be carried from location to location but rather discarded close to the location of their capture thus making them ideal for the creation of an isotopic baseline. This is visible in their high recovery rates in midden contexts.

The Huron-Wendat engaged in trade with a large number of local indigenous populations, including those that spoke Algonquian and other Iroquoian languages. For example, luxury items such as tobacco, black squirrel skins, raccoon skin robes, wampum beads, conch and other shells and gourds were obtained from populations in the south (Heidenreich 1963:140; Trigger 1987:62-63) while clothing, camping equipment, buffalo robes, charms, dried fish and native copper were imported from populations in the north in exchange for tobacco, nets, rope and cornmeal (Heidenreich 1963:141; Trigger 1987:39, 63). Trade was an important influence on Huron-Wendat society, encouraging positive relationships and camaraderie since the Huron-Wendat would not trade with anyone who was classified as an enemy (Ramsden 1977:291). Furthermore, trade allowed for stratification of Huron-Wendat society, creating different social statuses and tiers, such as nobility and commoners (Jamieson 1981; Birch 2010). This is because trade routes were viewed as the property of certain people (Williamson 2012). As such, not everybody could engage in trade; rather, it was the privilege of a select few who held proprietorship over the routes. Later, with the establishment of the fur trade, the view of trade routes as property resulted in fission (Ramsden 2009) and relocation of villages, such as the Sidey-McKay site (Ramsden 1977). Trade has also been hypothesized as being a primary factor in the eventual dispersal of the Huron-Wendat (Heidenreich 1971).

Historically, the Huron-Wendat were believed to have practiced a unilocal matrilocal post-marital residence pattern. Matrilocal residence refers to the social convention were men moved to live with their wives' families, while women held a position of elevated social status in the local socio-political organization. This idea was originally proposed by Morgan (1962) and has since become entrenched in Iroquoian studies (Warrick 2000:422), influencing interpretations of social organization and cultural development of groups like the Huron-Wendat (Birch 2008:195). For example, research has focused on the link between subsistence and post-marital residence patterns, suggesting that with the emergence of agriculture as the primary mode of subsistence for the Northern Iroquoians, matrilocality became the principal dimension of social organization (e.g., Trigger 1978; Hart 2001). Similarly, ideas about matrilocality and its occurrence within societies involved in endemic warfare, such as occurred in the 17^{th} century in southern Ontario, have been explored (Divale 1984; Snow 1995; Snow 1996). Despite this proclivity to assume matrilocality in Northern Iroquoian populations, conflicting archaeological and osteological data suggest patrilocality rather than matrilocality (e.g., Richards 1967; Spence et al. 1984; DeLaurier and Spence 2003). It may therefore be more appropriate to view matrilocality as a flexible social custom in Huron-Wendat society that could change as needed (Creese 2011).

Death was an important event for the Huron-Wendat in the 17^{th} century with elaborate celebrations and mortuary rituals. It was a four-stage process, starting with the realization that one is about to die, followed by the physical death of the individual, his or her interment in a cemetery and, finally, his or her interment in an ossuary (see Ramsden

1991, Seeman 2011). Much of what is known about the ceremonial aspect of ossuary interment comes from Brebeuf, a Jesuit missionary who observed the creation of Ossossane ossuary in A.D. 1636 (JR 1896-1901:10:279-311). From his notes, it is known that ossuary creation was elaborate and designed to promote cohesion among different villages within the same nation. In brief, all qualified individuals who had died in the past 10 to 15 years within a specific geographic region were removed from their initial resting places in cemeteries and stripped of any remaining flesh. They were then transported to a designated location to be buried together with everyone who had died in a mass burial pit (the ossuary) during a symbolic ritual, the Feast of the Dead or the Feast of the Kettle. The Feast of the Dead was the way in which the living communicated to the dead that they were leaving the village and the ancestors could move onto the spirit world. This was important, as the living would no longer be around to tend to the cemetery and therefore to the souls of those who had passed. Upon completion of the feast, the host village was abandoned.

The Feast of the Dead was a nation-wide event, including not just those who belonged to the nation hosting the feast but also their valued allies and friends. However, guidelines were established as to who was included in ossuary burial. For example, those individuals who had died violently or in a way considered to be unnatural (e.g., suicide, freezing to death or drowning) were not permitted to be buried within the ossuary. This is because these spirits were viewed as being angry and therefore were feared. These people were buried elsewhere, such as at the LaFarge site. The LaFarge site consists solely of the burial of a single man, who had been shot four times from behind with projectiles and then scalped. The isolated nature of this burial showcases the fear that the Northern Iroquoians had of the spirits who died violently (Spence and Wilson 2015). Similarly, those who were too young or too old were also excluded from ossuary burial, as it was believed that they did not have the strength to make the journey to the spirit world (JR 1896-1901 10:143). Rather, infants were often buried next to paths or under houses (Kapches 1976) so that their spirits could be reincarnated as they impregnated passing women. This belief in a lack of strength to make the journey to the spirit world holds true for those individuals who were chronically ill as well (Forrest 2010). Finally, witches and enemies were excluded from ossuary burial but instead were discarded in middens (Trigger 1987:51).

However, exceptions to these rules have been documented. For example, although the ethnohistoric record suggests that infants were not to be included in ossuaries, the Uxbridge ossuary (~A.D. 1490) contained the remains of a large number of infants (Pfeiffer and Fairgrieve 1994). Similarly, the remains of an adult male who fit the guidelines for ossuary burial was instead recovered under a house in the same burial as an adolescent at the Hidden Spring site (Bower 2011). This illustrates the potential biases inherent in the ethnohistoric records as discussed in Chapter Four.

Although ossuary burial can be viewed as a cohesion technique that was used to promote unity throughout the confederation, it is interesting to note that it did not always include everyone in the surrounding area. Not only do ethnohistoric accounts state that each nation had their own feast, a separate village of souls and different mortuary customs (Kidd 1953; Trigger 1987:87), but not everyone within a nation would attend the

Feast of the Dead. Brebeuf (JR 1896-190110:279-311) notes that political disagreements between different groups of villages in the same nation (the *Attignaouantan*) resulted in the exclusion of individuals from the communal ossuary burial. That particular year, five villages refused to participate in the nation's Feast of the Dead. The chief of the discontented villages stated that the "kettle and his feast had been spoiled, and that he was obliged to make another" (JR 1896-1901 10:280) as an explanation for his village's absence.

Furthermore, inclusion in ossuary burial was considered to be a privilege, and as such, invitations to favoured guests were often issued in order to cement alliances. However, alliances were fluid in Huron-Wendat society and who was considered a friend would change throughout time. For example, the Huron-Wendat had a tempestuous alliance with the Mohawk for years before eventually becoming and remaining enemies (see Heidenreich 1971 for a summary). As such, neighbours and allies could be invited to attend a Feast one year but excluded in a later year with the dissolution of their alliance. Further complicating this matter was the creation of different alliances depending on nation (Sutton 1988). For example, in A.D. 1647, the Huron-Wendat negotiated for peace with the Onondaga, Oneida and Cayuga (JR 1896-1901 33:71-73, 117-127). However, not everyone within the confederacy wanted to establish this truce and nations were divided on the matter (Heidenreich 1971:273). Therefore, whom a nation invited to their individual ceremony would change, not only through time but also from nation to nation, reflecting the autonomy of the individual nation and not the cohesive confederacy.

5.2 The Neutral

Similar to the Huron-Wendat, the Neutral were a Northern Iroquoian confederacy composed of ten indigenous nations at the time of European contact. Between A.D. 1615-1650, the largest of these nations was the *Chonnonton* (Keepers of the Deer), with approximately 30,000 people, of which 4,000-6,000 were warriors (Wright 1963; Sagard 1866 3:157; Noble 2007). Other groups include the *Attiragenrega* (*Attiouandaronk*), *Ahondironons*, *Niagagarega*, *Antouaronons* and *Kakouagoga* (White 1972). Samuel De Champlain named them the Neutral after his observation that they were unaligned despite the hostilities that existed between their neighbours (Wright 1963; Lennox 1984). They were distinguished physically from the Huron-Wendat by their large number of visible tattoos (Wright 1963).

By A.D. 1640, the Neutral lived in 40 settlements located within a 32-kilometer radius of Hamilton, Ontario between the territory occupied by the Huron-Wendat and *Haudenosaunee* (White 1972). The Neutral exhibited a preference to locate their villages near wetlands (Noble 1984; Stewart 2000), perhaps so that they could take advantage of white-tailed deer habitat preferences (Stewart 2000). However, their villages were not permanent fixtures, as similar to the Huron-Wendat, the Neutral also moved around their traditional territory, abandoning their villages and moving to a new location after approximately 20 years (Fitzgerald 1982). Finlayson (1982) hypothesizes that this was a result of natural resource exhaustion; however, other reasons such as those identified for the Huron-Wendat above would also be logical explanations.

The Neutral were horticulturalists who grew maize, beans and squash in addition to hunting animals like deer, raccoon, black bear, wapiti and passenger pigeons (Wright 1963; Prevec and Noble 1983; Stewart 2000). Of these, deer were their favoured source of protein, and eventually the Neutral started penning deer in order to ensure a steady supply of valuable deerskins for trading (Noble 2007 but see Needs-Howarth and Hawkins 2017). This would serve to restrict the mobility of the deer, a benefit for strontium isotope analysis.

According to Sagard (1939), deer were more readily available in Neutral territory relative to the lands occupied by the Huron-Wendat. However, raccoons were also preferentially taken, particularly after the fur trade with the Europeans flourished (Prevec and Noble 1983:45; Stewart 2000). They also cultivated tobacco for ritual and trade purposes (Stewart 2000). Overall, the diet of the Neutral is similar to that of the Huron-Wendat; however, they consumed different species of fish, such as catfish (*Siluriformes* sp.), suckers (*Catostomus* sp.) and freshwater drum (*Aplodinotus grunniens*) (Stewart 2000) and tended to eat more fruits and nuts (Dallion 1866).

The Neutral were part of a vibrant social landscape and participated in both trading and war alliances during the 17th century. For example, they were part of a loose federation with both the *Aondironon* and Wenroe with whom they were allied (White 1972) whereas they engaged in periodic warfare against groups such as their longstanding rivals, the Mascouten (the Fire Nation) (Lennox 1977; Noble 2007). Occasionally, the Neutral would capture prisoners and bring them back to their villages, either for torture or adoption, as was documented in A.D. 1640-1642 (JR 1896-1901 21:195; 27:10). It is important to note, however, that those whom they considered allies or enemies were easily changeable. A group that they might consider to be an ally one month could quickly be viewed as enemies the next (White 1972).

The Neutral were also part of the large exchange network that existed between northern indigenous populations, trading with various groups in the Great Lakes region including the Huron-Wendat, Wenroe, Erie, Andaste and Ottawa (Jamieson 1981). Unlike the Huron-Wendat, however, they did not require positive relationships to trade, and exchanged goods with both allies and aggressors alike (Fitzgerald 1982:285). They actively traded furs from animals such as beaver, mink, muskrat, otter, chipmunk, black and grey squirrel, fisher and weasel (Campbell and Campbell 1989), in addition to meat, bone and antlers (Stewart 2000). Prevec and Noble (1983:45) also suggest that passenger pigeon might have become a favoured trade item during the period of European contact between A.D. 1615-1651. It is interesting to note that the Neutral refrained from direct trade with the French and instead obtained European goods from the Huron-Wendat, who acted as middlemen (JR 1896-1901 21:203). This is because the Huron-Wendat did not like the thought of losing their profitable status as middlemen in trade with the Europeans and started spreading vicious rumours about the French, which the Neutral believed. A corollary of this practice of avoidance is that the Neutral had limited contact with the Europeans prior to their dispersal and as such, there are minimal ethnohistoric accounts relative to the plethora of information available detailing the life of the Huron-Wendat.

The first contact that the Neutral had with Europeans was with Etienne Brule in A.D. 1615-1616 (Lennox 1977:1). Later, in A.D. 1626, Joseph de la Roche Daillon arrived to establish a mission in Neutral lands. Daillon was initially welcomed by the Neutral and invited them to trade with the French (Sagard 1866:3:801-802). However, the Neutral believed the rumours spread by the Huron-Wendat and threatened the missionary, forcing him to return to Huronia in early A.D. 1627 (Sagard 1866). This was not the end of European involvement in Neutral life, however, as in A.D. 1640 Jesuit missionaries Jean de Brebeuf and Chaumonont arrived in the lands occupied by the Neutral. They stayed in the area for approximately four months, unsuccessfully attempting to convert the local population to Christianity before leaving; Brebeuf with a broken clavicle (JR 1896-1901 21:187-237).

It is suggested that the Neutral viewed death slightly differently than the Huron-Wendat. The latter engaged in elaborate ceremonies with interment first in cemeteries and then secondary burial in ossuaries with strict mortuary customs. Conversely, the Neutral interred their dead in both ossuaries and cemeteries, and not necessarily in a sequence (Noble 1972:13; Fitzgerald 1982). Minimal restrictions for inclusion in an ossuary are visible archaeologically, with subadults recovered in ossuary contexts (Wright 1977; Fitzgerald 1982). Additionally, large quantities of grave offerings have been recovered in Neutral mortuary contexts, with more items such as beads, pots and knives than bodies located in ossuary pits (Stothers 1972; Noble 1978:163; Jamieson 1981; Fitzgerald 1982). For example, 195 individuals were recovered from two pits known as the Shaver ossuary along with over 1200 shell beads, 400 glass beads, iron knives, cut and polished bone tubes, an iron axe, a clay pipe, a brass ladle and a European medallion (Stothers 1972). Furthermore, a number of primary burials were located around the ossuary burial pits.

One of these primary burials contained an individual wrapped completely in trade cloth (Stothers 1969 in Jamieson 1981). Neutral ossuaries themselves were also elaborately constructed. For example, the Carton ossuary was lined with bark and fur in addition to the deposition of numerous grave offerings (Halpern 1973:31-32).

Unlike the Huron-Wendat, the Neutral had a hierarchical nascent chiefdom in place for approximately 20 years during European contact, which enabled them to persevere against their enemies until A.D. 1646 (Noble 1978; Jamieson 1981:19). At this time, their chief, Tsouharissen, died and the Iroquois, specifically the Seneca, were able to disperse and destroy the Neutral around A.D. 1651 (Noble 1972; Fitzgerald 1982:44). It has been suggested that the Seneca dispersed the Neutral for access to new territory in which to hunt beaver for trade with Europeans (Wright 1977:3).

5.3 Movement in southern Ontario

Archaeological populations in southern Ontario, such as the Huron-Wendat and Neutral, were characterized by continuous population movement and realignment (Ramsden 1990b:375). Phenomena such as coalescence and fission resulted from a desire for trade, defense, war, practical concerns, as well as mortuary practices and beliefs, all of which contributed to a constant shift in village composition and change in village locations across the landscape. In this section, a focus is placed specifically on movement and how it has been identified previously in the archaeological record.

Fission of villages, or the process during which a village split into a number of smaller villages, and coalescence, the process during which smaller villages combined to become a single larger village, were relatively established phenomena in Northern

Iroquoian society. Evidence for these processes in different groups is visible as early as the Uren complex in the Middle Iroquoian period, A.D. 1300-1350 (Warrick 2008:175). By the late 15th and early 16th centuries, coalescence was characteristic of southern Ontario settlement patterns (Birch 2012).

A number of hypotheses have been suggested to explain the motivation behind the shifting village composition visible in the southern Ontario archaeological record (see Haydon 1978). For example, factors promoting fission include economics (Ramsden 1977:273), factionalism within communities (Trigger 1987:158; Ramsden 2009), war (Trigger 1987:158), population pressure (Heidenreich 1963; Duffy 2015) and a lack of social mechanisms to deal with larger groups (Heidenreich 1971:130). Similarly, hypotheses for coalescence include defense (Finlayson 1985:439; Trigger 1987:32; Ramsden 1990b; Birch 2012; Birch and Williamson 2015:22), regional population growth (Birch and Williamson 2015:18), competition for trade (Damkjar 1990:50), internal social dynamics (Ramsden 1990b), and good leadership at a specific village (Heidenreich 1971:132). Phenomena such as individual needs (e.g., food and shelter) and environmental conditions (e.g., pollution, presence of pests, natural resource exhaustion, etc.) also influence village size and movement (Heidenreich 1971:214; Haydon 1978; Finlayson 1985:434).

Not only did village composition change, but also the location of the villages themselves. For example, upon completion of the Feast of the Dead, which culminated with the creation of an ossuary, the host village was abandoned. This was often correlated with soil exhaustion in the local area, as well as an abundance of pests. The entire village would relocate to a new area with fresh natural resources, leaving the exhausted location behind. As such, researchers have traced the sequence of movement of entire villages from site to site across the landscape (e.g., White 1972; Fitzgerald 1982; Birch and Williamson 2015).

These processes have been identified archaeologically using different methods. For example, Haydon (1978) suggests that archaeological evidence for the new relationships that arise out of the processes of fission and coalescence should be visible in the presence of different stylistic traditions within a single village. Each style would be representative of a different group that had either arrived or stayed behind. Damkjar (1990) uses this premise to investigate the changing ceramic styles located at the Coulter site. He explores the idea that the stylistic differences documented indicate degrees of relatedness, suggesting the repeated incorporation of new groups, either entire villages or village segments, throughout time into the existing population (Damkjar 1990:46). Similarly, the material culture recovered from the Kirche site exhibits stylistic variation, which has been suggested to reflect the heterogeneity of the individuals who resided at the site, again potentially as a result of their different origins (Naismith Ramsden 1989).

A second method involves investigation of the layout and planning of a village, or lack thereof (e.g., Damkjar 1990). This is because the expansion of the original village could reflect unanticipated population increases, potentially as a result of coalescence, while contractions could reflect population loss from fission (Finlayson 1985; Ramsden 2009; Birch 2012). For example, the Coulter site was expanded a number of times suggesting an influx of unanticipated people, particularly given the topography immediately surrounding the village (Damkjar 1990). Similarly, the Draper site was repeatedly expanded (Finlayson 1985), as was the Mantle site (Williamson 2012). Each expansion is characterized by the alignment of longhouses in different directions and at the Draper site, Finlayson (1985) has identified potential chief residences in each expansion. These aspects again suggest the addition of entire villages or village segments.

Thirdly, it has been suggested that the orientation of longhouses reflected internal divisions within a village (Heidenreich 1971; Finlayson 1985; Damkjar 1990 but see Norcliffe and Heidenreich 1974; Latta 1985; Birch 2008). As new people moved into a village, they built their longhouses in a manner similar to how they had beforehand. This may or may not adhere to the same standards espoused by those longhouses and individuals who were already in place. Finlayson (1985) uses this as support for his argument that the Draper site was expanded a number of times, incorporating new residents during coalescence. This is an idea supported by Burmeister's (2000) suggestion that when people travel, they bring the familiar with them.

Finally, Ramsden (1988) suggests that the presence of light palisades within village confines could represent the gradual incorporation of new community members. As new, unknown individuals move into a village, the village inhabitants built a fence between themselves and the newcomers. Eventually, as time passed and the newcomers became full-fledged members of the community, the fence was removed, symbolizing their unity as a village.

Other research not concerned with coalescence or fission but focusing instead on movement has also been conducted. For example, Molto (1983) examined the utility of using craniometrics to establish biodistance from skulls recovered in land traditionally occupied by the Northern Iroquoians. Biodistance refers to the measurement and interpretation of relatedness between populations using skeletal traits, such as those found on the skull. This is not an isolated study, with several others investigating population affiliation in Ontario using craniometric measurements (e.g., Pfeiffer 1979; Schneider and Sciulli 1982; Dupras and Pratte 1998). Alternatively, Hart and Englebrecht (2011) and Hart (2012) investigated mobility and the extent of interaction between Northern Iroquoian populations using variation in pottery manufacture. They focused on the influence that distance and movement between different traditional ethnic territories had on similarities in material culture.

Furthermore, the question of post-marital residence patterns has been raised with conflicting data on the type of patterns practiced in southern Ontario. Consideration of both archaeological (e.g., ceramic manufacture) and osteological evidence (e.g., craniometrics) has not been able to provide a conclusive answer. It is hoped that future research, making use of different methods such as strontium isotope analysis, or a combination of methods, can clarify this topic and resolve the longstanding debate as to the type of post-marital residence patterns that the Northern Iroquoians practiced.

Finally, the origins of the Northern Iroquoians as a population is a longstanding research area, influencing the theoretical paradigms used to interpret data since the 1900’s (see Chapter Four). The question of how one population, the Northern Iroquoians, came to speak such a unique language has been the focus of various studies (e.g., MacNeish 1952; Wright 1966; Ramsden 1977). Originally, a migration hypothesis was blindly accepted before an *in situ* development was formally proposed in 1952 (MacNeish 1952). However, in 1995, Snow identified several anomalies in the argument for an *in situ* development and once again suggested that the Northern Iroquoians migrated into the area based on subsistence, linguistic, ceramic and post-marital residence pattern evidence. This spurred debate as to the plausibility of the migration hypothesis (e.g., Crawford and Smith 1996; Snow 1996; Ferris 1999; Hart 2001; Ramsden 2006). Current research has yet to come to a conclusive answer regarding the origins of the Northern Iroquoians (e.g., Williamson 2012; Curtis 2014).

5.4 Summary

Overall, the Huron-Wendat and Neutral were indigenous confederacies that were part of a vibrant social landscape observed by European explorers and missionaries at the beginning of the 17th century. During this time, warfare and trade were common, with highly mobile populations who left a rich archaeological record. Topics such as coalescence, fission, trade, post-marital residence populations, population origins and the social and economic relationships that existed both between and within different groups have dominated research in this area. Strontium isotope analysis has the ability to contribute to the research that exists on the Huron-Wendat and Neutral, addressing these topics.

Chapter Six: Samples and Methods

This chapter presents an overview of the methods and samples that were used to obtain bioavailable strontium values from white-tailed deer teeth. An overview of the archaeological sites that provided samples is provided first in order to ground the research in the archaeological record. Further information on these sites can be found in Appendix B. A brief overview of the sampling protocol is then presented before a description of the physical sampling procedure is provided. This is followed by an outline of the chemical preparation of the samples and mass spectrometry.

6.1 Sample contexts

Samples from 31 archaeological sites were obtained to characterize the range of variation in bioavailable strontium isotopes in southern Ontario. Information such as the geographic location, a description of the physical environment (including any bedrock, sediment and elevation information), and the cultural context (e.g., occupation date) can be found in Figure 6.1 and Table 6.1. The occupation dates for these sites have been established by previously published studies. Additional information (e.g., settlement patterns, site use, artifact assemblages and faunal collections) for these sites can be found in Appendix B. Unfortunately, due to the nature of the collections from which the samples originate, the available information varies for each site.

These sites have been excavated by a number of people with different goals. Some have been salvage excavations, others have been excavated for academic purposes, and yet others have been looted. Furthermore, the storage of these collections has changed geographic locations with parts of the collection available at different universities, others in provincial repositories and yet other artifacts in the hands of private collectors. This affects the provenience of the artifacts that are available, as with each move from location to location, the chances of losing an artifact or its provenience increase. Furthermore, the catalogues for sites are often incomplete, with artifacts stored in bags with mixed contents. Although researchers are working to rectify this, at the time this project was completed, cataloguing was ongoing. Finally, several Borden numbers are associated with different site names complicating site proveniences. These factors affect the amount and type of information that is available for each of the sites and their associated collections.

The Ontario Ministry of Culture, Sports and Tourism was contacted for information on the sites used for this research and although the specific information available for each site varies, the locations, and therefore the geology they are located on, have been confirmed. Figure 6.1 shows the location of these sites graphically while Table 6.1 provides a summary of the sites used in this research, their temporal occupation, the type of site, the geology, sediment and elevation (meters above sea level or masl) of their location, as well as the geological formation in their general area.

6.2 Cervidae sampling protocol

Cervidae is a family of ungulates that includes white-tailed deer (see Chapter Two for further description of white-tailed deer). Deer teeth were sampled in order to maintain comparability between previous studies that have been conducted using strontium in this region (Williamson *n.d.*).

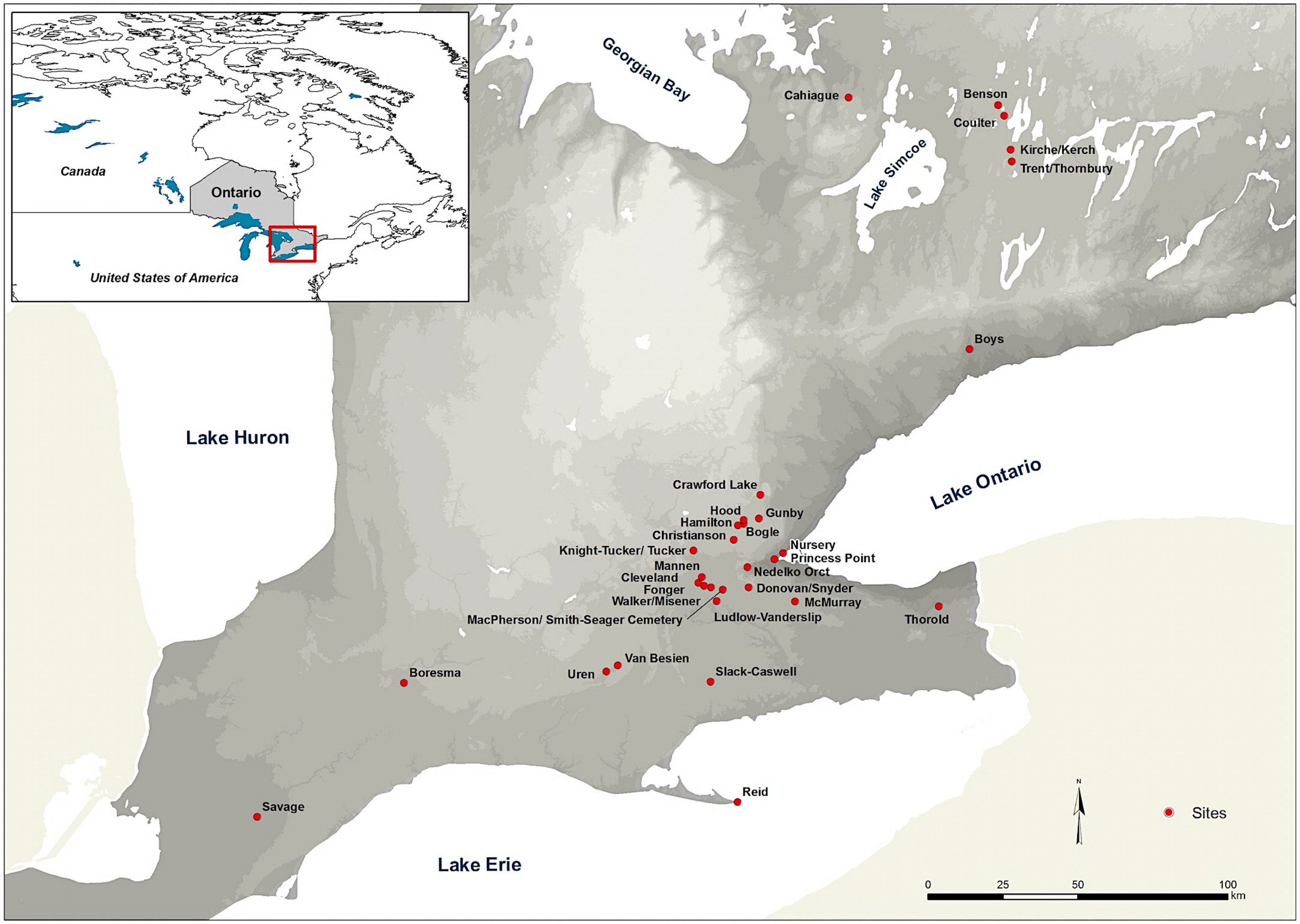

Figure 6.1 Location of those sites that provided faunal remains for this research. The map was created using ARC GIS and coordinates provided by the Ontario Ministry of Culture, Sports and Tourism.

Table 6.1: Temporal occupation, geology, sediment, elevation and geological formations of the archaeological sites providing faunal remains for this research. Those sites with multiple names indicate that both of these names are associated with the same Borden number.

Site	Borden Number	Occupation Date	Site Type	Geological Time Period	Geology	Sediment	Elevation (masl)	Geological Formation
Benson	BdGr-1	A.D. 1550-1580	Village	Middle Ordovician	Limestone	Sand	260	Simcoe Group
Bogle II	AiHa-11	A.D. 1640-1651	Hamlet	Middle/Lower Silurian	Sandstone	Gravel	265	Clinton/ Cataract Groups
Boresma	AfHa-121	A.D. 75-605	Basecamp	Middle Devonian	Limestone	Sand/ silt	210	Delaware Formation
Boys	AlGs-10	A.D. 975	Village	Upper Ordovician	Shale	Sand/ loam	131	Billings Formation
Cahiague	BdGv-1	A.D.1620-1630	Village	Middle Ordovician	Limestone	Sand	282	Simcoe Group
Christianson	AiHa-2	A.D. 1615-1630	Village	Middle/Lower Silurian	Sandstone	Diamicton	265	Guelph/ Lockport/ Amabel Formations
Cleveland	AhHb-7	A.D.1450-1630	Village	Middle/Lower Silurian	Sandstone	Sand	219	Clinton/ Cataract Groups
Coulter	BdGr-10	A.D. 1550	Village	Middle Ordovician	Limestone	Glacial drift/ gravel	279	Simcoe Group
Crawford Lake	AiGx-6	A.D. 1350-1400	Village	Middle/Lower Silurian	Sandstone	Diamicton	305	Clinton/ Cataract Groups
Donovan/Snyder	AhHa-3	A.D. 1580-1600	Village	Middle/Lower Silurian	Sandstone	Sand/gravel	235	Clinton/ Cataract Groups
Fonger	AhHb-8	A.D. 1580-1600	Hamlet/ Village	Middle/Lower Silurian	Sandstone	Sand/gravel	207	Clinton/ Cataract Groups
Gunby	AiGx-5	A.D. 1300-1320	Village	Middle/Lower Silurian	Sandstone	Sand	259	Clinton/ Cataract Groups
Hamilton	AiHa-5	A.D. 1638-1650	Village	Middle/Lower Silurian	Sandstone	Diamicton	268	Clinton/ Cataract Groups
Hood	AiHa-7	A.D. 1630-1641	Village	Middle/Lower Silurian	Sandstone	Gravel	274	Clinton/ Cataract Groups
Kirche/Kerch	BcGr-8	A.D. 1495-1550	Village	Middle Ordovician	Limestone	Diamicton	282	Simcoe Group
Knight-Tucker/ Tucker	AhHb-1	A.D. 1520-1540	Village	Middle/Lower Silurian	Sandstone	Clay	238	Clinton/ Cataract Groups

Table 6.1 continued.

Site	Borden Number	Occupation Date	Site Type	Geological Time Period	Geology	Sediment	Elevation (masl)	Geological Formation
Ludlow Vanderlip	AgHa-8	N.A.	Hamlet	Upper Silurian	Sandstone	Sand	210	Clinton/ Cataract Groups
McPherson/Smith Seager Cemetery	AhHa-6	A.D. 1530-1580	Hamlet/ Village	Middle/Lower Silurian	Sandstone	Clay	223	Clinton/ Cataract Groups
Mannen	AhHb-6	A.D. 1585-1600	Village	Middle/Lower Silurian	Sandstone	Sand	235	Clinton/ Cataract Groups
McMurray	AgGw-1	A.D.1600-1620	Village	Middle/Lower Silurian	Sandstone	Silt	209	Clinton/ Cataract Groups
Nedelko-Orct	AhHa-20	Woodland	Village	Upper Ordovician	Shale	Diamicton	235	Clinton/ Cataract Groups
Nursery	AhGx-8	A.D. 500-1000	Basecamp/ hamlet/ village	Upper Ordovician	Shale	Sand	100	Queenston Formation
Princess Point	AhGx-1	A.D. 500-1000	Seasonal camp	Upper Ordovician	Shale	Sand	73	Queenston Formation
Reid	AdHc-5	A.D. 1300	Village	Middle Devonian	Limestone	Sand	176	Delaware Formation
Savage	AdHm-29	A.D. 1350	N.A.	Upper Devonian	Shale	Sand	189	Bois Blanc Formation
Slack-Caswell	AfHa-1	A.D. 1380	Hamlet	Middle Devonian	Limestone	Clay/ loam	216	Bois Blanc Formation
Thorold	AgGt-1	A.D. 1615-1630	Village	Middle/Lower Silurian	Sandstone	Clay	172	Guelph/ Lockport / Amabel Formations
Trent/Thornbury	BcGr-2	A.D. 1550	N.A.	Middle Ordovician	Limestone	Diamicton	280	Simcoe Group
Uren	AfHd-3	A.D. 1250	Village	Middle Devonian	Limestone	Sand	245	Bois Blanc Formation
Van Besien	AfHd-2	A.D. 900-940	Village	Middle Devonian	Limestone dolomite	Silt	247	Salina Formation
Walker/Misener	AhHa-9	A.D. 1620-1645	Village	Middle/Lower Silurian	Sandstone	Sand	220	Clinton/ Cataract Groups

The amount of variation in a single deer tooth has not yet been published and so multiple samples were taken from each loph on a tooth, starting at the apex of the loph near the occlusal surface and serially sampling to the CEJ (see Figure 6.2). Well-preserved teeth were selected for serially sampling. It was established experimentally in this study that at least five milligrams of enamel is necessary to provide enough strontium for analyses. A minimum of five milligrams (mg) of enamel was removed for each sample, ranging in width from one to four millimetres (mm), depending on the thickness of the enamel (deer teeth have thinner enamel near the CEJ). Samples were also taken from the buccal and lingual sections of a single loph (see Figure 6.3). Once the extent of variation had been established, the exterior section of the distal lingual loph was preferentially sampled as it exhibited the best preservation in the most teeth.

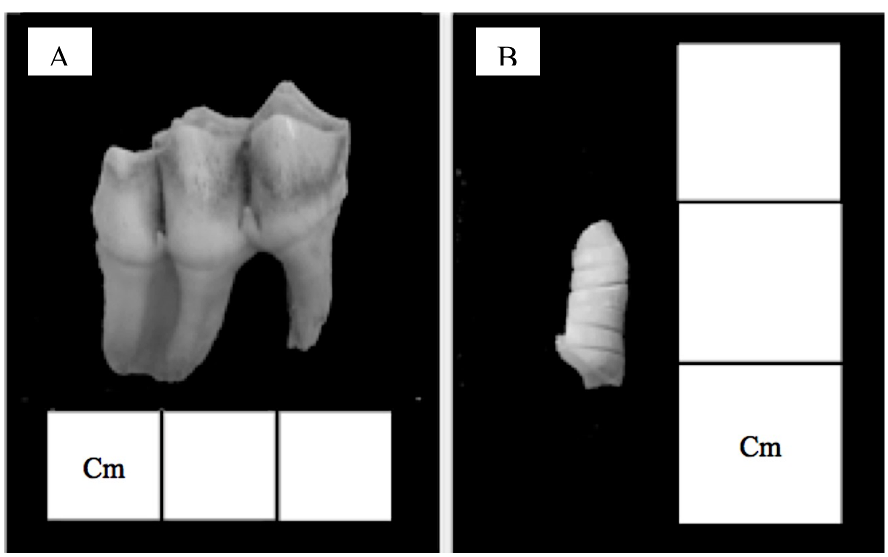

Figure 6.2 A: Lingual view of a third mandibular molar (MCHAM6) from a white-tailed deer. B: Example of a serially sectioned buccal loph. This loph has been divided into seven samples with the top scored by a tungsten carbide drill bit in a Gorbet U.S.A. Micromotor 110/220V high precision drill.

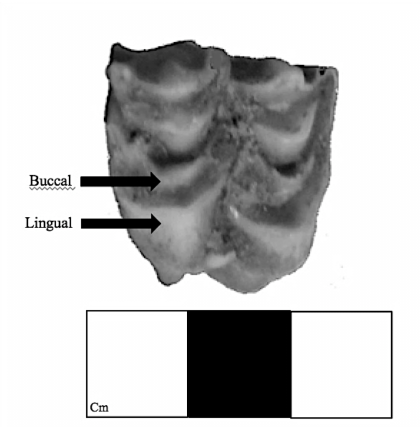

Figure 6.3 Occlusal view of a first maxillary molar (MCHAM3) illustrating the double layer of enamel on a single loph (the buccal and lingual sections on the lingual mesial loph).

6.3 Sample preparation

All samples were prepared in the Memorial Applied Archaeological Sciences Laboratory (MAAS) at the Memorial University of Newfoundland. Each tooth was photographed with information such as crown height and general state of preservation recorded prior to sampling. Measurements were taken using a Mastercraft © electronic caliper with digital display (accuracy= +/- 0.2mm, precision= 0.01). All measurements represent the maximum length, taken from the apex of the loph near the occlusal surface to the CEJ for each loph. The loph of the tooth that was sampled varied from tooth to tooth, depending on preservation and availability of enamel. However, an effort was made to consistently sample the same tooth loph whenever possible to minimize variation.

Teeth recovered from middens were chosen preferentially over those in other cultural contexts whenever possible. This was done as a precaution to help ensure that the strontium values obtained were local values rather than those that would reflect human movement or modern values that could be influenced by anthropogenic sources of strontium. Similarly, no culturally modified teeth were used as they could have been imported. However, any abnormal strontium values were considered to be unreliable for map construction and excluded from construction of the strontium baseline map. Strontium values were considered to be abnormal if the concentrations were below zero (i.e., ^{88}Sr voltage =0) or outside of the natural range in ^{87}Sr/^{86}Sr values. This could have resulted from small sample size (i.e., less than five milligrams of sample) or analytical error.

Before sampling, teeth were brushed clean in order to remove any remaining soil from excavation. The surface of each tooth was then cleaned mechanically using a tungsten carbide drill bit in a Gorbet U.S.A. Micromotor 110/220V high precision drill. According to Schoeninger and colleagues (2003), removing approximately 0.5mm of surface tooth enamel removes any potential surface contamination. Between five and twenty milligrams of core enamel was taken from the tooth with any dentine adhering to the sample removed using the tungsten carbide drill bit. The core enamel was ultrasonicated in deionized water (~18.3MΩ) for five minutes before one millilitre (mL) of acetone was added; the sample was agitated and the acetone immediately removed.

As a result of the unknown variation within a single tooth, serial samples were taken from a single loph in addition to bulk samples when appropriate. Serial sampling was conducted in a similar fashion to bulk enamel sampling as described above; however, smaller samples of approximately 1-2mm of the length of the tooth are taken after scoring the top of the enamel with the high precision drill with a tungsten carbide cut-off wheel and snapped off using a small metal spatula (see Figure 6.2). This minimizes the amount of enamel lost in between samples and improves enamel collection for analyses; however, it can result in the enamel breaking into small pieces. It should be noted that these samples were taken as enamel chunks and not as powder. Samples were also taken from different lophs of the same tooth (e.g., from the lingual left loph, lingual right loph, buccal left loph, and buccal right loph) in order to establish the amount of variation between lophs as well as from lingual and buccal sections on the same loph. Finally, multiple teeth from the same individual were sampled to investigate differences between teeth and the possible influence of seasonality.

Samples were allowed to dry in a clean lab fume hood with a HEPA filter for a minimum of 24 hours. Once dry, the samples were weighed into clean, labeled 3 mL Savillex® vials (perfluoroalkoxy vials). Vials were cleaned via four washes prior to use, each lasting 24 hours: the first in deionized water (DI H_20, ~17 MΩ), the second in 6N HNO_3, the third in 8N HCl and the fourth and final wash in DI H_2O (~17 MΩ). Vials were left for 24 hours in each bath on a hot plate set to 100.0°C. One mL of distilled 8M nitric acid (HNO_3) was added to each sample and vial following the methodology based on that described in Grimes and colleagues (2014), which is a modified version of Deniel and Pin (2001). The vials were placed on a hotplate set at 100.0°C and left for approximately 30 minutes or until the sample of tooth enamel was completely dissolved. Once dissolved, the samples were removed from the heat and loaded into pre-conditioned columns (one mL pipette tips containing a medium porosity [70 µm] polyethylene frit) with Eichrom® Sr-Spec resin at the base of the column on the frit following Charlier and colleagues (2006). Prior to use, resin was cleaned using DI H_2O (~17 MΩ), followed by soaking in 8M HNO_3 and then 6M HCl, with the removal of any stray floating resin following the procedure outlined by DeMunyk and colleagues (2009). Columns were prepared using rinses of DI H_2O (~17 MΩ, 2mL), 6M HCl (1mL), and 8M HNO_3 (1mL). This was followed by 2mL of 6M HCl, 3mL of deionized water (~17 MΩ) and 3mL of 8M HNO_3 with the resin added before samples were loaded into the columns. Samples were loaded twice to improve strontium collection. After loading the column, the sample was washed three times with 8M HNO_3, and strontium was eluted from the Sr-spec resin using 2mL of DI H_2O (~17 MΩ). Samples were then acidified to 0.3M HNO_3 with the addition of 0.75 µL of 8M HNO_3 and run using a Thermo Fisher Scientific Neptune multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) at the CREAIT Micro-Analysis Facility under the supervision of Dr. Rebecca Lam. Data were collected using one block of 50 cycles with an integration time of two seconds.

Fifty samples in 0.3M HNO_3 were sent to the Max Planck Institute for Evolutionary Anthropology (MPI-EVA), Leipzig, Germany, in July of 2014 for analysis after being prepared at MAAS. These were analyzed in a similar fashion to that described above also on a Thermo Fisher Scientific Neptune MC-ICP-MS at the MPI-EVI Archaeological Science Research Group. These samples are bolded in Appendix E.

6.4 Mass spectrometry

During this process, samples are drawn into a sample inlet of the mass spectrometer, a Thermo Fisher Neptune MC-ICP-MS, using an automated sampler and are vaporized. An inert gas, argon, is added and the sample is conveyed into a plasma ionization chamber where it is bombarded with electrons resulting in positively charged ions. These cations exit the ionization chamber, accelerating through charged parallel plates, and are collimated into ion beams with similar kinetic energies. These ion beams pass through a curve where they are subjected to a magnetic field. Depending on the mass of the ions, they are deflected onto metal plate detectors. The heaviest ions will be deflected the least. As the ions move through the magnetic field, they converge, continuing through to the ion collector. These are then measured using Faraday detectors as an electric current (see Sharp 2007:16-19).

All samples are measured against the international strontium carbonate standard, NIST SRM-987 and corrected to the published value of 0.71024, with corrections made for krypton (Kr) and rubidium (Rb) interferences. Mass bias was corrected for using $^{88}Sr/^{86}Sr$= 8.375209. The corrected $^{87}Sr/^{86}Sr$ values obtained from the standards can be found in Table 6.2.

Strontium concentrations were calculated using ^{88}Sr signal intensities (voltage, V) of stoichiometrically known concentrations of SRM-987 (e.g., 101ppb, 404ppb and 606ppb), following the methodology outlined in Copeland and colleagues (2008). These measurements were taken throughout the analysis, as well as at the beginning and end of each session. A regression equation was created using ^{88}Sr (V) as a function of strontium concentration (ppb) allowing for strontium concentration to be calculated. With consideration of the dilution factor and the starting mass of the sample (weighed after being dried in the clean lab fume hood with a HEPA filter before 1mL of distilled 8M HNO_3 was added), strontium concentrations were converted from ppb into ppm levels. Copeland and colleagues (2008:3191) found that this method has an accuracy of 90% (+/-

Table 6.2 Mean MAF-IIC standard values obtained at the CREAIT Micro-Analysis Facility (MUN) and Max Planck Institute for Evolutionary Anthropology (MPI-EVA) Archaeological Science Research Group and difference to the accepted value for international strontium carbonate standard NIST SRM987.

Date	Laboratory	$^{87}Sr/^{86}Sr$ value	Difference to accepted value	n
July 22, 2014	MAF-IIC	0.71026	-0.00003	4
July 23, 2014	MAF-IIC	0.71027	-0.00003	8
July 24, 2014	MAF-IIC	0.71028	-0.00003	7
July 24, 2014	MPI-EVA	0.71030	-0.00006	8
July 25, 2014	MPI-EVA	0.71030	-0.00006	8
July 26, 2014	MPI-EVA	0.71029	-0.00005	8
April 1, 2015	MAF-IIC	0.71026	-0.00003	12
April 2, 2015	MAF-IIC	0.71027	-0.00003	13
July 27, 2015	MAF-IIC	0.71027	-0.00003	10
July 28, 2015	MAF-IIC	0.71027	-0.00003	10
July 29, 2015	MAF-IIC	0.71027	-0.00003	13
December 17, 2015	MAF-IIC	0.71027	-0.00003	7

31ppm, 1σ, n=14) when compared with the isotope dilution thermal ionization mass spectrometry (TIMS) concentration data from an in-house tooth enamel standard. The accuracy of samples is checked using blanks and standards prepared alongside the enamel samples.

Samples were diluted if necessary to achieve a ^{88}Sr value between 5V and 30V. Dilutions were conducted at the CREAIT Micro-Analysis Facility using a 1:8 dilution factor (i.e., 250µL of sample in 2mL of 0.3M HNO_3).

6.5 Statistical analyses

All data were tested for statistical significance using student's t-tests run in Microsoft Excel. Normality of the data set was confirmed using Shapiro-Wilks test for normality. Data were tested at a 95% confidence level (p=0.05).

6.6 Summary

Overall, samples of enamel from white-tailed deer recovered at 31 Northern Iroquoian archaeological sites situated in southern Ontario were obtained for strontium isotope analysis. Multiple samples of enamel were taken from the same tooth to establish the amount of variation within a single tooth Samples were prepared following the method proposed by Grimes and colleagues (2014) and run using MC-ICP-MS. Archaeological sites are located in traditional Huron-Wendat and Neutral territory and represent hamlets and villages (both palisaded and unpalisaded) from A.D. 75-1640 (see Appendix B). They are situated on various types of bedrock and sediment at different elevations. As such, these sites represent an adequate avenue within which to explore the influence of environmental and cultural factors on strontium isotope analysis.

Chapter Seven: Results

This chapter details the results from the strontium isotope analyses conducted on the archaeological white-tailed deer teeth recovered in southern Ontario. Data on the range of variation within a single deer tooth is presented first, followed by variation within a single individual (i.e., between teeth from the same individual). Strontium data are sorted by geology, sediment and elevation before ranges and mean $^{87}Sr/^{86}Sr$ values for each archaeological site are provided. All data presented are corrected for analytical error and error bars on charts represent the standard deviation. Background information on each sample can be found in Appendices C and D while uncorrected data can be found in Appendix E.

7.1 Variation within a single deer tooth

Overall, there is minimal variation in the third decimal place of $^{87}Sr/^{86}Sr$ values within a single deer tooth. No statistically significant differences between lophs are present, nor does it matter where a sample is obtained on a loph (i.e., the apex of the loph versus near the CEJ) for the majority of white-tailed deer teeth. Similarly, the majority of teeth do not exhibit statistically significant differences between lingual and buccal sections of enamel on the same loph.

7.1.1 Interloph variation

Ten teeth were sampled to establish whether different lophs exhibited different $^{87}Sr/^{86}Sr$ values. Of these, two teeth (MCMCP1 and MCVBE4), both mandibular molars, had data sets that were robust enough with a normal distribution for statistical analyses. The $^{87}Sr/^{86}Sr$ values for each tooth can be found in Table 7.1 with Tables 7.2 and 7.3

Table 7.1 Mean bioavailable $^{87}Sr/^{86}Sr$ values obtained from different lophs of the same white-tailed deer tooth.

Tooth	Loph	n	$^{87}Sr/^{86}Sr$	SD
MCCHR36	Buccal mesial	1	0.70998	
	Buccal distal	1	0.70944	
	Lingual distal	3	0.71009	0.00002
	Lingual mesial	1	0.71002	
MCREI10	Lingual mesial	3	0.71092	0.00008
	Lingual distal	2	0.71086	0.00019
MCTHO1	Lingual distal	2	0.71210	0.00002
	Buccal distal	3	0.71206	0.00003
MCBEN13	Lingual distal	2	0.70892	0.00001
	Lingual mesial	1	0.70894	
MCKIR7	Buccal distal	3	0.70888	0.00001
	Buccal middle	3	0.70880	0.00002
	Buccal mesial	2	0.70872	0.00001
	Lingual distal	3	0.70892	0.00014
	Lingual middle	3	0.70879	0.00001
	Lingual mesial	3	0.70871	0.00012
MCGUN10	Lingual mesial	3	0.70972	0.00006
	Buccal distal	2	0.70971	0.00004
MCVBE4	Lingual distal	6	0.70973	0.00005
	Buccal mesial	4	0.70970	0.00009
	Lingual mesial	2	0.70984	0.00002
	Lingual middle	7	0.70973	0.00005
	Buccal middle	7	0.70974	0.00005
	Buccal distal	8	0.70965	0.00013
MCVBE5	Lingual distal	5	0.70969	0.00035
	Lingual middle	3	0.71021	0.00014
MCMAN1	Lingual distal	5	0.71024	0.00004
	Buccal distal	4	0.71027	0.00002
MCMCP1	Lingual distal	8	0.71026	0.00015
	Lingual middle	3	0.71026	0.00013
	Lingual mesial	7	0.71031	0.00008
	Buccal mesial	5	0.71036	0.00005
	Buccal distal	5	0.71022	0.00015
	Buccal middle	4	0.71031	0.00007

Table 7.2 Summary of t-test results comparing bioavailable $^{87}Sr/^{86}Sr$ values obtained from different lophs of the same white-tailed deer tooth (MCMCP1). No statistically significant differences were obtained.

Lophs compared	t-statistic	p-value
Lingual distal vs. lingual middle	0.0416	0.9677
Lingual distal vs. lingual mesial	0.7477	0.4680
Lingual distal vs. buccal middle	0.5880	0.5696
Lingual distal vs. buccal mesial	0.4596	0.6548
Lingual distal vs. buccal distal	1.3481	0.2047
Lingual middle vs. lingual mesial	0.7239	0.4897
Lingual middle vs. buccal middle	0.6069	0.5704
Lingual middle vs. buccal mesial	0.3148	0.7636
Lingual middle vs. buccal distal	1.3951	0.2124
Lingual mesial vs. buccal middle	0.0067	0.9948
Lingual mesial vs. buccal mesial	1.2696	0.2330
Lingual mesial vs. buccal distal	1.1308	0.2845
Buccal distal vs. buccal middle	1.1537	0.2865
Buccal distal vs. buccal mesial	1.8236	0.1057
Buccal mesial vs. buccal middle	1.0176	0.3427

Table 7.3 Summary of t-test results comparing bioavailable $^{87}Sr/^{86}Sr$ values obtained from different lophs of the same white-tailed deer tooth (MCVBE4). No statistically significant differences were obtained.

Lophs compared	t-statistic	p-value
Lingual distal vs. lingual middle	0.8623	0.4136
Lingual distal vs. lingual mesial	0.8623	0.4136
Lingual distal vs. buccal middle	0.1484	0.8847
Lingual distal vs. buccal mesial	0.1323	0.8971
Lingual distal vs. buccal distal	0.5910	0.5708
Lingual middle vs. lingual mesial	0.9185	0.3751
Lingual middle vs. buccal middle	1.1809	0.2626
Lingual middle vs. buccal mesial	2.1148	0.0561
Lingual middle vs. buccal distal	0.9937	0.3588
Lingual mesial vs. buccal middle	0.0226	0.9823
Lingual mesial vs. buccal mesial	1.4472	0.1684
Lingual mesial vs. buccal distal	0.5212	0.6148
Buccal distal vs. buccal middle	0.7009	0.5011
Buccal distal vs. buccal mesial	0.6755	0.5147
Buccal mesial vs. buccal middle	1.5796	0.1382

providing the results of the statistical analyses conducted on MCMCP1 and MCVBE4. Neither tooth showed statistically significant differences (see Tables 7.2 and 7.3, Figures 7.1 and 7.2). The majority of the rest of the teeth support this conclusion; however, MCCHR36 exhibits $^{87}Sr/^{86}Sr$ values ranging from 0.70944 (buccal distal loph) to 0.71009 (lingual distal loph). Similarly, MCVBE5 has $^{87}Sr/^{86}Sr$ values ranging from 0.70969 to 0.71021 (lingual distal loph and lingual middle loph respectively). Therefore, despite the lack of statistical significance, a wider range of $^{87}Sr/^{86}Sr$ values exists in these two teeth.

7.1.2 Intraloph variation

Twenty-eight teeth were serially sampled to investigate whether there was variation within a single loph (see Table 7.4) with samples from lophs of the same tooth

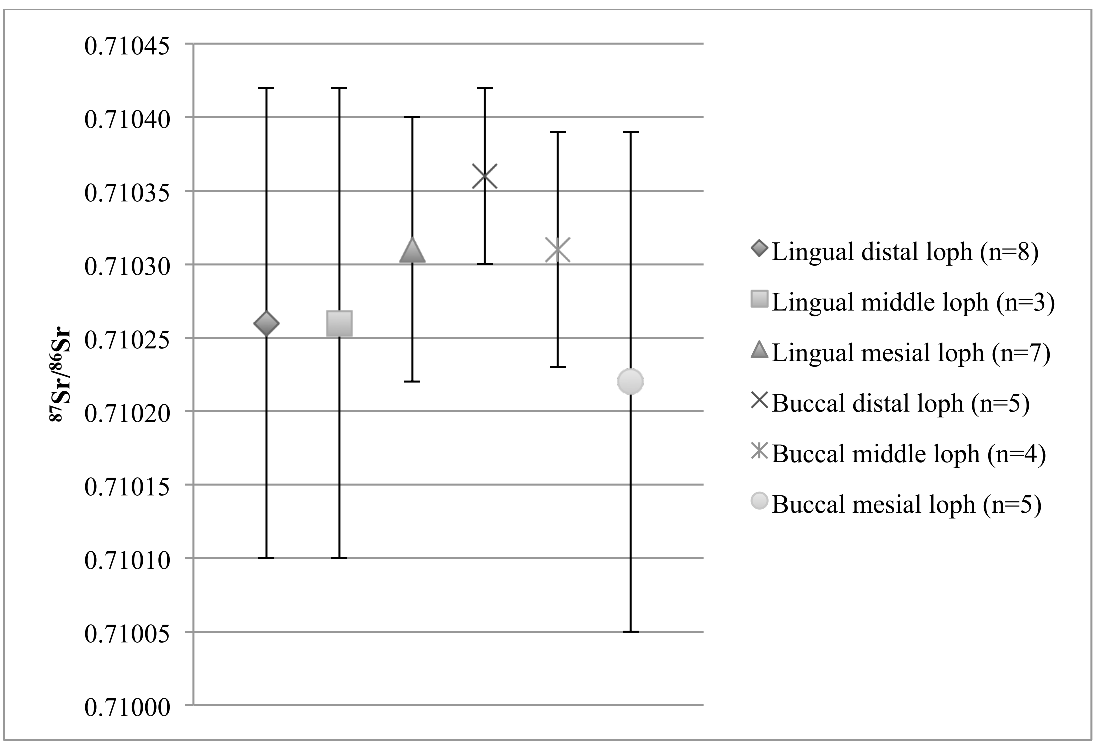

Figure 7.1 Variation in mean bioavailable $^{87}Sr/^{86}Sr$ values (+/- 1 S.D.) between lophs on the same white-tailed deer tooth (MCMCP1).

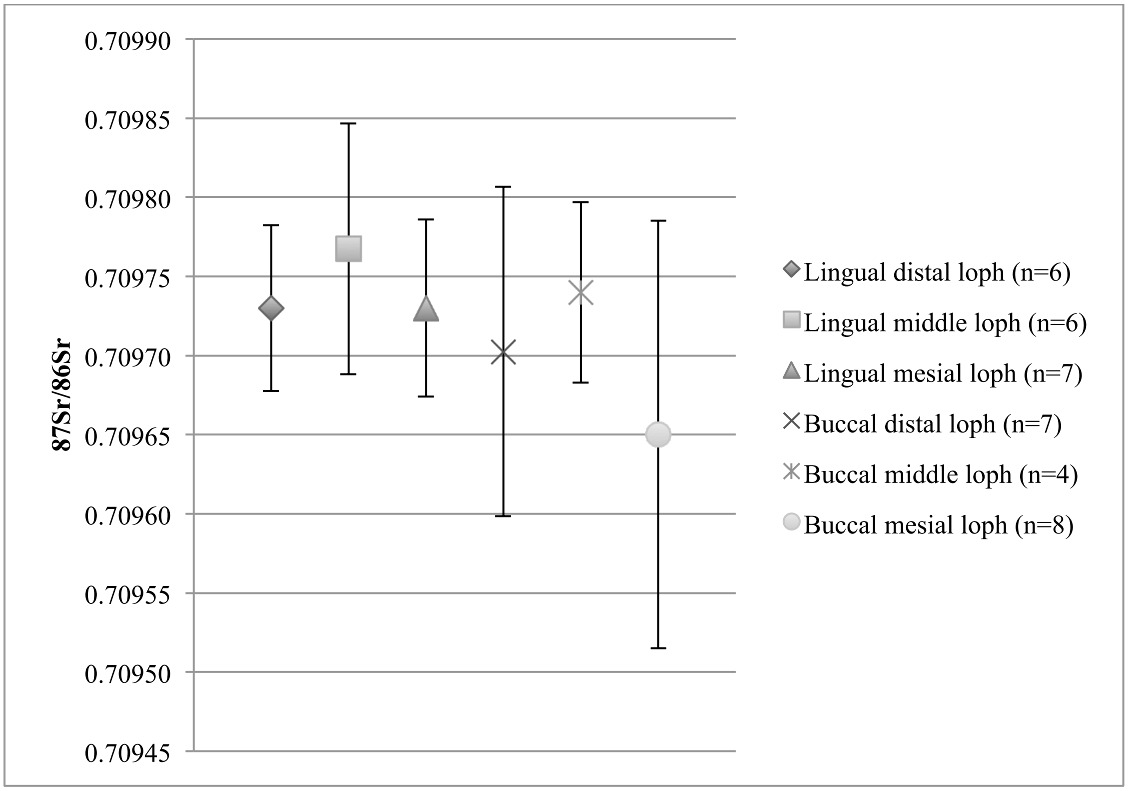

Figure 7.2 Variation in mean bioavailable $^{87}Sr/^{86}Sr$ values (+/- 1 S.D.) between lophs of the same white-tailed deer tooth (MCVBE4).

combined upon establishing that there were no statistically significant differences present between them so as to allow for statistical analyses. Of these 28 teeth, three had sample sets with normally distributed data (tested using Shapiro-Wilks) that were robust enough to undergo statistical analyses (MCKIR7, MCMCP1, MCVBE4). Two teeth, MCKIR7 and MCVBE4, did not exhibit any statistically significant variation (see Tables 7.5 and 7.6, Figures 7.3 and 7.4). The remaining tooth (MCMCP1), however, did exhibit differences in $^{87}Sr/^{86}Sr$ values that were statistically significant. Specifically, the bottom sixth of the loph provides a mean value ($^{87}Sr/^{86}Sr$=0.71015) that was significantly different from the rest of the tooth (see Table 7.7, Figure 7.5). This was also noted in two other teeth, MCVBE5 and MCCLV13, both of which exhibit differences between

Table 7.4 Mean bioavailable $^{87}Sr/^{86}Sr$ values for serially sampled white-tailed deer teeth. Blank cells indicate unavailable data. N refers to the number of lophs sampled. Teeth with a single loph sampled and therefore cannot have mean values are located at the bottom of the table.

Tooth		Top of the crown (1/7)	Next (2/7)	Next (3/7)	Middle (4/7)	Next (5/7)	Next (6/7)	Bottom (near CEJ) (7/7)	Whole tooth
MCMCP1	Mean	0.71031	0.71034	0.71039	0.71033	0.71038	0.71026	0.71015	0.71031
	SD	0.00008	0.00006	0.00003	0.00009	0.00004	0.00012	0.00014	0.00007
	n	6	3	2	6	3	3	6	29
MCKIR7	Mean	0.70879			0.70887			0.70879	0.70881
	SD	0.0001369			0.0001296			0.00005	0.00001
	n	6			5			6	17
MCVBE4	Mean	0.70969	0.70971	0.70968	0.70978	0.70972	0.70974	0.70965	0.70972
	SD	0.0001	0.000005	0.00009	0.00003	0.00004	0.0001	0.00013	0.00004
	n	4	3	4	5	5	5	5	31
MCMAN1	Mean	0.71026	0.71029		0.71027		0.7102	0.71026	0.71026
	SD	0.00001	0.00002				0.00004	0.00001	0.000003
	n	2	2		1		2	2	9
MCVBE5	Mean	0.71018	0.70965		0.7098		0.71019	0.70963	0.70989
	SD	0.00021			0.00038			0.00042	0.00025
	n	2	1		2		1	2	8
MCCLV11	Mean	0.7106	0.71072		0.71076			0.71067	0.71069
	SD	0.00009							
	n	2	1		1			1	5
MCREI10	Mean	0.71094			0.71091			0.71076	0.71087
	SD	0.0001			0.00008			0.00014	0.00008
	n	3			2			3	8

Table 7.4 continued

Tooth		Top of the crown (1/7)	Next (2/7)	Next (3/7)	Middle (4/7)	Next (5/7)	Next (6/7)	Bottom (near CEJ) (7/7)	Whole tooth
MCCHR36	Mean	0.70983			0.7101			0.71006	0.71000
	SD	0.00028						0.00004	0.00012
	n	3			1			2	6
MCTHO1	Mean	0.71205			0.71207			0.71206	0.71206
	SD	0.00003						0.00003	0.00001
	n	2			1			2	5
MCGUN10	Mean	0.70977			0.7097			0.70965	0.70971
	SD	0.00002			0.00003				0.00005
	n	2			2			1	5
MCCHR38	Mean	0.70971			0.70987			0.70981	0.70980
	SD	0.00011							0.00006
	n	2			1			1	4

Table 7.4 continued.

Tooth	Top of the crown (1/7)	Next (2/7)	Next (3/7)	Middle (4/7)	Next (5/7)	Next (6/7)	Bottom (near CEJ) (7/7)	Whole tooth mean	S.D.
MCTRE4	0.70882			0.70900			0.70869	0.70884	0.00013
MCREI4	0.70945	0.70942		0.70942		0.70942	0.70947	0.70944	0.00002
MCREI11	0.70977			0.70978			0.70977	0.70977	0.00000
MCCLV13	0.71134	0.71110		0.71090		0.71080	0.71054	0.71094	0.00027
MCBOR1	0.70924			0.70935			0.70929	0.70929	0.00004
MCURE1	0.70882			0.70899			0.70895	0.70892	0.00007
MCGUN1	0.70986	0.70950		0.70978	0.70992	0.70989	0.70984	0.70980	0.00014
MCLUD2	0.70911			0.70896		0.70896	0.70953	0.70914	0.00023
MCHAM7	0.71038	0.71043		0.71036		0.71044	0.71041	0.71040	0.00003
MCMCP2	0.71114	0.71112		0.71094		0.71111	0.71113	0.71109	0.00007
MCPRI2	0.71026	0.71003		0.70992		0.70997	0.71028	0.71009	0.00015
MCPRI3	0.71008			0.71001			0.71053	0.71021	0.00023
MCPRI1	0.71051			0.71059			0.71060	0.71057	0.00004
MCSAV1	0.70984	0.70975				0.71002	0.71002	0.70991	0.00012
MCHOO6	0.71053			0.71059			0.71072	0.71061	0.00008
MCBEN7	0.70919			0.70931			0.70953	0.70934	0.00014
MCHOO7B	0.70980			0.70969			0.70969	0.70973	0.00005

Table 7.5 Summary of t-test results comparing bioavailable $^{87}Sr/^{86}Sr$ values obtained from a single loph on MCKIR7. Each of the six lophs of the tooth was divided into three sections and subsequently compared. No statistically significant differences were obtained.

Sections compared	t-statistic	p-value
Top 1/3 vs. middle 2/3	1.0443	0.3236
Top 1/3 vs. bottom 2/3	0.0254	0.9802
Middle 2/3 vs. bottom 3/3	1.4665	0.1766

Table 7.6 Summary of t-test results comparing bioavailable $^{87}Sr/^{86}Sr$ values obtained from a single loph on MCVBE4. Each of the six lophs of the tooth was divided into seven sections and subsequently compared. No statistically significant differences were obtained.

Sections compared	t-statistic	p-value
Top vs. middle	1.7578	0.1222
Top (1/7) vs. next (2/7)	0.3043	0.7732
Top (1/7) vs. next (3/7)	0.0956	0.927
Top (1/7) vs. middle (4/7)	1.7578	0.1222
Top (1/7) vs. next (5/7)	0.6227	0.5532
Top (1/7) vs. next (6/7)	0.677	0.5201
Top (1/7) vs. bottom (7/7)	0.3939	0.7054
Next (2/7) vs. next (3/7)	0.4317	0.684
Next (2/7) vs. middle (4/7)	2.2805	0.0628
Next (2/7) vs. next (5/7)	0.3256	0.7558
Next (2/7) vs. next (6/7)	0.4038	0.7003
Next (2/7) vs. bottom (7/7)	0.6349	0.5489
Next (3/7) vs. middle (4/7)	2.034	0.0814
Next (3/7) vs. next (5/7)	0.8056	0.447
Next (3/7) vs. next (6/7)	0.8304	0.4482
Next (3/7) vs. bottom (7/7)	0.3176	0.76
Middle (4/7) vs. next (5/7)	2.4209	0.0418
Middle (4/7) vs. next (6/7)	0.8377	0.4265
Middle (4/7) vs. bottom (7/7)	1.9073	0.0929
Next (5/7) vs. next (6/7)	0.3052	0.768
Next (5/7) vs. bottom (7/7)	1.017	0.3389
Next (6/7) vs. bottom (7/7)	1.0524	0.3234

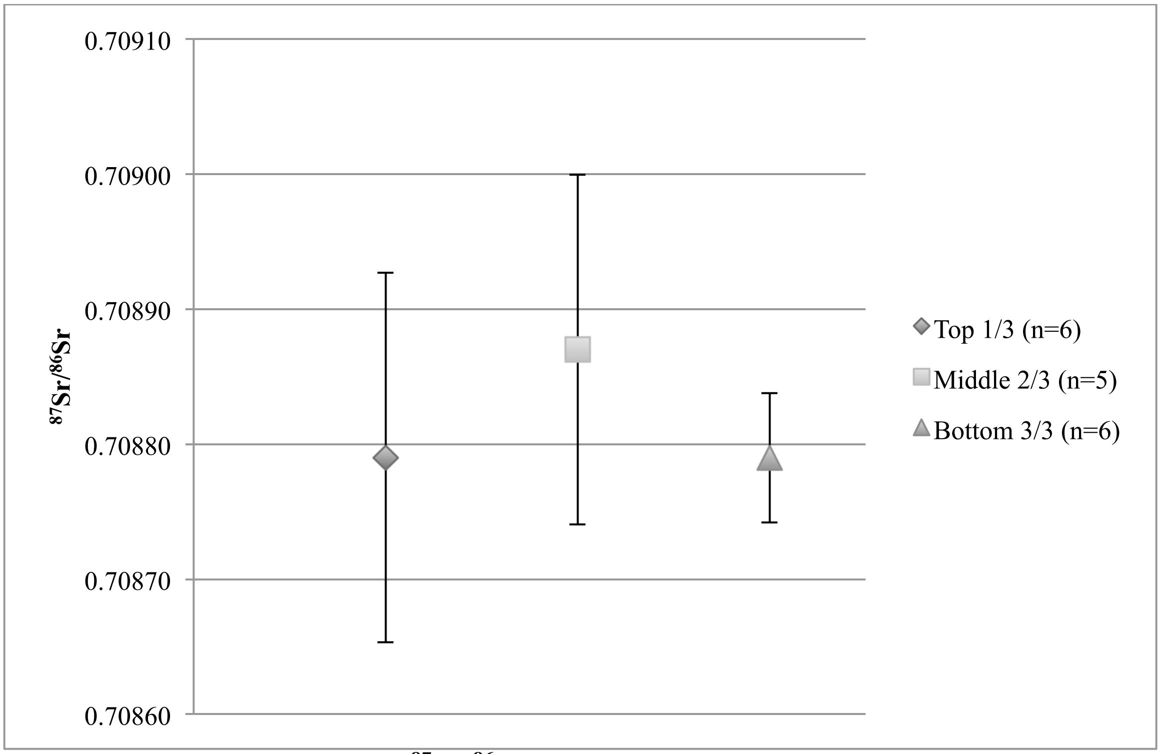

Figure 7.3 Mean bioavailable $^{87}Sr/^{86}Sr$ values (+/- 1 S.D.) obtained from serial sampling a single loph of a white-tailed deer tooth (MCKIR7).

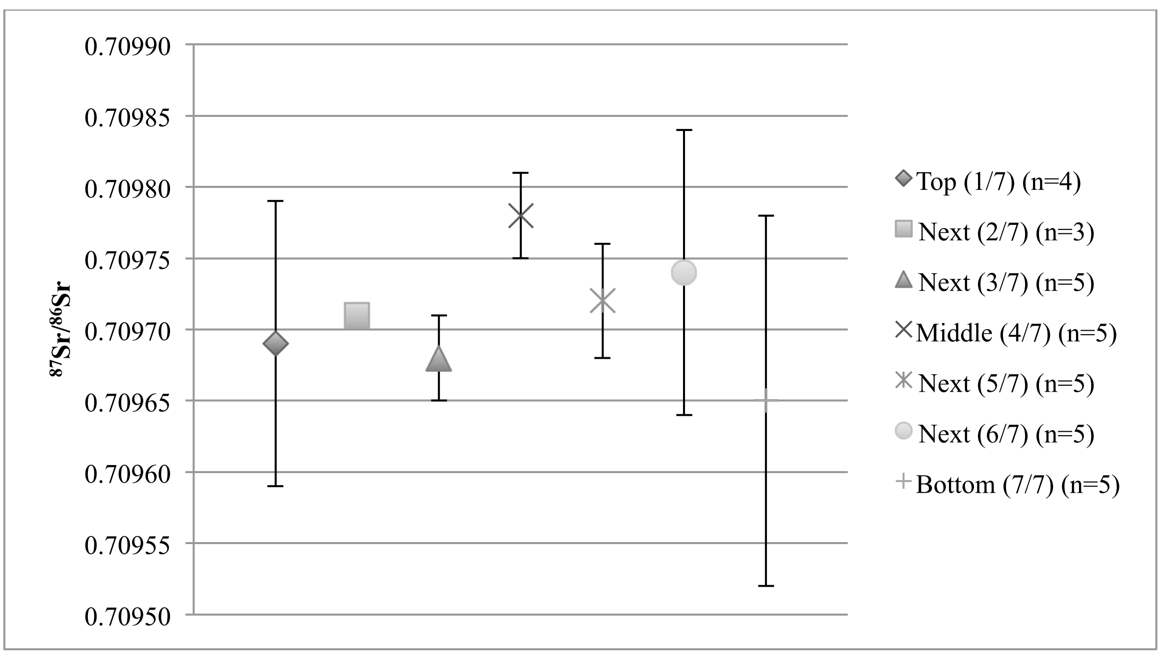

Figure 7.4 Mean bioavailable $^{87}Sr/^{86}Sr$ values (+/- 1 S.D.) obtained from serial sampling a single loph of a white-tailed deer tooth (MCVBE4).

Table 7.7 Summary of t-test results comparing within-loph variation of bioavailable $^{87}Sr/^{86}Sr$ values from MCMCP1 based on six lophs. Statistically significant differences are in bold.

Sections compared	t-statistic	p-value
Top (1/6) vs. next (2/6)	0.5846	0.5772
Top (1/6) vs. middle (3/6)	0.428	0.6777
Top (1/6) vs. middle (4/6)	1.4968	0.1781
Top (1/6) vs. next (5/6)	0.611	0.5605
Top (1/6) vs. bottom (6/6)	**2.3306**	**0.042**
Next (2/6) vs. middle (3/6)	0.1573	0.8795
Next (2/6) vs. middle (4/6)	0.8705	0.4331
Next (2/6) vs. next (5/6)	0.7959	0.4706
Next (2/6) vs. bottom (6/6)	2.0754	0.0766
Middle (3/6) vs. middle (4/6)	0.8865	0.4047
Middle (3/6) vs. next (5/6)	0.8248	0.4367
Middle (3/6) vs. bottom (6/6)	**2.513**	**0.0308**
Middle (4/6) vs. next (5/6)	1.3181	0.2579
Middle (4/6) vs. bottom (6/6)	**2.6213**	**0.0343**
Next (5/6) vs. bottom (6/6)	1.0783	0.3167

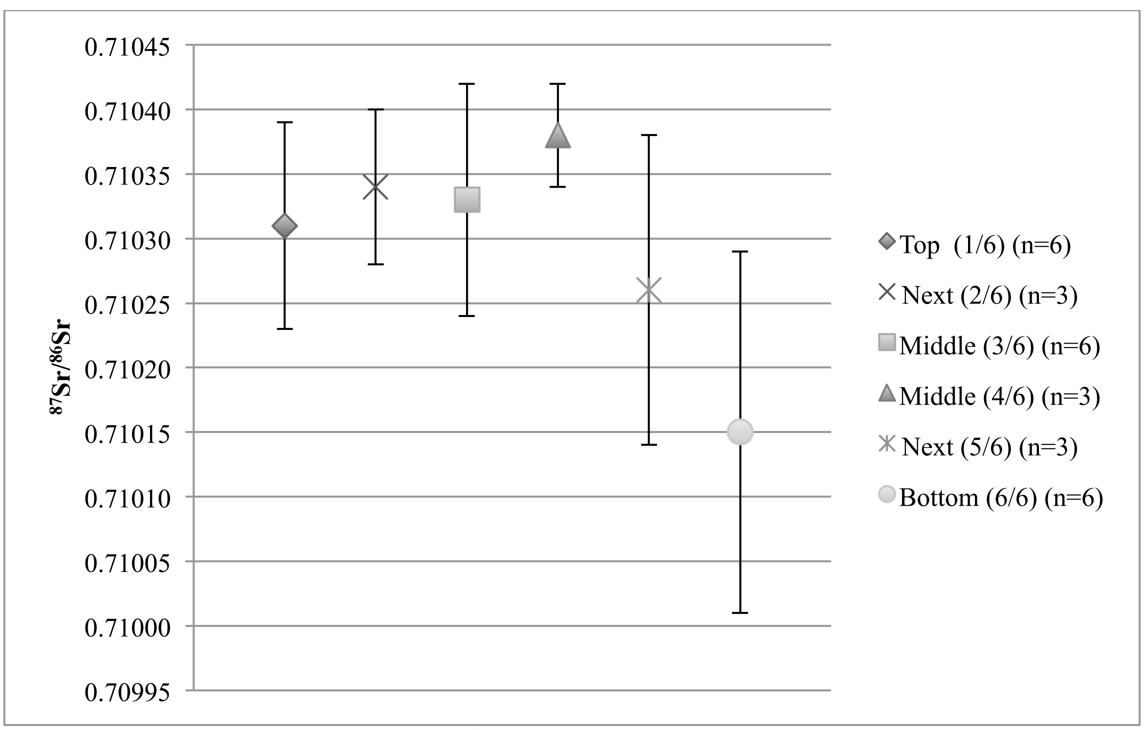

Figure 7.5 Mean bioavailable $^{87}Sr/^{86}Sr$ values (+/- 1 S.D.) obtained from serial sampling a single loph of a white-tailed deer tooth (MCMCP1).

different sections of the tooth (Table 7.4). The $^{87}Sr/^{86}Sr$ value obtained from enamel on the apex of the crown near the occlusal surface of MCVBE5, $^{87}Sr/^{86}Sr$ =0.71018, is higher than the $^{87}Sr/^{86}Sr$ value obtained from enamel near the CEJ ($^{87}Sr/^{86}Sr$=0.70963). MCCLV13 also exhibits a greater difference between the two sections of the tooth, with the apex of the crown exhibiting a $^{87}Sr/^{86}Sr$ value of 0.71134 and the CEJ of $^{87}Sr/^{86}Sr$=0.71054. The remaining teeth all exhibit similar $^{87}Sr/^{86}Sr$ values throughout the loph.

7.1.3 Variation between sections

Deer teeth have an infundibulum in the center of their molars, resulting in two layers of enamel on a single loph (lingual and buccal sections). Both the lingual and buccal sections of enamel on a single loph were sampled to determine whether there was a difference between them. Of the five teeth that had buccal and lingual sections of enamel sampled (MCCHR36, MCCHR38, MCREI10, MCTRE4 and MCMCP1), only a single tooth, MCMCP1, exhibits a statistically significant difference between lingual and buccal sections on the same loph (see Table 7.8). However, $^{87}Sr/^{86}Sr$ values from lingual and buccal sections on MCREI10 show a difference of 0.00128, which is conventionally an interpretable difference despite the lack of statistical significance (Montgomery 2002).

Table 7.8 Mean bioavailable $^{87}Sr/^{86}Sr$ values and associated p-values for lingual and buccal sections of enamel from the left lingual loph of white-tailed deer teeth. P-values for MCTRE4 are not possible as a minimum of 2 values per section is required.

Tooth	Mean ($^{87}Sr/^{86}Sr$)$_{lingual}$	Mean ($^{87}Sr/^{86}Sr$)$_{buccal}$	Difference	p-value
MCCHR36	0.70995	0.71066	0.00071	0.1019
MCCHR38	0.70983	0.70950	0.00033	0.2658
MCMCP1	**0.70970**	**0.71038**	**0.00068**	**0.0012**
MCREI10	0.71210	0.71082	0.00128	0.2982
MCTRE4	0.70884	0.70873	0.00011	NA

7.2 Variation between teeth from the same animal

Multiple teeth were sampled from the same individuals (12 teeth from five individuals) to establish the amount of variation within a single animal (see Table 7.9). Of these, three teeth from one animal have a sample set robust enough for statistical analyses, MCHOO7, which contains a mandibular M2, M1 and PM3 (see Figure 7.6). The p-values obtained from the t-tests conducted on the resulting data suggest that there are statistically significant differences between all of the teeth sampled (see Table 7.10). For the remaining teeth, two individuals exhibit differences that can be interpreted as meaningful, MCHAM3 and MCWAL2. MCHAM3 indicates that the second molar ($^{87}Sr/^{86}Sr$= 0.70941) is different from M1 ($^{87}Sr/^{86}Sr$=0.71002) and M3 ($^{87}Sr/^{86}Sr$=0.71000) while MCWAL2 suggests that the first molar is different from the third molar ($^{87}Sr/^{86}Sr$=0.71083 and $^{87}Sr/^{86}Sr$=0.71104, respectively).

Table 7.9 Bioavailable $^{87}Sr/^{86}Sr$ values from multiple white-tailed deer teeth from the same individuals.

Tooth	Type	n	$^{87}Sr/^{86}Sr$	SD
MCGUN9A	Maxillary right M1	1	0.70951	
MCGUN9C	Maxillary right M3	1	0.70962	
MCHAM3A	Maxillary right M1	1	0.71002	
MCHAM3B	Maxillary right M2	1	0.70941	
MCHAM3C	Maxillary right M3	1	0.71000	
MCHOO7A	Mandibular right M2	2	0.71072	0.00008
MCHOO7B	Mandibular right M1	3	0.70973	0.00004
MCHOO7C	Mandibular right PM3	2	0.71000	0.00006
MCWAL2A	Maxillary right M1	1	0.71083	
MCWAL2C	Maxillary right M3	1	0.71104	
MCWAL3A	Maxillary left M1	1	0.70913	
MCWAL3B	Maxillary left M3	1	0.70926	

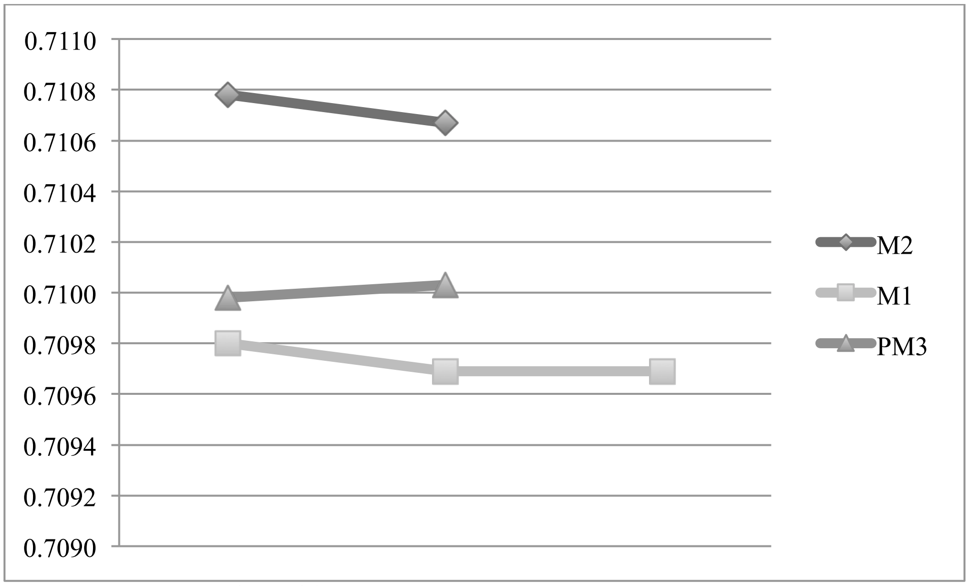

Figure 7.6 Bioavailable $^{87}Sr/^{86}Sr$ values from a right mandibular M2 (MCHOO7A), M1 (MCHOO7B), and PM3 (MCHOO7C) from a single white-tailed deer.

7.3 Strontium values and geology

The range of $^{87}Sr/^{86}Sr$ values and mean local bioavailable $^{87}Sr/^{86}Sr$ values obtained from white-tailed deer teeth for the different types of bedrock present in southern Ontario can be found in Table 7.11, Figure 7.7 and Figure 7.8. There is minimal variation with $^{87}Sr/^{86}Sr$ values ranging from 0.70852 (Middle Ordovician limestone) to 0.71212 (Middle and Lower Silurian sandstone). The mean $^{87}Sr/^{86}Sr$ values for the two types of limestone cluster together within 0.00065 of each other, with the standard deviations overlapping ($^{87}Sr/^{86}Sr_{\text{Middle Ordovician limestone}}$= 0.70900, S.D.= 0.00060

Table 7.10 Summary of t-test results comparing bioavailable $^{87}Sr/^{86}Sr$ values from different teeth of the same white-tailed deer recovered at the Hood site. Statistically significant differences are in bold.

Teeth compared	t-statistic	p-value
M2 vs. M1	**19.1713**	**0.0003**
M2 vs. PM3	**10.1823**	**0.0095**
M1 vs. PM3	**6.2124**	**0.0084**

Table 7.11 Mean bioavailable $^{87}Sr/^{86}Sr$ values from white-tailed deer teeth recovered at archaeological sites located on different types of bedrock present in southern Ontario.

Bedrock	Age	Sites (n)	Teeth (n)	Samples (n)	$^{87}Sr/^{86}Sr$	SD	Range
Limestone, dolostone, shale, arkose, sandstone	Middle Ordovician	6	16	42	0.70900	0.00060	0.70852-0.71153
Limestone, dolostone, shale	Middle Devonian	3	9	56	0.70965	0.00030	0.70881-0.71018
Sandstone, shale, dolostone, siltstone	Middle and Lower Silurian	16	60	166	0.71029	0.00067	0.70854-0.71212
Shale, limestone, dolostone, siltstone	Upper Ordovician	3	10	22	0.71006	0.00048	0.70884-0.71067
Shale	Upper Devonian	1	1	1	0.70991		

vs. $^{87}Sr/^{86}Sr_{\text{Middle Devonian limestone}}$= 070965, S.D.=0.00030). However, despite the similar means and overlapping ranges, there are statistically significant differences between the two different limestone categories (p-value=0.0001). Similarly, there are statistically significant differences between both limestone categories and the Middle and Lower Silurian sandstone mixture and Upper Ordovician shale mixture. There is no statistically significant difference between the Middle and Lower Silurian sandstone and the Upper Ordovician shale mixture (p-value=0.1170). The results from the statistical analyses can be found in Table 7.12. In other words, limestone mixtures and sandstone mixtures, and shale mixtures are isotopically distinct but sandstone and shales are not.

Individually, there is a wide range of values found within each bedrock category. For example, within the category of Middle Ordovician limestone, dolostone, shale, arkose and sandstone, $^{87}Sr/^{86}Sr$ values range from 0.70852 to 0.71153, providing the

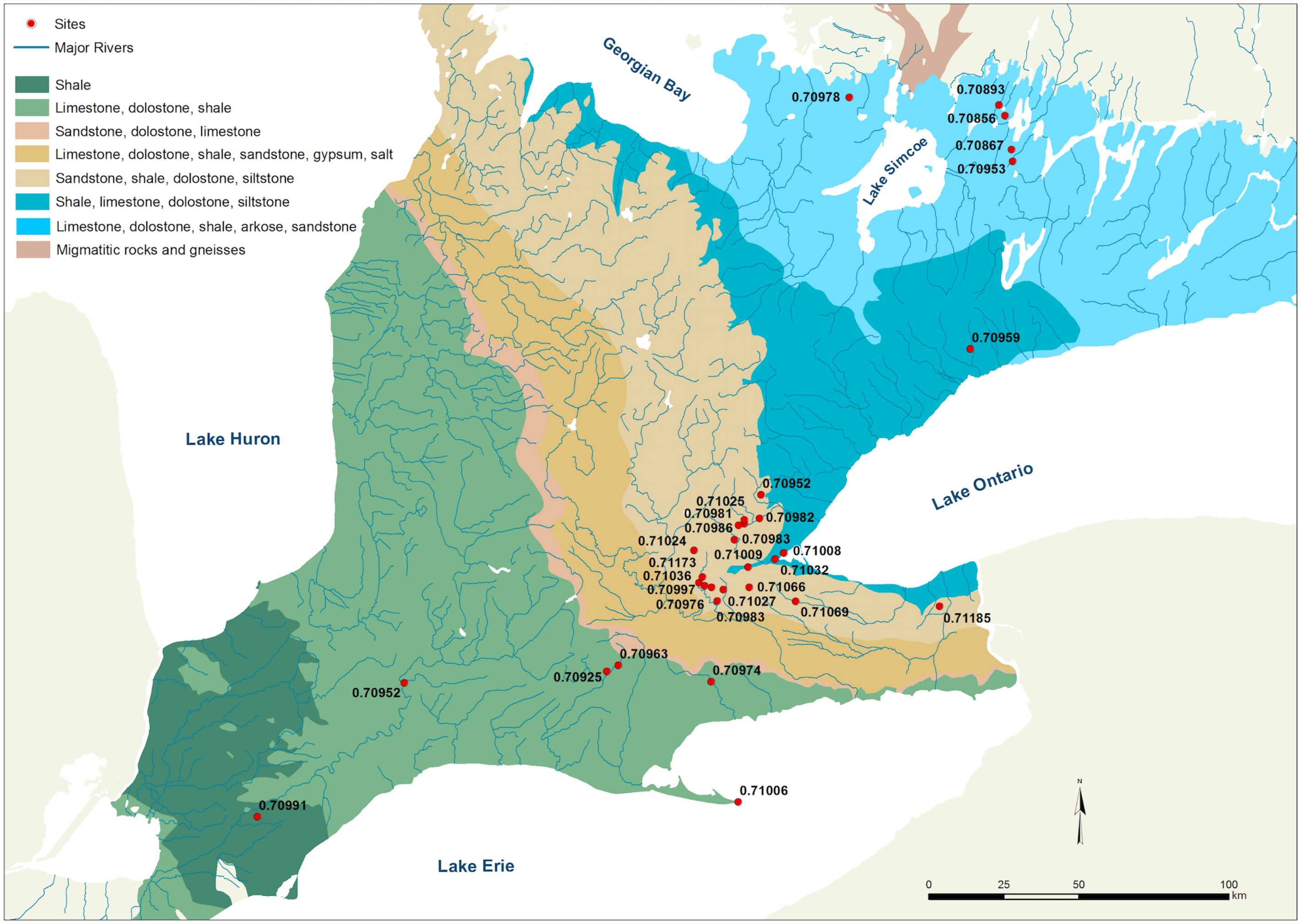

Figure 7.7 Map depicting the observed bioavailable $^{87}Sr/^{86}Sr$ values from white-tailed deer teeth relative to bedrock composition. Map created using ArcGIS and data from an open source ArcGIS database.

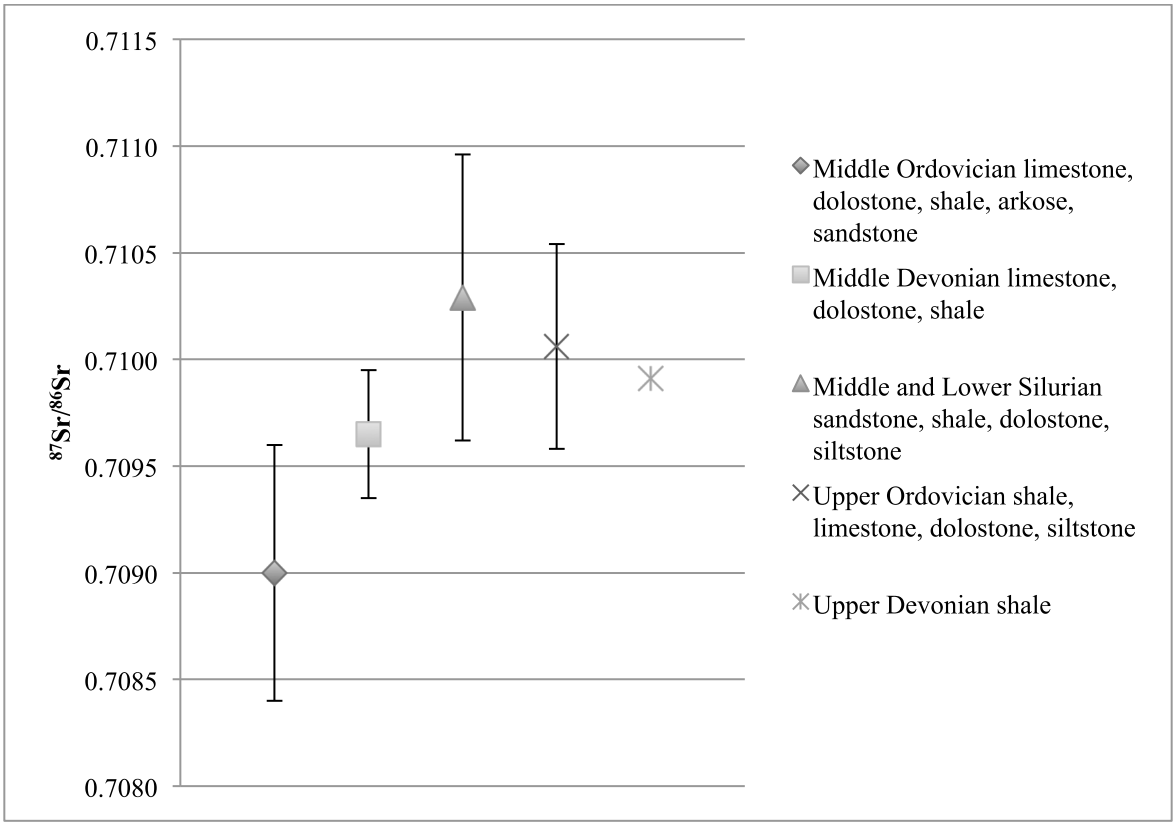

Figure 7.8 Mean bioavailable $^{87}Sr/^{86}Sr$ values (+/- 1 S.D.) from white-tailed deer teeth for different types of bedrock present in southern Ontario.

Table 7.12 Results from the t-tests for the different types of bedrock present in southern Ontario. Statistically significant differences are in bold.

Bedrock	t-statistic	p-value
Middle Ordovician limestone, dolostone, shale, arkose, sandstone vs. Middle Devonian limestone, dolostone, shale	**3.6666**	**0.0010**
Middle Ordovician limestone, dolostone, shale, arkose, sandstone vs. Middle and Lower Silurian sandstone, shale, dolostone, siltstone	**6.9947**	**0.0000**
Middle Ordovician limestone, dolostone, shale, arkose, sandstone vs. Upper Ordovician shale, limestone, dolostone, siltstone	**5.0246**	**0.0000**
Middle Devonian limestone, dolostone, shale vs. Middle and Lower Silurian sandstone, shale, dolostone, siltstone	**3.4806**	**0.0008**
Middle Devonian limestone, dolostone, shale vs. Upper Ordovician shale, limestone, dolostone, siltstone	**2.6527**	**0.0139**
Middle and Lower Silurian sandstone, shale, dolostone, siltstone vs. Upper Ordovician shale, limestone, dolostone, siltstone	1.1305	0.2620

mean $^{87}Sr/^{86}Sr$ value of 0.70900 +/-0.00060. Similarly in sandstone, shale, dolostone and siltstone, $^{87}Sr/^{86}Sr$ values range from 0.70854 to 0.71212, resulting in a mean value of 0.71029 +/- 0.00067 while shale, limestone, dolostone and siltstone range from $^{87}Sr/^{86}Sr$ = 0.70884 to 0.71067, with a mean value of $^{87}Sr/^{86}Sr$ =0.710006 +/-0.00048. Therefore, there is lots of overlapping variation visible in the range of $^{87}Sr/^{86}Sr$ values obtained for each type of bedrock minimizing the amount of possible interpretation.

7.3.1 Strontium values and geological formations

Strontium values for the geological formations range from $^{87}Sr/^{86}Sr$= 0.70895 to $^{87}Sr/^{86}Sr$= 0.71193 (see Figure 7.9 and Table 7.13). Like bedrock types, there is overlapping variation visible in the range of $^{87}Sr/^{86}Sr$ values between different geological formations. There is a relatively wide range of variation in most of the formations (e.g., $^{87}Sr/^{86}Sr$=0.70854 to 0.71304 for the Guelph Formation); however, the Hamilton Group does not exhibit this same range (e.g., $^{87}Sr/^{86}Sr$=0.70924-0.70976). There are statistically

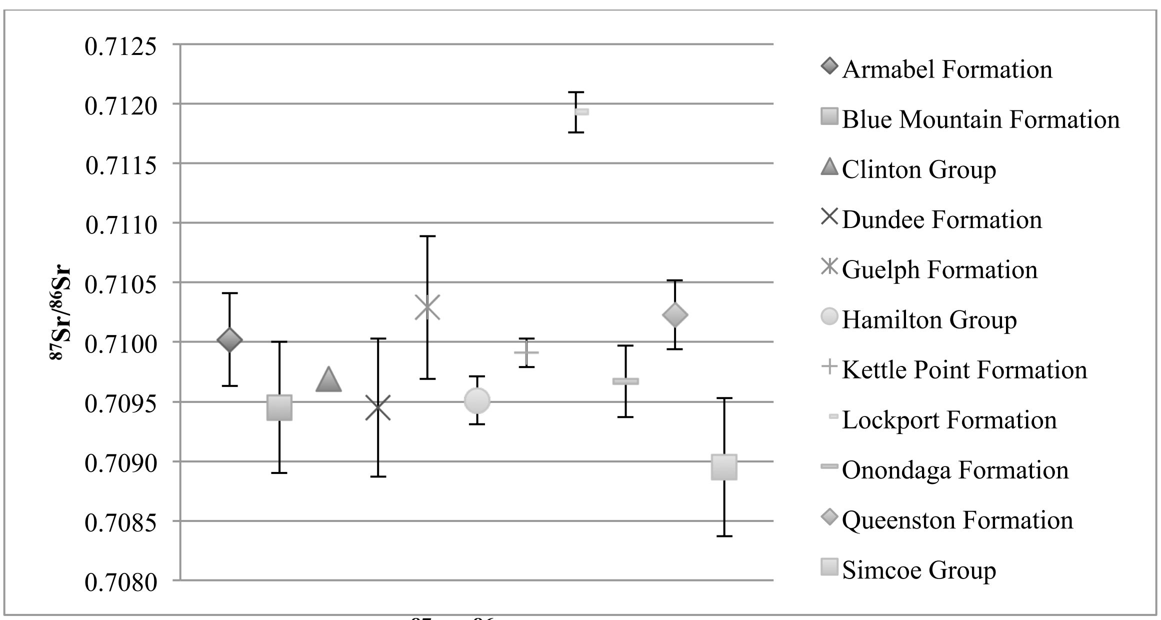

Figure 7.9 Mean bioavailable $^{87}Sr/^{86}Sr$ values (+/- 1 S.D.) from white-tailed deer teeth for geological formations present in southern Ontario.

Table 7.13 Mean bioavailable $^{87}Sr/^{86}Sr$ values from white-tailed deer teeth for geological formations present in southern Ontario.

Formation	Age	Type of bedrock	Sites (n)	Teeth (n)	Samples (n)	$^{87}Sr/^{86}Sr$	SD	Range
Amabel Formation	Middle/ Lower Silurian	Dolomite Limestone	4	23	52	0.71002	0.00039	0.70949-0.71078
Blue Mountain Formation	Upper Ordovician	Shale Limestone Dolomite Siltstone	1	3	5	0.70945	0.00055	0.70884-0.71030
Clinton Group	Middle/ Lower Silurian	Sandstone Shale Dolomite Siltstone	1	1	1	0.70969		
Dundee Formation	Middle Devonian	Limestone Dolomite Shale	1	5	16	0.70969	0.00058	0.70892-0.71031
Guelph Formation	Middle/ Lower Silurian	Dolomite Limestone	10	34	108	0.71029	0.00060	0.70854-0.71304
Hamilton Group	Middle Devonian	Shale Limestone Dolomite	1	3	7	0.70951	0.00020	0.70924-0.70976
Kettle Point Formation	Upper Devonian	Shale Dolomite	1	1	4	0.70991	0.00012	0.70975-0.71002
Lockport Formation	Middle/ Lower Silurian	Dolomite Limestone	1	3	9	0.71193	0.00017	0.71169-0.71225
Onondaga Formation	Middle Devonian	Limestone Dolomite Shale	3	9	52	0.70967	0.00030	0.70882-0.71018
Queenston Formation	Upper Ordovician	Shale Limestone Dolomite Siltstone	3	9	19	0.71023	0.00029	0.70952-0.71067
Simcoe Group	Middle Ordovician	Limestone Dolomite Shale Arkose Sandstone	5	13	39	0.70895	0.00058	0.70850-0.71153

Table 7.14 Results from the t-tests for geological formations present in southern Ontario. The Clinton Formation was excluded because of a lack of samples. Statistically significant differences are in bold.

Geological formation	t-statistic	p-value
Amabel vs. Blue Mountain	**3.0149**	**0.0038**
Amabel vs. Dundee	**2.6208**	**0.0108**
Amabel vs. Guelph	**2.9557**	**0.0035**
Amabel vs. Hamilton	**10.9469**	**0.0013**
Amabel vs. Kettle Point	0.7365	0.5792
Amabel vs. Lockport	**9.6584**	**0.0000**
Amabel vs. Onondaga	**2.5575**	**0.0000**
Amabel vs. Queenston	**3.1158**	**0.0361**
Amabel vs. Simcoe	**8.9212**	**0.0000**
Blue Mountain vs. Dundee	0.8904	0.3843
Blue Mountain vs. Guelph	**3.1086**	**0.0023**
Blue Mountain vs. Hamilton	0.6520	0.6400
Blue Mountain vs. Kettle Point	**4.5508**	**0.0088**
Blue Mountain vs. Lockport	**17.9088**	**0.0000**
Blue Mountain vs. Onondaga	1.4156	0.1175
Blue Mountain vs. Queenston	**5.8235**	**0.0000**
Blue Mountain vs. Simcoe	1.8638	0.0653
Dundee vs. Guelph	**3.9611**	**0.0001**
Dundee vs. Hamilton	**3.3996**	**0.0445**
Dundee vs. Kettle Point	**2.9405**	**0.0339**
Dundee vs. Lockport	**22.4644**	**0.0000**
Dundee vs. Onondaga	0.2096	0.8016
Dundee vs. Queenston	**7.0223**	**0.0000**
Dundee vs. Simcoe	**4.8984**	**0.0000**
Guelph vs. Hamilton	**13.0117**	**0.0007**
Guelph vs. Kettle Point	1.6950	0.2026
Guelph vs. Lockport	**5.5287**	**0.0000**
Guelph vs. Onondaga	**3.1101**	**0.0000**
Guelph vs. Queenston	0.6933	0.6656
Guelph vs. Simcoe	**9.1515**	**0.0000**
Hamilton vs. Kettle Point	**3.6957**	**0.0188**
Hamilton vs. Lockport	**16.5083**	**0.0000**
Hamilton vs. Onondaga	1.1197	0.1847
Hamilton vs. Queenston	**6.2314**	**0.0000**
Hamilton vs. Simcoe	**2.4411**	**0.0165**
Kettle Point vs. Lockport	**6.1912**	**0.0000**
Kettle Point vs. Onondaga	0.9582	0.1631
Kettle Point vs. Queenston	1.9359	0.1199
Kettle Point vs. Simcoe	**2.9708**	**0.0031**
Lockport vs. Onondaga	**22.5499**	**0.0000**
Lockport vs. Queenston	**17.4577**	**0.0000**
Lockport vs. Simcoe	**15.2560**	**0.0000**

Table 7.14 continued.

Geological formation	t-statistic	p-value
Onondaga vs. Queenston	**11.6476**	**0.0000**
Onondaga vs. Simcoe	**7.9395**	**0.0000**
Queenston vs. Simcoe	**9.5503**	**0.0000**

significant differences between the majority of the formations (see Table 7.14).

7.4 Strontium values and sediment and soil

There is minimal variation in $^{87}Sr/^{86}Sr$ values obtained from deer teeth recovered on different sediments and soils present in southern Ontario (see Table 7.15, Figures 7.10 and 7.11). Individual $^{87}Sr/^{86}Sr$ values range from 0.70850 (diamicton) to 0.71304 (silt) with mean $^{87}Sr/^{86}Sr$ values ranging from 0.70948 (diamicton) to 0.71056 (clay). All sediments in the region are from the most recent Quaternary system and so time periods have not been considered for analysis. Statistically significant differences exist between clay and diamicton, clay and gravel, clay and sand, diamicton and gravel, and diamicton and sand (see Table 7.16). There is a range of values present in each sediment category, with values within a single sediment type spanning three decimal places. There is a wide range in $^{87}Sr/^{86}Sr$ values between different types of sediment that overlap.

7.5 Strontium values and elevation

The elevation of sampled sites in southern Ontario ranges from 73 to 305 masl

Table 7.15 Mean bioavailable $^{87}Sr/^{86}Sr$ values from white-tailed deer teeth for different types of sediment and soil present in southern Ontario.

Sediment	Sites (n)	Teeth (n)	Samples (n)	Mean $^{87}Sr/^{86}Sr$	SD	Range
Clay	4	11	60	0.71056	0.00066	0.70915-0.71212
Diamicton	6	19	57	0.70948	0.00075	0.70850-0.71153
Gravel	4	19	30	0.70999	0.00062	0.70854-0.71078
Sand	15	49	119	0.70989	0.00066	0.70852-0.71144
Silt	2	6	46	0.70987	0.00060	0.70921-0.71304

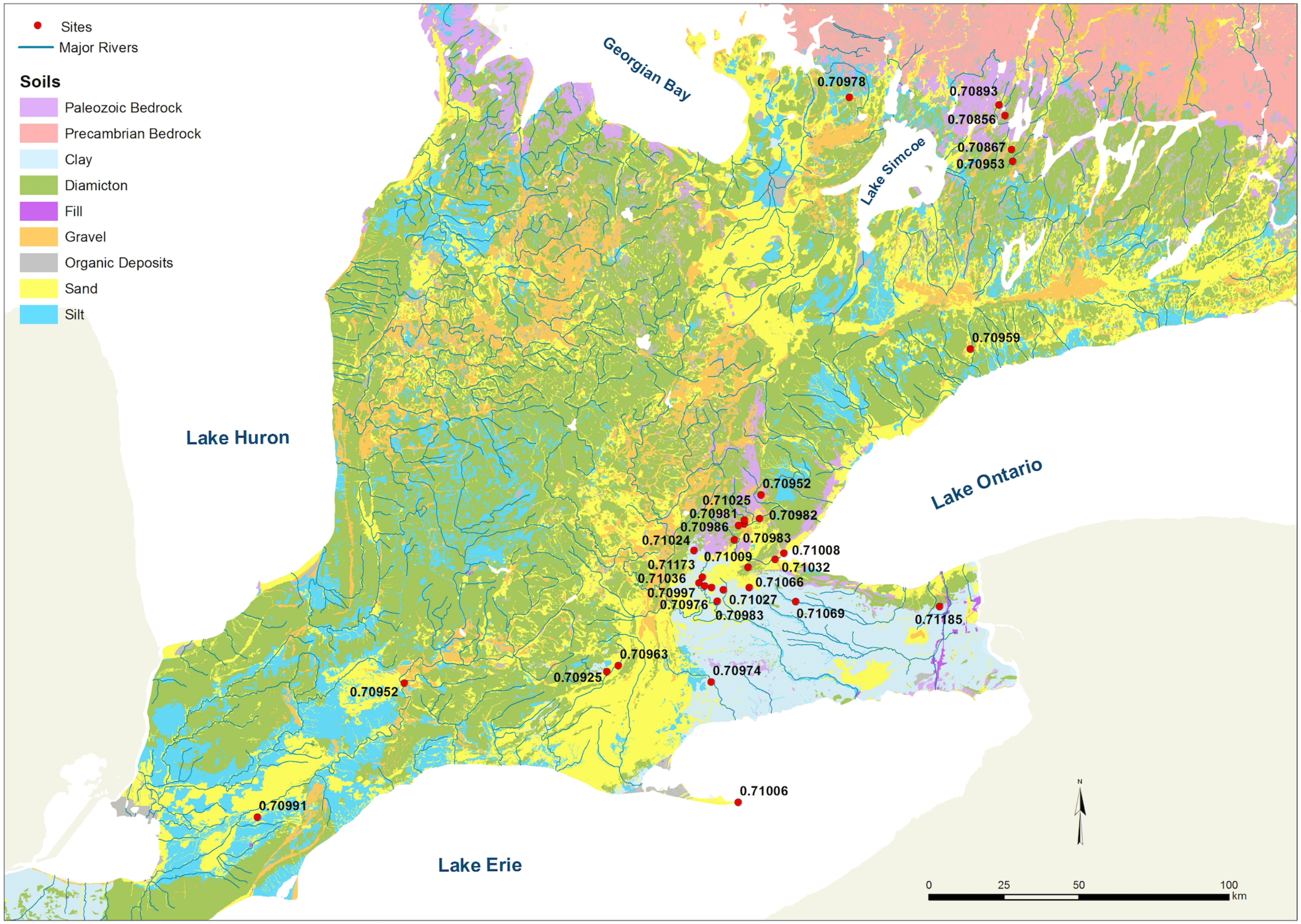

Figure 7.10 Map depicting the observed $^{87}Sr/^{86}Sr$ values from white-tailed deer teeth relative to sediment and soil composition. Map created using ArcGIS and data from an open source ArcGIS database.

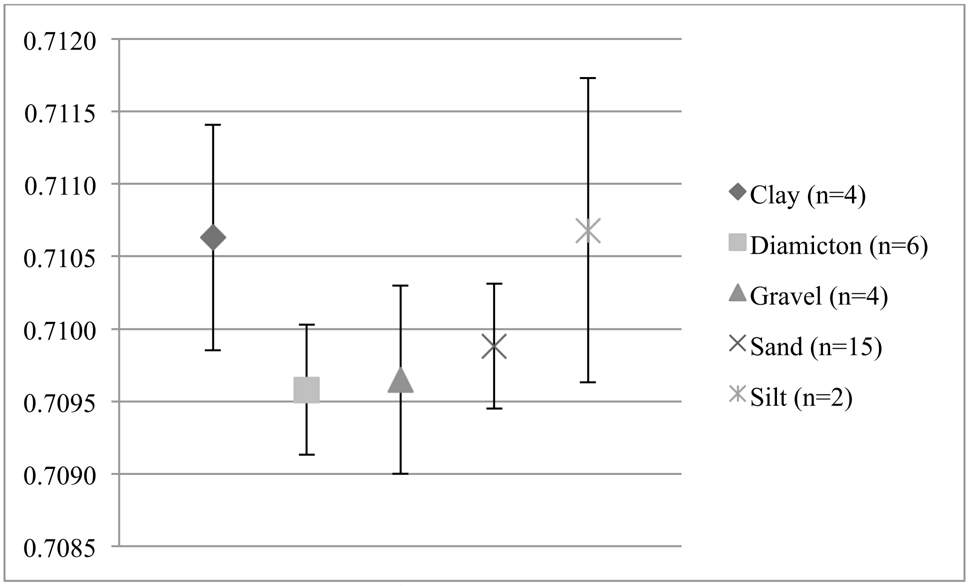

Figure 7.11 Mean bioavailable $^{87}Sr/^{86}Sr$ values (+/- 1 S.D.) from white-tailed deer teeth for different types of sediment and soil present in southern Ontario.

with mean $^{87}Sr/^{86}Sr$ values ranging from 0.70941 to 0.71054 (see Figure 7.12 and Table 7.17). There is a minimal correlation between elevation and decreasing mean $^{87}Sr/^{86}Sr$ values from archaeological sites (see Figure 7.13) with an R^2 value of 0.1248, calculated using a linear trend line (y= -5E-06x + 0.71100). Sites were then grouped in elevation categories of 20m for statistical analyses to ensure robusticity as well as a Gaussian

Table 7.16 Results from the t-tests for the different types of sediment and soil present in southern Ontario. Statistically significant differences are in bold.

Sediment comparison	t-statistics	p-values
Clay vs. diamicton	**3.9638**	**0.0004**
Clay vs. gravel	**2.3708**	**0.0248**
Clay vs. sand	**3.0426**	**0.0035**
Clay vs. silt	2.1222	0.0508
Diamicton vs. gravel	**2.2845**	**0.0283**
Diamicton vs. sand	**2.2123**	**0.0304**
Diamicton vs. silt	1.1565	0.2593
Gravel vs. sand	0.5698	0.5707
Gravel vs. silt	0.4161	0.6811
Sand vs. silt	0.0706	0.9439

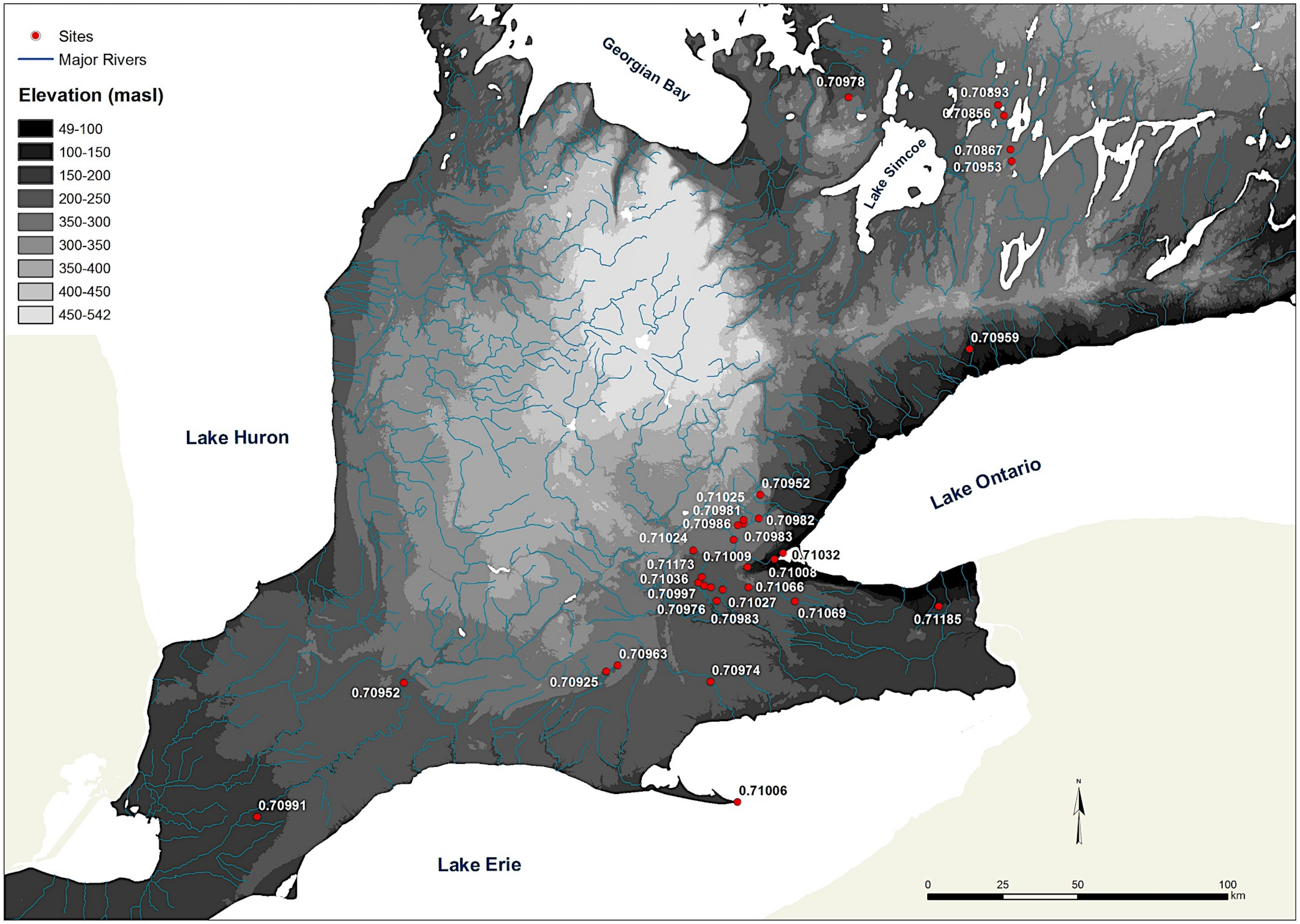

Figure 7.12 Map depicting observed $^{87}Sr/^{86}Sr$ values from white-tailed deer teeth relative to elevation. Map created using ArcGIS and data from an open source ArcGIS database.

Table 7.17 Mean bioavailable $^{87}Sr/^{86}Sr$ values from white-tailed deer teeth for sampled elevations in southern Ontario.

masl	Sites	n (teeth)	n (samples)	Mean $^{87}Sr/^{86}Sr$	SD
71-90	1	4	14	0.71032	0.00018
131-150	1	3	5	0.70959	0.00059
171-190	4	12	36	0.71054	0.00131
191-210	5	16	23	0.71005	0.00100
211-230	5	15	61	0.71035	0.00051
231-250	5	16	72	0.70986	0.00039
251-270	5	23	59	0.70973	0.00049
271-290	4	14	41	0.70941	0.00081
291-310	1	1	1	0.70952	

distribution. T-test results indicate that there are statistically significant differences between various elevation groups (see Table 7.18).

7.6 Strontium values for archaeological sites

The $^{87}Sr/^{86}Sr$ values obtained for each archaeological site are located in Table 7.19 and Figure 7.14. $^{87}Sr/^{86}Sr$ values range from 0.70856 (Coulter) to 0.71185 (Thorold). There is no discernable link between $^{87}Sr/^{86}Sr$ values and cultural affiliation, date of site occupation, or time of site occupation (i.e., seasonal versus year round). Five sites, Ludlow Vanderlip, McMurray, Reid, Trent, and Van Besien, all exhibit significant variation in teeth recovered at that site. Multiple sites are isotopically distinct with significant statistical differences observed (see Tables 7.20 and 7.21).

7.7 Summary

Overall, $^{87}Sr/^{86}Sr$ values from deer teeth range from $^{87}Sr/^{86}Sr$=0.708 to $^{87}Sr/^{86}Sr$=0.713; however, these average to provide more uniform values in bedrock, types of sediment and soil, elevation and between archaeological sites. There is minimal variation within the majority of white-tailed deer teeth with no statistically significant

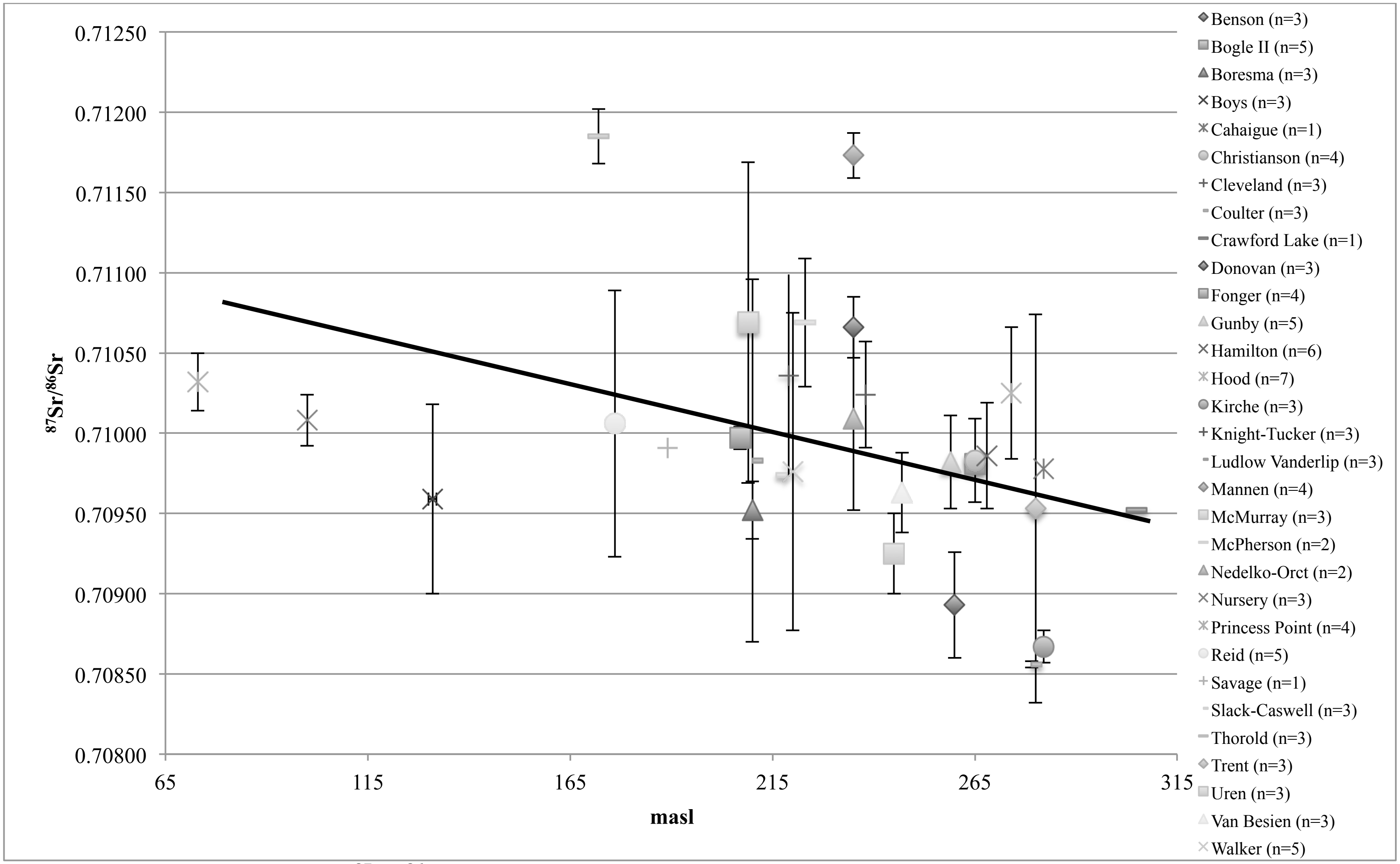

Figure 7.13 Mean bioavailable $^{87}Sr/^{86}Sr$ values (+/- 1 S.D.) from white-tailed deer teeth recovered at archaeological sites in southern Ontario organized by elevation (masl). The line represents a linear regression (y= -5E-06x + 0.71100) with R^2=0.1248.

Table 7.18 Results from the t-tests for the sampled elevation clusters in southern Ontario. Statistically significant differences are in bold.

MASL comparison	t-statistic	p-value
71-90 vs. 131-150	2.3994	0.0616
71-90 vs. 171-190	0.3273	0.7482
71-90 vs. 191-210	0.5273	0.6043
71-90 vs. 211-230	0.1136	0.9108
71-90 vs. 231-250	**2.2635**	**0.0361**
71-90 vs. 251-270	**2.3478**	**0.0271**
71-90 vs. 271-290	**2.1859**	**0.0440**
131-150 vs.171-190	1.1994	0.2517
131-150 vs.191-210	0.7609	0.4571
131-150 vs. 211-230	**2.3079**	**0.0347**
131-150 vs. 231-250	1.0253	0.3195
131-150 vs. 251-270	0.4569	0.6518
131-150 vs. 271-290	0.3607	0.7233
171-190 vs. 191-210	1.1240	0.2712
171-190 vs. 211-230	0.5169	0.6097
171-190 vs. 231-250	1.9738	0.0591
171-190 vs. 251-270	**2.6584**	**0.0120**
171-190 vs. 271-290	**2.6879**	**0.0128**
191-210 vs. 211-230	1.0411	0.3064
191-210 vs. 231-250	0.7080	0.4843
191-210 vs. 251-270	1.3276	0.1924
191-210 vs. 271-290	1.9077	0.0667
211-230 vs. 231-250	**3.0168**	**0.0052**
211-230 vs. 251-270	**3.7522**	**0.0006**
211-230 vs. 271-290	**3.7675**	**0.0008**
231-250 vs. 251-270	0.8832	0.3828
231-250 vs. 271-290	1.9789	0.0577
251-270 vs. 271-290	1.5027	0.1418

differences present between lophs of the same tooth. Similarly there is minimal variation within a loph with only a single tooth, MCMCP1, exhibiting statistically significant variation between the top of the loph versus the bottom of the loph ($^{87}Sr/^{86}Sr_{top}$= 0.71031 versus $^{87}Sr/^{86}Sr_{bottom}$= 0.71015, p=0.042). MCMCP1 also exhibits statistically significant variation between buccal and lingual enamel ($^{87}Sr/^{86}Sr_{lingual}$= 0.70970 versus $^{87}Sr/^{86}Sr_{buccal}$= 0.71038, p=0.0012). There is statistically significant variation noted

Table 7.19 Mean bioavailable $^{87}Sr/^{86}Sr$ value from white-tailed deer teeth for archaeological sites located in southern Ontario.

Site	Teeth (n)	Samples (n)	Mean $^{87}Sr/^{86}Sr$	SD	Range
Benson	3	8	0.70893	0.00033	0.70854-0.70934
Bogle II	5	6	0.70981	0.00023	0.70952-0.71013
Boresma	3	7	0.70952	0.00018	0.70929-0.70972
Boys	3	5	0.70959	0.00059	0.70885-0.71030
Cahaigue	1	1	0.70978		
Christianson	4	16	0.70983	0.00026	0.70949-0.71013
Cleveland	3	11	0.71036	0.00063	0.70949-0.71093
Coulter	3	3	0.70856	0.00002	0.70854-0.70859
Crawford Lake	1	1	0.70952		
Donovan	3	3	0.71066	0.00019	0.71039-0.71082
Fonger	4	4	0.70997	0.00007	0.70988-0.71008
Gunby	5	18	0.70982	0.00029	0.70951-0.71036
Hamilton	6	11	0.70986	0.00033	0.70941-0.71040
Hood	7	17	0.71025	0.00041	0.70975-0.71075
Kirche	3	20	0.70867	0.00010	0.70859-0.70881
Knight-Tucker	3	8	0.71024	0.00033	0.70999-0.71061
Ludlow Vanderlip	3	6	0.70983	0.00113	0.70892-0.71142
Mannen	4	12	0.71027	0.00014	0.71024-0.71049
McMurray	3	3	0.71173	0.00100	0.71045-0.71304
McPherson	2	40	0.71069	0.00040	0.71029-0.71109
Nedelko-Orct	2	2	0.71009	0.00057	0.70952-0.71067
Nursery	3	3	0.71008	0.00016	0.70986-0.71024
Princess Point	4	14	0.71032	0.00018	0.71009-0.71057
Reid	5	16	0.71006	0.00083	0.70892-0.71146
Savage	1	4	0.70991		
Slack-Caswell	3	3	0.70974	0.00049	0.70915-0.71034
Thorold	3	9	0.71185	0.00017	0.71169-0.71208
Trent	3	7	0.70953	0.00121	0.70855-0.71124
Uren	3	6	0.70925	0.00025	0.70892-0.70951
Van Besien	3	43	0.70963	0.00025	0.70928-0.70988
Walker	5	5	0.70976	0.00099	0.70854-0.71104

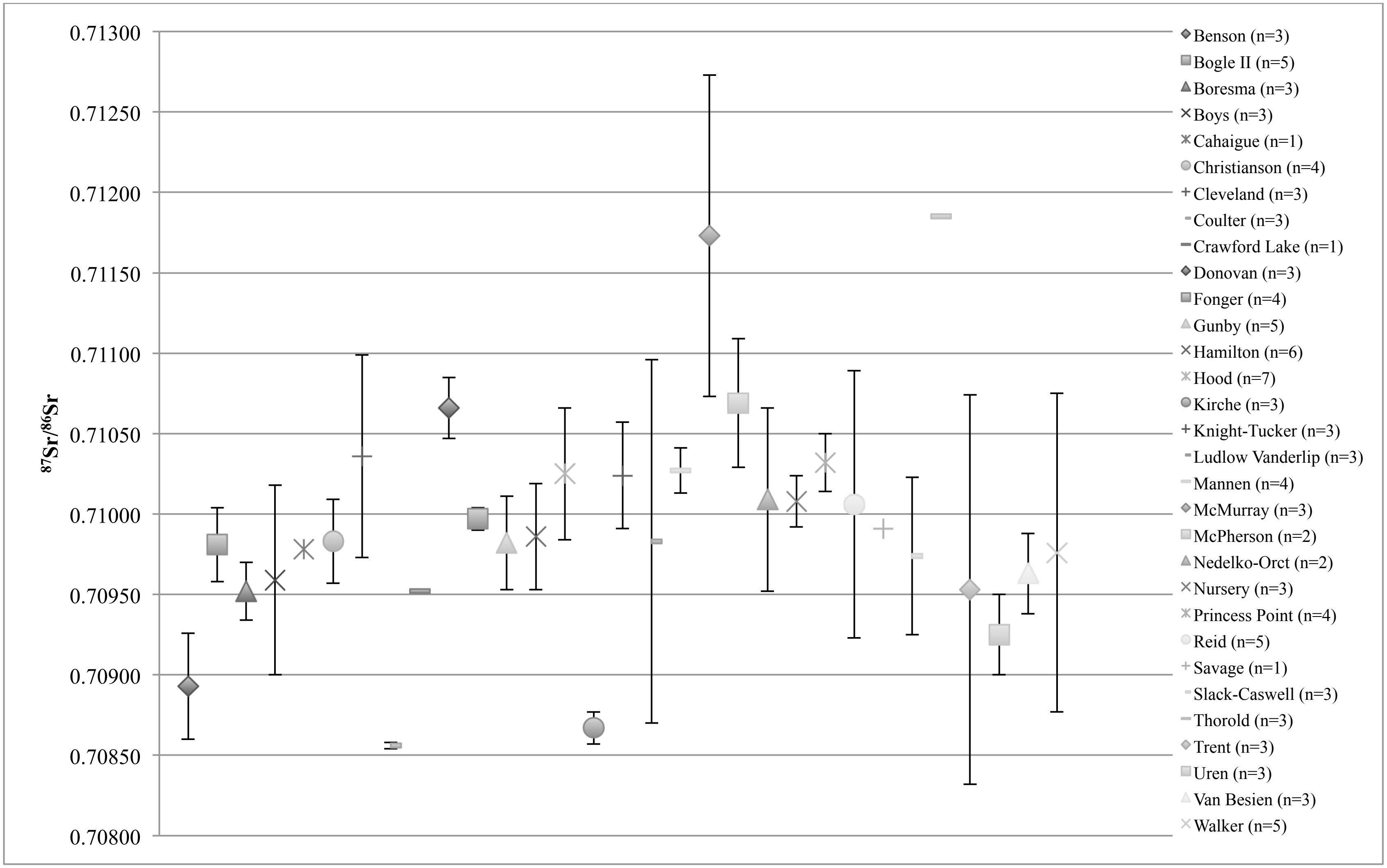

Figure 7.14 Mean bioavailable $^{87}Sr/^{86}Sr$ values (+/- 1 S.D.) from white-tailed deer teeth for archaeological sites located in southern Ontario.

Table 7.20 T-values for bioavailable $^{87}Sr/^{86}Sr$ from white-tailed deer teeth at archaeological sites in southern Ontario.

Benson	Benson										
Bogle	4.5043	Bogle									
Boresma	2.7185	1.8501	Boresma								
Boys	1.6910	0.7744	0.2583	Boys							
Christianson	4.0628	0.1225	2.1206	0.7410	Christianson						
Cleveland	3.4826	1.8397	2.9319	1.5451	1.5543	Cleveland					
Coulter	1.9384	9.0972	8.9167	3.0220	8.2402	4.9462	Coulter				
Donovan	7.8690	5.3516	8.5117	2.9899	4.6338	0.7896	19.0385	Donovan			
Fonger	6.3146	1.3265	4.6722	1.3194	1.0398	1.2698	33.1573	6.8527	Fonger		
Gunby	4.0098	0.0604	1.9653	0.7591	0.0537	1.7036	7.2778	4.4076	0.9984	Gunby	
Hamilton	3.9855	0.2848	2.0516	0.9069	0.1520	1.6171	6.5870	3.8116	0.6445	0.2111	Hamilton
Hood	4.8855	2.1511	3.6953	2.0718	1.8264	0.3358	6.8946	1.6164	1.3248	2.0023	1.8655
Kirche	1.3059	7.9453	7.3710	2.6628	7.1949	4.5888	1.8682	16.0532	20.4317	6.4610	5.9262
Knight-Tucker	4.8618	2.2009	4.0972	1.6653	1.8508	0.2922	8.8015	1.9104	1.6393	1.8923	1.6284
Ludlow Vanderlip	1.3241	0.0403	0.6347	0.3260	0	0.7095	1.9463	1.2546	0.2557	0.0197	0.0637
Mannen	7.4594	3.4889	6.8149	2.2911	2.9800	0.2853	20.5068	3.1546	3.8332	2.8232	2.3129
McMurray	4.6054	4.3303	5.0794	3.1923	3.7479	2.0076	5.4895	1.8207	3.6302	4.1911	4.3863
McPherson	5.4329	3.8581	5.8106	2.2555	3.2973	0.6411	10.0783	0.1181	3.9781	3.300	2.9665
Nedelko-Orct	2.9876	1.0216	2.2596	0.9388	0.8265	0.4843	5.0866	1.7162	0.4755	0.8873	0.7400
Nursery	5.4312	1.7665	4.4173	1.3883	1.4522	0.7461	16.3274	4.0443	1.2545	1.400	1.0665
Princess Point	7.2508	3.6197	6.6253	2.3994	3.0990	0.1240	16.4598	2.4185	3.6244	2.9948	2.5161
Reid	2.1980	0.6490	1.4217	0.8484	0.5274	0.5340	3.0303	1.1967	0.2132	0.6103	0.5454
Slack-Caswell	2.3748	0.2822	0.9449	0.3387	0.3188	1.3454	4.1675	3.0320	0.9571	0.2969	0.4435
Thorold	13.6244	13.1827	18.0529	6.3752	11.5848	3.9549	33.2906	8.0844	20.4416	10.8446	9.5942
Trent	0.8286	0.5300	0.0191	0.0771	0.4963	1.0538	1.3883	1.5979	0.7509	0.5383	0.6625
Uren	1.3387	3.2374	1.7947	0.9190	2.9658	2.8365	4.7652	7.7775	5.6397	2.8145	2.7894
Van Besien	0.4808	0.1693	0.1038	0.0269	0.1642	0.4904	0.7412	0.7115	0.2813	0.1778	0.2382
Walker	1.3685	0.1100	0.5333	0.2653	0.1359	0.9268	2.0325	1.5107	0.4175	0.1300	0.2344

Table 7.20 continued.

Hood	Hood								
Kirche	6.3854	Kirche							
Knight-Tucker	0.0370	0	Knight-Tucker						
Ludlow Vanderlip	0.9120	7.8862	0.6032	Ludlow Vanderlip					
Mannen	0.0926	1.7711	0.1670	0.7969	Mannen				
McMurray	3.4973	16.6872	2.4507	2.1809	2.9790	McMurray			
McPherson	1.3431	5.2737	1.3890	0.9905	2.0736	1.3426	McPherson		
Nedelko-Orct	0.4572	9.0337	0.3863	0.2907	0.6710	2.0407	1.2185	Nedelko-Orct	
Nursery	0.6768	4.5876	0.7556	0.3794	1.6771	2.8219	2.5184	0.0309	Nursery
Princess Point	0.3186	12.9435	0.4173	0.8810	0.4385	2.8505	1.6848	0.8175	1.8239
Reid	0.5288	14.1106	0.3501	0.3347	0.4937	2.5685	0.9860	0.0456	0.0400
Slack-Caswell	1.7131	2.7984	1.4659	0.1265	2.1135	3.0951	2.2527	0.7401	1.1424
Thorold	6.3505	3.7058	7.5121	3.0617	13.5467	0.2049	4.7160	5.3980	13.1321
Trent	1.4873	27.9262	0.9805	0.3138	1.2535	2.4274	1.2524	0.5891	0.7805
Uren	3.8496	1.2268	4.1418	0.8680	6.9655	4.1672	5.1178	2.3761	4.8434
Van Besien	0.6914	3.7309	0.4189	0.1262	0.5287	1.3508	0.5652	0.2437	0.3111
Walker	1.1919	0.6645	0.7914	0.0922	1.0083	2.7156	1.2304	0.4280	0.5385

Table 7.20 continued.

Princess Point	Princess Point						
Reid	0.6071	Reid					
Slack-Caswell	2.2346	0.5966	Slack-Caswell				
Thorold	11.3776	3.5794	7.0463	Thorold			
Trent	1.3297	0.7456	0.2786	3.2886	Trent		
Uren	6.6456	1.6007	1.5428	14.8956	0.3925	Uren	
Van Besien	0.5691	0.3692	0.0747	1.5345	0.0623	0.2619	Van Besien
Walker	1.1019	0.5192	0.03197	3.5146	0.2947	0.8504	0.1076

Table 7.21 P-values for mean bioavailable $^{87}Sr/^{86}Sr$ values of archaeological sites in southern Ontario. Statistically significant differences are in bold.

Benson	Benson									
Bogle	**0.0040**	Bogle								
Boresma	0.0530	0.1137	Boresma							
Boys	0.1660	0.4680	0.8537	Boys						
Christianson	**0.0097**	0.9059	0.1397	0.4919	Christianson					
Cleveland	**0.0252**	0.1154	0.0905	0.1971	0.1808	Cleveland				
Coulter	0.1246	**0.000009**	**0.0007**	**0.0390**	**0.0004**	**0.0077**	Coulter			
Donovan	**0.0014**	**0.0017**	**0.0016**	**0.0403**	**0.0056**	**0.4739**	**0.000004**	Donovan		
Fonger	**0.0014**	0.2262	0.0054	0.2441	0.3384	0.2600	**0.0000004**	**0.0010**	Fonger	
Gunby	**0.0070**	0.9533	0.1632	0.4765	0.9586	0.1393	**0.0003**	**0.0045**	0.3513	Gunby
Hamilton	**0.0052**	0.7821	0.1471	0.3945	0.8829	0.1498	**0.0003**	**0.0066**	0.5372	0.8374
Hood	**0.0012**	**0.0569**	**0.0202**	**0.0720**	0.1010	0.7456	**0.0001**	0.1446	0.2178	**0.0730**
Kirche	0.2615	**0.0002**	**0.0020**	**0.0562**	**0.0008**	**0.0101**	0.1351	**0.00008**	**0.000005**	**0.0006**
Knight-Tucker	**0.0082**	**0.0700**	**0.0294**	0.1711	0.1234	0.7846	**0.0009**	0.1286	0.1620	0.1073
Ludlow Vanderlip	0.2560	0.9691	0.6633	0.7606	1	0.5171	0.1234	0.2779	0.8083	0.9848
Mannen	**0.0006**	**0.0101**	**0.0015**	**0.0705**	**0.0246**	0.7868	**0.000005**	**0.0252**	**0.0086**	**0.0256**
McMurray	**0.0099**	**0.0049**	**0.0196**	**0.0331**	**0.0133**	0.1151	**0.0053**	0.1427	**0.0150**	**0.0057**
McPherson	**0.0122**	**0.0119**	**0.0184**	0.1093	**0.0300**	0.5670	**0.0020**	0.9134	**0.0164**	**0.0214**
Nedelko-Orct	0.0582	0.3538	0.1816	0.4170	0.4549	0.6612	**0.0146**	0.1846	0.6592	0.4155
Nursery	**0.0055**	0.1277	**0.0157**	0.2373	0.2061	0.4970	**0.00008**	**0.0155**	0.2651	0.2108
Princess Point	**0.0007**	**0.0085**	**0.0021**	**0.0616**	**0.0211**	0.9061	**0.00001**	**0.0602**	**0.0110**	**0.0200**
Reid	**0.0702**	0.5344	0.3222	0.4287	0.6142	0.6124	**0.0230**	0.2765	0.8371	0.5585
Slack-Caswell	**0.0764**	0.7872	0.5058	0.7518	0.7627	0.2496	**0.0140**	**0.0387**	0.3824	0.7765
Thorold	**0.0001**	**0.00001**	**0.00008**	**0.0031**	**0.00008**	**0.0167**	**0.000004**	**0.0012**	**0.000005**	**0.00003**
Trent	0.4539	0.6151	0.9893	0.9421	0.6406	0.3514	0.2373	0.1852	0.4865	0.6097
Uren	0.2516	**0.0177**	0.2036	0.4100	**0.0313**	**0.0470**	**0.0088**	**0.0014**	**0.0024**	**0.0305**
Van Besien	0.6557	0.8710	0.9430	0.9797	0.8759	0.6495	0.4996	0.5160	0.7896	0.8646
Walker	0.2201	0.9151	0.7007	0.7996	0.8956	0.3897	**0.0883**	0.1816	0.6888	0.8997

Table 7.21 continued.

Hamilton	Hamilton								
Hood	**0.0889**	Hood							
Kirche	**0.0005**	**0.0002**	Kirche						
Knight-Tucker	0.1474	0.9713	**0.00139**	Knight-Tucker					
Ludlow Vanderlip	0.9509	0.3883	0.15124	0.5788	Ludlow Vanderlip				
Mannen	**0.0494**	0.9282	**0.00001**	0.8739	0.4616	Mannen			
McMurray	**0.0032**	**0.0081**	**0.0061**	**0.0703**	**0.0946**	**0.0308**	McMurray		
McPherson	**0.0250**	0.2211	**0.0028**	0.2589	0.3949	0.1067	0.2719	McPherson	
Nedelko-Orct	0.4872	0.6613	**0.0194**	0.7250	0.7901	0.5389	0.1339	0.3472	Nedelko-Orct
Nursery	0.3215	0.5175	**0.0002**	0.4919	0.7236	0.1543	**0.0477**	**0.0862**	0.9772
Princess Point	**0.0360**	0.7572	**0.00003**	0.6937	0.4186	0.6763	**0.0358**	0.1672	0.4595
Reid	0.5987	0.6084	**0.0312**	0.7382	0.7491	0.6366	**0.0424**	0.3693	0.9653
Slack-Caswell	0.6707	0.1250	**0.0207**	0.2165	0.9053	**0.0882**	**0.0363**	0.1096	0.5128
Thorold	**0.00002**	**0.0002**	**0.000009**	**0.0016**	**0.0375**	**0.00003**	0.8476	**0.0180**	**0.0124**
Trent	0.5287	0.1752	0.2871	0.3823	0.7693	0.2654	**0.0721**	0.2991	0.5972
Uren	**0.0269**	**0.0048**	**0.0202**	**0.0143**	0.4343	**0.0009**	**0.0140**	**0.0144**	**0.0979**
Van Besien	0.8184	0.5088	0.5426	0.6967	0.9056	0.6196	0.2480	0.6114	0.8231
Walker	0.8198	0.2607	0.1150	0.4588	0.9294	0.3468	**0.0348**	0.2732	0.6864

Table 7.21 continued.

Nursery	Nursery							
Princess Point	0.1277	Princess Point						
Reid	0.9693	0.5730	Reid					
Slack-Caswell	0.3169	0.0757	0.5725	Slack-Caswell				
Thorold	**0.0001**	**0.0000**	**0.0116**	**0.0021**	Thorold			
Trent	0.4787	0.2410	0.4840	0.7943	**0.0302**	Trent		
Uren	**0.0083**	**0.0011**	0.1605	0.1977	**0.0001**	0.7146	Uren	
Van Besien	0.7712	0.5938	0.7246	0.9439	0.1996	0.9532	0.8062	Van Besien
Walker	0.6095	0.3069	0.6176	0.9755	**0.0126**	0.7780	0.4276	0.9178

between teeth from the same animal (MCHOO7) with interpretable differences present in MCHAM3 and MCWAL2.

With respect to different types of bedrock, $^{87}Sr/^{86}Sr$ values range from $^{87}Sr/^{86}Sr$= 0.70852 (Middle Ordovician limestone) to $^{87}Sr/^{86}Sr$= 0.71212 (Middle and Lower Silurian sandstone) and different geological formations are statistically different from one another. Sediment and soil $^{87}Sr/^{86}Sr$ values range from $^{87}Sr/^{86}Sr_{diamicton}$= 0.70850 to $^{87}Sr/^{86}Sr_{silt}$ = 0.71304 while a minimal correlation is present between elevation and a decreasing mean bioavailable $^{87}Sr/^{86}Sr$ value. Overlapping ranges in $^{87}Sr/^{86}Sr$ values from bedrock, geological formations, and sediment and soil are all present. There is more variation present between different archaeological sites with statistically significant variation present between multiple sites. There is no discernable significant link between $^{87}Sr/^{86}Sr$ values and cultural affiliation, date of site occupation, or time of site occupation (e.g., seasonal versus year-round). Environmental aspects, white-tailed deer behaviour and ecology, cultural factors, individual variation and methodological influences may all be possible explanations for the minimal variation observed in the mean values and wide range in $^{87}Sr/^{86}Sr$ values. These will be discussed in the following chapter.

Chapter Eight: Discussion

This chapter discusses the results obtained from conducting strontium isotope analysis on white-tailed deer teeth. It considers intra- and intertooth $^{87}Sr/^{86}Sr$ variation, strontium in bedrock and sediment and soil, strontium's relationship to elevation, variation within and between archaeological sites, and comparisons between predicted and experimental values. Aspects such as white-tailed deer ecology and behaviour, cultural context, and environmental factors such as seasonality, geological variation and anthropogenic effects are considered.

8.1 Strontium isotope analysis and white-tailed deer teeth

8.1.1 Intratooth variation

Given the limited home range and repeated use of territory by white-tailed deer (Beier and McCullough 1990; Nelson and Mech 1999) combined with the relatively consistent bedrock composition and sediment/soil mixing in the study area, the minimal amount of variation observed within a single deer tooth is unsurprising. However, there are some anomalies to this general trend within a single tooth. Slight differences between lophs, sections and parts of the loph (i.e., apex of the crown near the occlusal surface versus the CEJ) in a small number of teeth were noted. Specifically, MCCHR36 (a mandibular M1) and MCVBE5 (a mandibular M3) exhibit differences in $^{87}Sr/^{86}Sr$ values between lophs of the same tooth: MCCHR36 between a buccal distal and lingual distal loph ($^{87}Sr/^{86}Sr$= 0.70944 versus $^{87}Sr/^{86}Sr$= 0.71009 respectively) and MCVBE5 between a lingual distal loph and a lingual middle loph ($^{87}Sr/^{86}Sr$= 0.70969 versus $^{87}Sr/^{86}Sr$= 0.71021 respectively). Similarly, differences within a single loph were noted in

MCMCP1, a mandibular M3. Statistically significant differences between the lingual and buccal sections of the buccal left loph ($^{87}Sr/^{86}Sr_{lingual}$= 0.70970 versus $^{87}Sr/^{86}Sr_{buccal}$= 0.71038; p-value: 0.0012) as well as within a single loph (enamel obtained from the apex of the crown versus enamel from the CEJ of the tooth [$^{87}Sr/^{86}Sr_{crown}$=0.71031 versus $^{87}Sr/^{86}Sr_{CEJ}$=0.71015]) are present. The observed differences within these teeth could be unique characteristics; however, other teeth exhibit similar differences.

There are four possible explanations for the observed differences within a single tooth. First, they could be a result of tooth development and the incorporation of strontium into enamel during mineralization. Since deer teeth are composed of multiple lophs with two separate layers of enamel due to the presence of the infundibulum (see Figure 6.3), there exists the possibility that each loph and layer grows individually, thereby incorporating different $^{87}Sr/^{86}Sr$ values. For example, the buccal section of MCMCP1 may have developed while the deer was located on one type of bedrock (e.g., shale) and the lingual section on another (e.g., sandstone), suggesting that the deer this tooth originated from was relatively mobile during tooth development.

This mobility could be a result of the fawn travelling from location to location with its mother before the tooth was fully developed. Similarly, the observed difference could result from the consumption of foods with different root systems and therefore different strontium isotope compositions. Alternatively, although less likely, the stream where the deer obtained water may have contained different $^{87}Sr/^{86}Sr$ values, perhaps as a result of seasonality, which were, in turn, incorporated into the deer's tissues.

Seasonal differences in white-tailed deer territory or diet may also explain these differences. Although literature states that white-tailed deer are relatively consistent in what they eat year round in northern North America (Beier and McCullough 1990; Weckerly and Nelson 1990), during winter certain food items that they rely on would be unavailable necessitating the consumption of different food items or a more restricted diet. For example, deer consume tree bark year round; however, they may consume more of it during the winter months when other food items are scarce. Material such as tree bark has large amounts of fibre (Rothman et al. 2008) and will influence strontium absorption. Should a deer change its diet, such as with the arrival of winter, this could be visible in the $^{87}Sr/^{86}Sr$ values obtained from the different locations on a single tooth. As diet is individualized, this could explain why some teeth exhibited these differences while other teeth did not.

To investigate the potential of seasonality, consider the difference in MCVBE5. According to the radiographs in Appendix J of Morris (2015), it appears that the middle loph develops before the distal loph. Given the seasons in which the M3 develops (e.g., the middle loph mineralizes in fall while the distal loph mineralizes closer to winter), seasonal differences in the diet and/or location of the animal may result in the different $^{87}Sr/^{86}Sr$ values. However, the fact that the mesial loph did not exhibit a different $^{87}Sr/^{86}Sr$ value from the middle loph, when those two lophs develop during two separate seasons (e.g., the start of fall relative to the middle of winter), indicates that seasonal differences in conjunction with the timing of mineralization is not necessarily responsible for the observed differences. Furthermore, studies investigating the timing of formation and mineralization of red deer (*Cervus elaphus*) teeth suggest the infundibulum appears after the lingual and buccal lophs have mineralized (Brown and Chapman 1991). Therefore, separate mineralization of buccal and lingual sections in white-tailed deer teeth seems less likely.

The second possibility, although unlikely, involves metabolism. Strontium aggregates in mineral components such as apatite in bones and teeth. Even though teeth do not remodel, bone does. During remodelling, the elements in bone, including strontium, are released into the body, mixed with the strontium that has been consumed and reincorporated into the apatite. Remodelling is a continuous process and so it may be that it contributed different strontium isotopes than those that were present when different parts of the tooth was developing. However, when teeth are forming, bones tend to grow rather than remodel, which minimizes the potential of this possibility.

The third possibility for why there are differences between strontium values within teeth concerns the cultural context of the teeth's recovery. For example, MCMCP1 was recovered at the McPherson site, which was a village that experienced two separate expansions (Fitzgerald 1990:284; Katzenberg et al. 1993). As sites expand, their population increases, thus necessitating the use of more resources, including land for their village, as well as agriculture. This conversion of land from forest to maize fields, which did not contribute to the diet of white-tailed deer (Morris 2015), would change the home range of the local animals. This could translate into differences in grazing, in the dietary components and/or the sediments, soils and bedrock where the plants were growing, resulting in a change in the $^{87}Sr/^{86}Sr$ values ingested and subsequently incorporated into enamel.

Finally, analytical error or natural variation may have resulted in the different strontium values. The samples may have been contaminated during preparation or there could have been an error during the measurement of strontium. However, a standard and/or blank was prepared alongside each sample set (i.e., with every seven samples prepared) and subjected to mass spectrometry to ensure sample integrity. Similarly, standards (SRM987) were run after every three to five samples during analyses with the position of collector cups in the mass spectrometer checked to minimize the potential of analytical error (i.e., peak centering). These repeated measurements of SRM987 resulted in an analytical error of +/- 0.00003 used to correct data.

Furthermore, a certain degree of variation is expected in strontium isotope analysis with previous research showing variation at the fourth decimal point in samples originating from the same geological substrate (depending on the substrate and its composition) (Hoppe et al. 1999). Therefore, researchers traditionally interpret the first three places past the decimal (e.g., 0.708, 0.709, 0.710) (Montgomery 2002). The remaining decimal places are generally associated with individual variation and methodological precision. Therefore, although these anomalies in strontium values were noted and some are statistically significant, realistically, they have minimal influence on the interpretation of strontium isotope data. However, if the analytical protocol is changed and a single sample is measured more times (e.g., 100-200 two second analyses rather than 50 two second analyses), these anomalies might exert a greater influence necessitating in a more consistent sampling protocol ((i.e., all samples should be taken from the same location and section of the loph in future studies).

The minimal amount of variation can be construed as a desirable outcome as it allows for comparisons between studies when researchers have not specified where on the tooth their samples were taken. In other words, $^{87}Sr/^{86}Sr$ values from samples from the apex of the loph can be compared to those obtained from the CEJ near the roots of the tooth. Additionally, this enables samples to be obtained from incomplete and/or damaged teeth since samples can be taken from any piece of enamel.

8.1.2 Intertooth variation

There are both interpretable and statistically significant differences present between different teeth (e.g., PM3, M1, M2, M3) from the same animal. Differences are present between M1 and M2 in two animals (MCHAM3 and MCHOO7), M1 and M3 in one animal (MCWAL2), and M1 and PM3 in another animal (MCHOO7). Similar to the variation observed within a tooth, different explanations exist for the noted differences in $^{87}Sr/^{86}Sr$ values. These include seasonality as discussed previously, residential mobility, and metabolism.

As noted, seasonality can influence observed $^{87}Sr/^{86}Sr$ values because of deer behaviour. Specifically, the different $^{87}Sr/^{86}Sr$ values could reflect dietary changes relating to food availability and home range changes dictated by season as discussed in Chapter Two and Section 8.1.1. It could also be a result of the influence of temperature on water, which plays a role in the release and transportation of strontium isotopes (see Chapter Two). In spring when M1 develops, water flow rates are increased as a result of melting snow and there is more standing water due to ground saturation. M2 mineralizes in summer, when flow rates are reduced with less standing water and more precipitation. In winter, when M3 finishes developing, precipitation rates drop with water bound up in snow and ice on top of the frozen ground. Given the similarities between M1 and M3 and the difference between M2, this suggests that the presence of standing water and flow rates are important for the incorporation of bioavailable $^{87}Sr/^{86}Sr$ values.

The similarities observed between teeth could be a result of the strontium residence time within deer tissues. Teeth develop over a period of months and therefore represent an average of what the deer was eating during this few month time period. Strontium has a long residence time in the body (~26 months) while mineralization of teeth is only three to four months per tooth. The second and third molars therefore have the potential to incorporate $^{87}Sr/^{86}Sr$ values ingested while the first molar was developing. It may be that the similar $^{87}Sr/^{86}Sr$ values observed between teeth are because the strontium in the third molars comes from the same source as the strontium in the first molar due to the residence time of strontium in the body. However, this is unlikely given the successful application of isotopes in tracing diet.

8.1.3 Summary

Overall, the strontium isotopic composition of white-tailed deer teeth is fairly homogenous with minimal differences present within and between teeth. This reflects the averaging effect that takes place in mammalian tissues as the strontium isotope composition in enamel represents a mixture of all of those isotopes that were consumed during mineralization. It could also reflect the amount of time required for mineralization and the residence time of strontium within a white-tailed deer's tissues. The lack of difference within the majority of teeth enables for comparison between studies, which increases the amount of interpretation that can be made.

Individual preferences, however, can introduce some variation between animals, potentially explaining the range of variation observed within teeth (e.g., diet, mobility). What an animal was eating and where they were eating it may change while different parts of the teeth were mineralizing resulting in the observed variation.

The impact of seasonality on white-tailed deer teeth requires further investigation given the observed differences between different types of teeth (e.g., M1 versus M2) and within a single tooth (e.g., enamel from the apex versus the CEJ). Changes in diet and territory of individual animals, as well as environmental changes in strontium may all result in the observed variation in $^{87}Sr/^{86}Sr$ values. The inclusion of more samples from both white-tailed deer, as well as different species, will help clarify the observed differences and establish their cause (e.g., seasonal changes in mobility or diet).

The influence of metabolism and human interaction also need to be considered. The incorporation of strontium from bone in addition to that consumed by the animal may change depending on the remodelling process. Additionally, where humans live and grow their crops will dictate the distribution of white-tailed deer in southern Ontario with research suggesting that where crops are grown affects deer dispersal (Morris 2015). Finally, the local environmental variation in the territory occupied by the white-tailed deer will dictate what strontium isotopes are available for consumption and interpretation. Therefore, some degree of variation is expected between individuals, as not all deer will live in the same location. This is important, however, as it is this variation between areas that enables strontium isotope analysis to identify non-local individuals in archaeological studies.

Overall, given their limited mobility and the large amount of research available on their behaviour, white-tailed deer represent a viable option for establishing local bioavailable strontium isotope baselines in southern Ontario. Although further data to elucidate observed variation would be ideal, based on the current project, white-tailed deer can provide meaningful strontium isotope data. This is beneficial given their relative abundance at archaeological sites throughout the area.

8.2 Strontium in bedrock

Overall, there is minimal variation in $^{87}Sr/^{86}Sr$ values from sampled deer teeth located on different types of bedrock. Observed mean $^{87}Sr/^{86}Sr$ values range between 0.70900 (Middle Ordovician limestone) and 0.71029 (Middle and Lower Silurian sandstone) and exhibit wide overlapping ranges. This minimizes the ability of researchers to investigate mobility in southern Ontario using a strontium isotopic baseline created with white-tailed deer teeth.

Although some degree of averaging is expected given the biological nature of the samples (i.e., strontium in teeth is obtained from a number of different sources), the extent of the similarities observed between limestone, shale and sandstone is somewhat unexpected given the variation in predicted and proxy values presented in Chapter Three. According to the previous research that has been conducted on strontium in bedrock, as well as the theoretical model, limestone should have a value of approximately 0.708 (both predicted and proxy), shale of 0.722 (predicted) and 0.710 (proxy) and sandstone of 0.714 (predicted) and 0.711 (proxy). The observed mean values from deer teeth, on the other hand, are $^{87}Sr/^{86}Sr$=0.709 for limestone and $^{87}Sr/^{86}Sr$=0.710 for both sandstone and shale.

There are a number of possible phenomena that explain these similar mean $^{87}Sr/^{86}Sr$ values with wide overlapping ranges including: mineral composition, bedrock heterogeneity, sediment composition, and white-tailed deer acquisition. Additionally, the location of the bedrock and number of samples may exert an influence on the similar mean $^{87}Sr/^{86}Sr$ values while white-tailed deer behaviour can contribute to the wide range of $^{87}Sr/^{86}Sr$ values recorded within a single location.

8.2.1 Mineral composition

Bedrock is heterogeneous in that it is composed of different types of minerals, which can explain both the similar mean values between different types of bedrock as well as the wide range of values within and between types of bedrock. For example, sandstone is a sedimentary rock composed primarily of quartz, chert, and feldspar, with traces of micas and chlorite (McBride 1963: Table1). Shale, on the other hand, is 59% clay, 20% quartz and chert, 8% feldspars, 7% carbonates, 3% iron oxides, 1% organic matter and 2% miscellaneous minerals (Yaalon 1961). Of these individual components, feldspars, clays and micas all contain enriched rubidium concentrations that contribute higher $^{87}Sr/^{86}Sr$ values (Capo et al. 1998:199, Ericson 1985:505). Shale contains two of these enriched rubidium minerals (clay and feldspar) while sandstone contains feldspar and mica. It may be that these minerals contribute comparable strontium to the overall similar mean strontium isotope ratios and overlapping ranges. However, should this be the case, one would expect to see similar $^{87}Sr/^{86}Sr$ values in the proxy and predicted models, which does not occur. Therefore, unless there are unusual proportions and/or concentrations of specific minerals unique to this area, the mineral composition is not responsible for the observed similarities.

However, the various minerals that comprise bedrock can explain the wide range of values within a single type of bedrock. Minerals will erode at a unique pace releasing strontium isotopes at different rates (Price et al. 2002). This has the possibility to change the observed $^{87}Sr/^{86}Sr$ values within a single type of bedrock and result in the wide overlapping range in observed $^{87}Sr/^{86}Sr$ values obtained from white-tailed deer teeth.

8.2.2 Bedrock heterogeneity

Similar to how a single type of bedrock is composed of a variety of different minerals, there are few locations where a site is composed exclusively of one type of bedrock. Rather, a location will typically contain a mixture of different types and proportions of bedrock. For example, within the two categories of shale and sandstone located in Ontario, shale, dolostone and siltstone are all shared between them (i.e., sandstone contains shale, dolostone and siltstone while shale also contains dolostone and siltstone). This is also visible in archaeological reports. For example, at sites such as Hood (AiHa-7), which is situated primarily on Middle and Lower Silurian sandstone, excavators noted the presence of limestone boulders nearby (Lennox 1984). Therefore, the mixtures of different types of bedrock at a single location may have resulted in the similar observed mean $^{87}Sr/^{86}Sr$ values and overlapping ranges from deer teeth.

The wide range of values will also reflect this heterogeneity as each of the different types of bedrock at a location has a unique strontium value to contribute, different from the principal type of rock. Individual deer teeth may be reflecting consumption of plants growing on different types of bedrock present in the same location.

Despite the observed similarities in $^{87}Sr/^{86}Sr$ values, there is a statistically significant difference between the mean $^{87}Sr/^{86}Sr$ values from two different limestone categories. Two possibilities can account for this difference. First, the difference could be a result of the age of the limestone. One of the limestones originates in the Middle Ordovician (470mya- 458mya) while the other is from the Middle Devonian (390mya-385mya). However, this is unlikely given the large half-life of rubidium (48.8 billion years). Therefore the other possibility, the heterogeneity of the bedrock contributing a variety of $^{87}Sr/^{86}Sr$ values, is more probable. Although both groups are primarily limestone, one contains traces of sandstone and arkose while the other one does not. Therefore the slight difference in $^{87}Sr/^{86}Sr$ values may be reflecting the presence of the mixture of bedrock types.

8.2.3 Sediment and soil composition

One of the biggest potential influences on $^{87}Sr/^{86}Sr$ values is the presence of sediment and soil located on top of the bedrock resulting in the similar $^{87}Sr/^{86}Sr$ values. According to the predicted values obtained in Chapter Three, local sediments and soils all exhibit mean $^{87}Sr/^{86}Sr$ values of 0.71145-0.71147, no matter the type of sediment or soil. Similarly, the observed values from deer teeth for sediments and soils range between $^{87}Sr/^{86}Sr$ =0.70948 and $^{87}Sr/^{86}Sr$ =0.71056, which are very similar to the observed values for bedrock. Therefore, strontium from the sediment and soil may be exerting a stronger influence on local $^{87}Sr/^{86}Sr$ values than the bedrock itself, resulting in an averaging mechanism that makes $^{87}Sr/^{86}Sr$ values more alike. This is likely given the extensive glaciation that occurred in southern Ontario, which resulted in extensive churning of the local sediments and soils, resulting in widespread mixing and the wide range and similar mean $^{87}Sr/^{86}Sr$ values noted.

The presence of different types of sediments and soils located on top of the bedrock of a location may also be a significant contribution to the range in values present. Different types of sediments and soils can potentially contribute a variety of strontium isotopes to the observed values for each type of bedrock. Given the mobile nature of sediment/soil relative to bedrock, as well as the nature of the incorporation of strontium into the food chain, it is not improbable that local sediment and soil values can contribute a range of values to a single location. This is particularly pertinent in areas that have experienced extensive glaciation resulting in mixing of sediments. However, the similarity in sediment and soil $^{87}Sr/^{86}Sr$ values makes this possibility less likely.

8.2.4 White-tailed deer acquisition

Cultural influences on strontium isotope analysis such as white-tailed deer acquisition by local indigenous groups can likewise result in the observed $^{87}Sr/^{86}Sr$ values. Although the archaeological sites where the deer teeth were recovered are located on different types of bedrock, the deer themselves may have been obtained from the same geographic location. Many archaeological sites in southern Ontario are located close to one another. Therefore, it could be that their hunting territories, which were approximately six to thirteen kilometers per village (Gramly 1977; Turner and Santley 1979; Webster 1979), overlapped with deer originating from the same place. This is particularly plausible if Morris' (2015) suggestion that deer were not eating maize, which was grown next to the village, is true. As such, hunting territories would have been located further away from villages and more apt to be inadvertently shared or located on different types of bedrock. This would result in similar mean $^{87}Sr/^{86}Sr$ values and overlapping ranges.

Additionally, it may be that sampled white-tailed deer were obtained at different times of the year thus resulting in the wide range of $^{87}Sr/^{86}Sr$ values. For example, in the summer, poor weather would not have been a concern for hunters and so extended hunting trips could be engaged in safely. Hunters could have traveled to areas with different types of bedrock to obtain deer. In winter, however, hunting strategies may have changed depending on weather and deer behaviour. Therefore, deer may have been obtained in a different area in the summer compared to winter, when weather and food availability was more unpredictable. The bedrock in the area where the deer are being obtained may or may not line up with the bedrock where the village is located. In other words, deer remains recovered on one type of bedrock may have lived in different locations.

8.2.5 Bedrock location

In southern Ontario, the superficial bedrock is situated in diagonal strips that are in close proximity to one another. Bands of sandstone are located next to shale while limestone is located closer to the Trent-Severn waterway near the border of the Canadian

Shield (see Figure 7.7). The potential for overlap between different types of bedrock thus exists, possibly muddling $^{87}Sr/^{86}Sr$ values. Furthermore, given the close proximity of the different types of bedrock, the sampled deer may have spent time on multiple types of bedrock. Therefore, their tissues will contain a mixture of $^{87}Sr/^{86}Sr$ values from various bedrock types (e.g., sandstone and shale) resulting in the similar mean $^{87}Sr/^{86}Sr$ values.

8.2.6 Number of samples

The number of samples obtained from each type of bedrock may also exert an influence on the observed values. There are a limited number of samples obtained from shale (11 teeth from 4 sites) compared to sandstone (60 teeth from 16 sites). With increased sample size comes increased accuracy and precision as the influence of any outliers is minimized. However, although shale has the smaller sample size, its observed mean $^{87}Sr/^{86}Sr$ value of 0.710 is identical to the proxy value for $^{87}Sr/^{86}Sr$ of shale obtained from previously published studies while sandstone exhibits a 0.001 difference between observed and proxy $^{87}Sr/^{86}Sr$ values. Therefore, sample size may not be responsible for the observed similarities in $^{87}Sr/^{86}Sr$ values.

8.2.7 White-tailed deer ecology and behaviour

The possible reasons for the range in variation have all been environmental in nature; however, white-tailed deer behaviour may also explain what is visible in the experimentally observed values from their teeth. For example, individual grazing patterns in white-tailed deer may result in the wide range of observed strontium values. There is a suggestion that deer have dietary preferences depending on characteristics such as sex (see Chapter Two, Section 2.3.5) and as such, individual deer could consume different food items. These food items could contribute various $^{87}Sr/^{86}Sr$ values depending on their root system and where they grow (e.g., next to a river or inland). This variation may therefore be a reflection of the dietary preferences for specific plants by individual deer.

Similarly, deer may have different territories depending on the time of year (see Chapter Two, Section 2.3.5). These territories may or may not have been located on the same type of bedrock, allowing for the incorporation of different strontium isotopes and resulting in different $^{87}Sr/^{86}Sr$ values. Similarly, should deer change elevation as Horsley and colleagues (2003) suggest, the variation in $^{87}Sr/^{86}Sr$ values may reflect elevation.

8.3 Strontium and geological formations

Geological formations are formally defined layers of similar rock and allow geologists to discuss different strata across wide distances. A number are present in southern Ontario, all composed of different types of bedrock from different time periods within the Palaeozoic era (see Table 2.1). There are a number of statistically significant differences in mean $^{87}Sr/^{86}Sr$ values between different geological formations. Those that exist between formations composed of different types and ages of bedrock are expected given the slight differences documented between bedrock. However, those that are present between formations composed of bedrock of the same age showcase the importance of sediment and soil in $^{87}Sr/^{86}Sr$ values. Specifically, the Amabel formation, Guelph formation, and Lockport formation are all composed of Middle/Lower Silurian dolomite, yet each is covered with a different mixture of sediments and soils with statistically significant differences present (see Table 7.14).

The presence of sediment and soil could also explain the relatively wide range of $^{87}Sr/^{86}Sr$ values within each formation. Although given the similarity of sediment/soil $^{87}Sr/^{86}Sr$ values, this is less likely. Alternatively, it could be a result of cultural practices. Cultural groups are not restricted to a single geological formation but rather lived and moved across a variety of formations. Although the Huron-Wendat and Neutral are similar in a number of ways, cultural differences do exist (see Chapter Five) that could result in the range of values present within a single formation (e.g., different trade partners, alliances and agricultural focus affecting white-tailed deer acquisition).

It is interesting that the Hamilton Group does not exhibit the same range in $^{87}Sr/^{86}Sr$ values as the rest of the sampled geological formations. The Hamilton Group is located primarily in the United States near traditional Neutral and Erie territory with small outcroppings in southwestern Ontario. It is composed primarily of shale and limestone (see Table 2.1). Given its relatively small size, there is only a single sampled site located on the Hamilton Group, the Boresma site, which could have resulted in the narrow range in variation present. However, a single archaeological site is located on a number of other geological formations, including the Blue Mountain Formation, Clinton Group, Dundee Formation, Kettle Point Formation, and Lockport Formation, and yet these sites exhibit a greater range of variation in $^{87}Sr/^{86}Sr$ values than the Hamilton Group. As such, the variation in these formations reflects a number of factors rather than solely sample size and is subject to a wide range of influences including environmental and cultural aspects such as those previously noted.

8.4 Strontium in sediment and soil

As with bedrock, there is a narrow range in mean values of sediments and soils found in southern Ontario ($^{87}Sr/^{86}Sr$= 0.70948-0.71056.) and a relatively wide range in values in individual types of sediment/soil (e.g., $^{87}Sr/^{86}Sr_{clay}$ = 0.70915-0.71212). Overall ranges in $^{87}Sr/^{86}Sr$ values for different types of sediment and soil overlap. Of the observed values, clay exhibits the most elevated $^{87}Sr/^{86}Sr$ values at $^{87}Sr/^{86}Sr$ =0.71056 relative to the other types of sediment. This is expected given its enriched rubidium concentrations (Capo et al. 1998). The remaining sediments and soils cluster together from $^{87}Sr/^{86}Sr$=0.70948 to 0.70999. The similar mean $^{87}Sr/^{86}Sr$ values and wider range of $^{87}Sr/^{86}Sr$ values can be explained by white-tailed deer behaviour (e.g., diet) and white-tailed deer acquisition as noted previously. Other explanations include heterogeneous composition, atmospheric deposition of strontium and sediment depth.

Cultural influences on sediment and soil should not have much impact on strontium isotope analysis. Northern Iroquoians were known to build their settlements in areas with sandy well-drained soil that is preferable for growing maize. This is visible in the number of sites located on sand (n_{sand}=15) relative to the other types of soil (n_{clay}=4, $n_{diamicton}$=6; n_{gravel}=4; n_{silt}=2). However, this is the extent of their documented relationship with soil. They did not fertilize their crops other than by burning down trees in the area in which they wished to plant, which would already contain local $^{87}Sr/^{86}Sr$ values, nor did they move sediment or soil around. Therefore, cultural influences on sediment and soil should not have much impact on strontium isotope analysis. Rather, the environmental factors and white-tailed deer behaviour and ecology should have a greater effect on local $^{87}Sr/^{86}Sr$ values.

8.4.1 Heterogeneous composition

Sediments and soils are seldom composed of a single type of mineral, as they are derived from the bedrock, which is often heterogeneous. Although general trends are present (e.g., clay is derived primarily from minerals such as illites while sand and silt originate from mica [Mengel et al. 1998]), sediment and soil are not usually homogenous. For example, sand describes a collection of small pebbles and granules smaller than one millimeter in diameter while silt is composed of particles smaller than sand but larger than clay (Wentworth 1922). Similarly, gravel is used to describe material made up of small pebbles and granules, larger than sand (Wentworth 1922). These particles may or may not derive from the same mineral within bedrock, or the same type of bedrock.

Furthermore, given the size of the grains of materials that make up sediments and soils, they are easily transported by water or wind and mixed with other particles. This leads to a mixture of sediments and soils located in a single location. This is compounded by the action of glaciers. As glaciers move across the landscape, they churn up sediments and soils, mixing them together and moving them from location to location. Therefore, different particles in sediment and soil may have originated from various areas and ended up mixed together in the same location with the similar mean $^{87}Sr/^{86}Sr$ values and overlapping ranges reflecting these phenomena.

8.4.2 Atmospheric deposition of strontium and sediment depth

Strontium isotopes can be deposited onto local sediments and soils and later incorporated into the food chain via organic material and atmospheric deposition. As discussed in Chapter Two, Section 2.3.2, inconsistencies in $^{87}Sr/^{86}Sr$ values between soil depths have been documented. Factors such as rain, animal action (e.g., worms), and wind can all contribute strontium that differs from the local bedrock. Therefore, it may be that white-tailed deer obtain strontium from different layers of sediment or soil in the same location. This is particularly feasible if white-tailed deer consumed a selective diet based on individual preferences because the roots of plants may have obtained strontium from different soil layers depending on nutrient availability and plant species.

8.5 Strontium and elevation

As elevation increases, it appears that observed $^{87}Sr/^{86}Sr$ values decrease slightly. This correlation could be a result of different types of bedrock and minerals present at higher elevations than those at lower elevations thus contributing different strontium isotopes to the observed $^{87}Sr/^{86}Sr$ values. For example, limestone ($^{87}Sr/^{86}Sr$ =0.709) could be located at the top of a hill while sandstone and shale ($^{87}Sr/^{86}Sr$ =0.710) are found at lower elevations.

This could also be a result of the movement of water and sediment/soil between different elevations. As Bentley (2006) suggests, $^{87}Sr/^{86}Sr$ values located at the top of a hill will reflect solely the contributing sources at that elevation whereas $^{87}Sr/^{86}Sr$ values located at the bottom will be derived from a mixture of sources located at both the top and bottom of the hill. Therefore, the difference in observed $^{87}Sr/^{86}Sr$ values and elevation could reflect the movement of bioavailable strontium isotopes from location to location.

Although there appears to be a slight negative correlation in $^{87}Sr/^{86}Sr$ values with elevation, it is important to remember that the strontium obtained from these sites is not exclusively from water, which is one of the principal factors influenced by elevation. Instead, these values are an average of all sources of strontium isotopes consumed by the individual deer. As such, these are not comparisons between the top of a hill and the bottom of the same hill, unlike the study conducted by Tricca and colleagues (1999). Although it has been noted that deer can move between altitudes (Horsley et al. 2003), other factors contribute strontium to the sample, including geology, sediments and soils, and water, with aspects such as intra- and inter-tooth variation also influencing strontium isotope ratios.

8.6 Strontium and archaeological sites

Archaeological sites sampled for this research are affiliated with two different indigenous populations (the Huron-Wendat and the Neutral) and represent a number of different types of site (e.g., village, palisaded village, hamlet). Their occupancy spans from A.D. 75 (Boresma) to A.D. 1651 (Bogle II). They are located on a range of bedrock and sediment/soil combinations at different elevations. The local environmental conditions, individual site backgrounds, and methodological influences are considered when discussing the observed variation both within and between archaeological sites in the following paragraphs.

8.6.1 Variation within sites

Most of the sampled archaeological sites provide white-tailed deer teeth with similar mean $^{87}Sr/^{86}Sr$ values, low standard deviations (i.e., at the fourth and fifth place past the decimal) and limited variation such as can be seen at the Coulter, Fonger and Kirche sites. However, four sites Trent, Ludlow Vanderlip, McMurray and Walker have a wide range of variation in $^{87}Sr/^{86}Sr$ values with large standard deviations (i.e., standard deviations at the third place past the decimal) (see Table 7.19). There are several possibilities to explain this range in variation in $^{87}Sr/^{86}Sr$ values at sampled archaeological sites. These include archaeological recovery methods, environmental factors, tooth type and cultural influences such as acquisition by local indigenous groups.

The first possibility concerns the archaeological methods used to obtain the teeth. For example, the Coulter site exhibits minimal variation in $^{87}Sr/^{86}Sr$ values while the Trent site has a wide range. Teeth from the Coulter site were all obtained from an archaeological context, in either a house midden or in a palisade square. Therefore, the chance of modern inclusion is slim thus minimizing the possibility that anthropogenic strontium influenced local $^{87}Sr/^{86}Sr$ values. Teeth from the Trent site, on the other hand were surface collected. These teeth could come from more modern animals, which are influenced by fertilizer and other sources of anthropogenic strontium. Two of the teeth from this site exhibit $^{87}Sr/^{86}Sr$ values that are similar to contemporaneous other teeth obtained nearby on the same type of bedrock (limestone, $^{87}Sr/^{86}Sr$=0.708) suggesting that these two teeth reflect the local values when the site was occupied. However, the third tooth with its anomalous value ($^{87}Sr/^{86}Sr$=0.71124) could represent a modern tooth rather than an archaeological one. This is a potential error introduced by the collection of the tooth rather than the environmental or cultural contexts. This illustrates the importance of using teeth from confirmed archaeological contexts.

However, use of archaeological teeth may result in limited variation in $^{87}Sr/^{86}Sr$ values as documented at Kirche, Coulter, and Fonger. Archaeological teeth were often obtained individually as loose samples, (i.e., were not anchored in bone), and therefore the possibility exists that some of the teeth originate from the same individual. This could explain why the $^{87}Sr/^{86}Sr$ values are all similar, as they came from the same animal and therefore the strontium isotopes are coming from the same sources. However, assuming this is correct indicates that there are no significant differences between teeth obtained from the same animal, which may or may not be true.

The second possibility for the documented range of values considers the local environment surrounding the archaeological sites. Archaeological sites are located on different combinations of bedrock and sediment/soil (see Table 6.2) eliminating the possibility that a specific type of bedrock and sediment/soil results in a smaller or larger range in variation of strontium isotopes. However, the amount of local variation surrounding each of these sites could explain the visible range in values. For example, Walker and Ludlow Vanderlip, which both exhibit a wide range of $^{87}Sr/^{86}Sr$ values, are located near one another on sandy soils with deposits of clay surrounding these sandy areas. Clay has higher concentrations of rubidium and therefore higher $^{87}Sr/^{86}Sr$ values (Stueber et al. 1972; Capo et al. 1998:199). The more variable $^{87}Sr/^{86}Sr$ values observed at Walker and Ludlow Vanderlip could reflect the acquisition of deer that grazed in areas dominated by different types of sediment or soil with the lower $^{87}Sr/^{86}Sr$ values resulting from sand and the higher $^{87}Sr/^{86}Sr$ values resulting from the clay nearby. This idea is supported, as the outlying values are around $^{87}Sr/^{86}Sr$ =0.711 ($^{87}Sr/^{86}Sr$= 0.71142 and $^{87}Sr/^{86}Sr$= 0.71104), similar to the $^{87}Sr/^{86}Sr$ value obtained from Thorold, which is located on clay (but see $^{87}Sr/^{86}Sr$ values for Knight-Tucker and McPherson which are also located on clay).

Similarly, the presence of different types of sediment or soils could explain the distribution of $^{87}Sr/^{86}Sr$ values noted at McMurray. The McMurray site is located on silt, a type of heterogeneous medium-grained sediment that is often the result of the movement of glaciers. It may be that local variation in sediments and soils resulting from glacial movement at this site resulted in the observed different $^{87}Sr/^{86}Sr$ values but at a local scale not necessarily documented in larger maps such as those created by the Department of Soils at the Ontario Agricultural College (Canada Department of Agriculture, Ottawa).

These possibilities do not, however, explain the outlying $^{87}Sr/^{86}Sr$ value obtained at the Trent site (MCTRE5), which is located in an area with a more consistent sediment/soil distribution. Instead, it could be that an outcrop of a secondary type of bedrock was present resulting in the outlying $^{87}Sr/^{86}Sr$ value of 0.71124. Middle Ordovician dolomite should have a $^{87}Sr/^{86}Sr$ value of 0.71069 according to the predictive model with Middle Ordovician arkose exhibiting a $^{87}Sr/^{86}Sr$ value of 0.71434 and Middle Ordovician sandstone a $^{87}Sr/^{86}Sr$ value of 0.71441. These could combine to give the observed $^{87}Sr/^{86}Sr$ value of 0.71124.

Despite these possible explanations, it bears noting that the Coulter, Fonger and Kirche sites all exhibit some degree of local environmental variation at each site and yet they do not exhibit the same range in $^{87}Sr/^{86}Sr$ values as Walker, McMurray, Ludlow Vanderlip and Trent (see Table 6.2). Therefore, the local environment may not explain the wide range in values noted at Walker, McMurray, Ludlow Vanderlip, and Trent.

The third potential explanation for the range in observed $^{87}Sr/^{86}Sr$ values could be the result of sampling different types of teeth (i.e., M1 versus M2 versus M3). As was demonstrated, differences between types of teeth are present. Different teeth from each site were sampled due to availability and as such, M1's are grouped with M2's and M3's to obtain the mean $^{87}Sr/^{86}Sr$ values and overall range in values. These different types of teeth could therefore reflect strontium ingested from the same area but at various times of the year. For example, teeth from sites with a wide range of $^{87}Sr/^{86}Sr$ values (e.g., Walker, McMurray, Ludlow Vanderlip, and Trent) included M2's while teeth from Coulter, Fonger, and Kirche, sites that did not exhibit the same range in values, only included M1's and M3's. The inclusion of M2's in the first sample set could have contributed to the range in variation. Should this be true, this has implications for how $^{87}Sr/^{86}Sr$ values are mapped, as the typical assumption is that a single mean value is representative of the area rather than a range of values.

However, differences were also observed between M1's and M3's in this research. Therefore, the exclusion of M2's in the sample set may not necessarily have resulted in the smaller range of variation but rather may be a coincidence. Furthermore, no M2's were sampled at the Walker site, which exhibited a wide range in $^{87}Sr/^{86}Sr$ values. Therefore, variation in $^{87}Sr/^{86}Sr$ values may not be a reflection of seasonality.

Finally, the influence of culture on the acquisition and processing of white-tailed deer remains could result in the visible variation (or lack thereof). Cultural affiliation does not appear to influence strontium values at a single site, as the Trent, Kirche, and Coulter sites are located in traditional Huron-Wendat territory and the other four sites (Walker, McMurray, Ludlow Vanderlip, and Fonger) are located in Neutral territory; however, the type and purpose of sites may exert an influence. Of those sites that have a wide range in $^{87}Sr/^{86}Sr$ values, Walker and McMurray are both classified as villages, the Trent site consists of a single heavily fortified longhouse and the Ludlow Vanderlip site is a hamlet. Conversely, the Kirche, Coulter, and Fonger sites are palisaded villages with at least 18 longhouses, pit features, and middens present at each. These three sites are all the same site type and each has minimal variation in $^{87}Sr/^{86}Sr$ values. Each of these site types will have different nutritional requirements, population numbers and defensive concerns, which could all dictate the acquisition of white-tailed deer and subsequent disposal of their remains.

The available literature that focuses on the Walker site states that it is a large village with minimal defensive structures (i.e., no palisade). This lack of defense suggests that warfare was not necessarily a concern for its residents. Therefore, they may have felt safer traveling further away from their village to obtain white-tailed deer. Furthermore, Walker would have been home to a large number of people given the number of longhouses present at the site. More people allows for a greater division of labour. One group of individuals could stay home to protect the village in the event of an attack while another group goes hunting to provide food for the village. Additionally, with more people available to participate in hunting activities, more territory could be covered, resulting in deer coming from a wider area. Finally, with greater numbers of people, more food is required to sustain them, perhaps more than the surrounding area was able to provide, necessitating a larger hunting territory. These factors could result in the consumption of deer obtained from different areas, with different sediment and soil types and/or bedrock, particularly given the local environmental variation present around the Walker site.

Unfortunately, not as much information is available for the McMurray site; however, a number of longhouses were documented (Fitzgerald 1990:322). As such, it follows that a larger number of individuals would be present allowing for a similar division in labour such as what could have occurred at Walker, as well as a requirement for more food. However, information about the defensive structures at McMurray is unavailable, limiting the amount of interpretation that can be made about deer acquisition at this site.

Similarly, there is a lack of published data for the Ludlow Vanderlip site; however, it is known to be a hamlet. Hamlets were occupied by smaller numbers of people with fewer buildings. However, this makes the range in $^{87}Sr/^{86}Sr$ values puzzling. With a smaller, less permanent settlement, the assumption is that resources would be obtained locally, with the inhabitants moving onto a new location once they are exhausted. It may be that people carried deer teeth with them while they moved;

however, they have minimal spiritual significance and were not used in the manufacture of tools, making their transportation unlikely. Therefore, based on this, Ludlow Vanderlip should have a narrow range in variation.

Alternatively, the Ludlow Vanderlip site could have been occupied for a specific reason, making it a special purpose site. Ethnohistoric literature suggests that occasionally seasonal camps were established for specific purposes, such as agriculture or fishing (Trigger 1987). Should this be the case, perhaps the Ludlow Vanderlip site was used as a staging ground for hunting in remote areas, thus the deer from this site are coming from a wide range of areas rather than locally. This might explain the observed range in $^{87}Sr/^{86}Sr$ values.

The Trent site was a small site, consisting of a single longhouse and three human burials within a heavily fortified area. This concern with defense and the presence of human burials suggests that warfare was a possibility at the site. Logically, this would mean that a small population with a fear of the surrounding area would not venture far away from the safety of the site while hunting. One would therefore expect a narrow range of $^{87}Sr/^{86}Sr$ values at the Trent site such as is visible at the Fonger site, which has a 3-4 row palisade (assuming a palisade is indicative of defensive concerns). Two of the three $^{87}Sr/^{86}Sr$ values from the Trent site cluster together around $^{87}Sr/^{86}Sr = 0.708$; however, the third tooth has a $^{87}Sr/^{86}Sr$ value of 0.71124. Therefore, based on the cultural context, it is probable that this tooth is not from the local area but rather was brought in from elsewhere.

Trade could be responsible for the wider range of values found at Walker, McMurray, Ludlow Vanderlip and Trent with the importation of white-tailed deer teeth. This may be true for larger sites such as the Walker, McMurray or Ludlow Vanderlip sites. However, given the possible turbulence at the Trent site, importing deer seems less likely. This is because of the Huron-Wendat's reluctance to trade with individuals who were deemed to be an enemy (Ramsden 1977:291) and the Trent site is located within traditional Huron-Wendat territory. Therefore, the potential warfare at the Trent site minimizes the prospect of abundant, long distance trade importing white-tailed deer teeth. Additionally, the abundance of white-tailed deer locally suggests that they would not need to be imported. Furthermore, the Coulter and Kirche sites, both of which were palisaded villages located in traditional Huron-Wendat territory, do not exhibit the wide range of $^{87}Sr/^{86}Sr$ values. Therefore, importation of white-tailed deer teeth may not be an acceptable explanation.

Overall, the outlying value at the Trent site is most likely a result of local environmental variation, given the concern with warfare and defense at the site, which would limit mobility for hunting and trade. The variation at the Walker site and McMurray site is expected, given the larger population and the benefits and disadvantages associated with their larger sizes. The Ludlow Vanderlip site, however, is more puzzling unless the site was used as a staging area for long distance hunting trips.

It has been suggested that both Coulter and Kirche were expanded at least once due to either warfare or a desire to take advantage of the fur trade. If either of these explanations are correct, it would suggest a preoccupation with both events. This would make the acquisition of food important but not the primary concern for the inhabitants at these sites. With the occupants focusing on these other concerns, obtaining deer located close by would allow more time to be spent either hunting beaver for the fur trade or conducting warfare. However, this is merely speculation and may or may not be a plausible explanation for the observed $^{87}Sr/^{86}Sr$ values.

Finally, there has been some ethnographic evidence suggesting that the Neutral penned white-tailed deer so as to ensure a ready supply (Noble 2007). If this were true, this could possibly explain the minimal range in $^{87}Sr/^{86}Sr$ values at the Fonger site. However, this lack of variation is not present at other Neutral sites suggesting that this practice was not common throughout Neutral territory. It is more likely that the type of site is influential in the observed range of values.

There is the possibility that the pattern present in the relationship between $^{87}Sr/^{86}Sr$ values and the type of site are the result of sample size. However, an identical number of samples were obtained from various types of sites that exhibit both a wide and narrow range of variation (e.g., n=3 teeth; Coulter, Kirche, Ludlow Vanderlip, McMurray, and Trent). The remaining two sites provide samples from four and five teeth (Fonger and Walker respectively). It may be with additional samples that a pattern emerges; however, currently sample size does not appear to affect the results.

The type of site may therefore explain the range in $^{87}Sr/^{86}Sr$ values, with cultural concerns influencing where and how white-tailed deer were obtained. In conjunction with environmental factors, the possibility of warfare, nutritional requirements and population density at specific types of site can dictate $^{87}Sr/^{86}Sr$ values.

8.6.2 Variation between sites

$^{87}Sr/^{86}Sr$ values for the sampled archaeological sites range from $^{87}Sr/^{86}Sr$ =0.70856 to $^{87}Sr/^{86}Sr$= 0.71185. This is not unexpected given the environmental and cultural influences on strontium isotopes at each site as discussed above. However, the potential exists that cultural affiliation may affect strontium isotope analysis in this region. While the Huron-Wendat and Neutral appear to be similar in many respects, differences have been noted between the two populations (see Chapter Five). Therefore, the possible impacts of cultural affiliation (e.g., Neutral or Huron-Wendat), the time of site occupation and site type (e.g., village versus hamlet) should be considered when analyzing strontium isotope data.

Traditionally, local indigenous groups are hypothesized as living within certain areas (see Figure 5.1). The Huron-Wendat are depicted as living further north than the Neutral on the shores of Georgian Bay in the Lake Simcoe region as that is where they were living at the time of European contact. The Neutral, however, lived closer to Lake Ontario, near what is now the city of Hamilton, Ontario. Different types of bedrock characterize these two areas (limestone versus sandstone and shale) and so the possibility exists that the two populations can be characterized isotopically.

Assuming this view of indigenous territories is correct, the Kirche, Trent, Coulter, Benson and Cahaigue sites are all located within traditional Huron-Wendat territory. Of these five sites, three exhibit $^{87}Sr/^{86}Sr$ values of approximately $^{87}Sr/^{86}Sr$= 0.708 (Benson, Coulter, Kirche) while the remaining two sites cluster around $^{87}Sr/^{86}Sr$=0.709 (Trent and Cahaigue). All are located on Middle Ordovician limestone with different types of sediment and soil. The remaining sites are situated within traditional Neutral territory and range from $^{87}Sr/^{86}Sr$=0.709 to $^{87}Sr/^{86}Sr$= 0.711. They are located on various types of bedrock and sediment including Middle/Lower Silurian sandstone and Upper Ordovician shale. There is some overlap between the two groups, with both exhibiting values of $^{87}Sr/^{86}Sr$=0.709. This makes classifying cultural affiliation using strontium isotope analysis problematic.

This overlap could be because of environmental mixing (i.e., sediment, soil, and bedrock heterogeneity) or white-tailed deer grazing behaviour and mobility between different types of bedrock. Another explanation relies on the similarities between the two populations. It may be that both the Huron-Wendat and Neutral obtained white-tailed deer in the same way with similar hunting strategies and treated the white-tailed deer remains in a comparable fashion once they are acquired. This is unsurprising given the degree of similarity between the two populations (e.g., longhouse construction, use of ossuaries, focus on growing crops etc.).

Similarly, minimal differences in $^{87}Sr/^{86}Sr$ values are noted between sites occupied before European contact and those afterwards. For example, the Crawford Lake site ($^{87}Sr/^{86}Sr$=0.70952) was occupied between A.D.1350-1400, before European contact. The similar Christianson and Hamilton sites, were occupied after European contact (A.D. 1615-1630; $^{87}Sr/^{86}Sr$= 0.70983, S.D.=0.00026 and A.D. 1638-1650,; $^{87}Sr/^{86}Sr$= 0.70986, S.D.= 0.00033 respectively) (see Table 6.2). There are no interpretable differences in $^{87}Sr/^{86}Sr$ values present between these sites. This suggests that white-tailed deer behaviour, acquisition and disposal were unchanged by the arrival of the Europeans in this region.

The type of site (e.g., hamlet, village), however, may affect strontium values with different types of sites exhibiting variation in $^{87}Sr/^{86}Sr$ values when other factors are comparable (e.g. environmental, cultural). The Donovan site ($^{87}Sr/^{86}Sr$=0.71066, S.D.=0.00019), for example, is a Neutral village while the Fonger site ($^{87}Sr/^{86}Sr$=0.70997, S.D.=0.00007) is similar in every way except that it was a palisaded Neutral village (see Table 6.2). There is a statistically significant difference (p=0.001011) present between these two sites. Similarly, the Bogle II site ($^{87}Sr/^{86}Sr$=0.70981, S.D.=0.00023) is a hamlet while the Hood site ($^{87}Sr/^{86}Sr$=0.71025, S.D.=0.00041) is a palisaded village with burials, middens and pits. Again, the p-value (p=0.0012) suggests that there is a statistically significant difference between the two otherwise identical sites.

The type of site therefore appears to be important in strontium isotope analysis. This is logical given the different purposes of the sites. The Bogle II site is hypothesized as having been a hamlet or satellite village (Lennox 1984; Stewart 2000). It would have a smaller population and different purpose than the Hood site, which was a more populous and permanent village. Similarly, the presence of the palisade at Fonger suggests that the socio-political climate was different relative to the Donovan site, which lacked this structure. Therefore, the type of site influences where and/or how white-tailed deer are obtained and subsequently discarded, and by association, the observed $^{87}Sr/^{86}Sr$ values.

Given these conclusions, strontium isotope analysis of white-tailed deer teeth cannot be used to distinguish between different populations based on cultural parameters or time period. However, some variation based on type of site (e.g., hamlet versus village versus palisaded village) is visible.

8.6.3 Influences on $^{87}Sr/^{86}Sr$ values

Comparison between sites can also shed light on what constitutes the principal influence on $^{87}Sr/^{86}Sr$ values. For example, consider the Benson site located on sand ($^{87}Sr/^{86}Sr$=0.70893, S.D.= 0.00033) versus the similar Coulter site located on glacial drift ($^{87}Sr/^{86}Sr$=0.70856, S.D.= 0.00002) (see Table 6.2). There is no statistically significant difference present between these two sites (p=0.1246). This suggests that sediment and soil may not be the largest contributor of strontium to white-tailed deer teeth.

There is a possibility that elevation may impact $^{87}Sr/^{86}Sr$ values between different archaeological sites. For example, the Gunby site ($^{87}Sr/^{86}Sr$=0.70982, S.D.=0.00029) is located at an elevation of 259 masl while the similar Cleveland site ($^{87}Sr/^{86}Sr$=0.71036, S.D.=0.00063) (see Table 6.2) is located at an elevation of 219 masl, a difference of 40 meters. However, despite the difference in $^{87}Sr/^{86}Sr$ values, there is no statistically significant difference between these two sites (p=0.1393) suggesting that elevation may not be the principal factor that dictates strontium isotope analysis in this region.

Given that sediment, soil, and elevation do not appear to affect $^{87}Sr/^{86}Sr$ values, the influence of bedrock on $^{87}Sr/^{86}Sr$ values needs to be considered. Despite the lack of variation in mean $^{87}Sr/^{86}Sr$ values and the wide overlapping ranges in variation obtained from deer teeth located on different types of bedrock, sites located at comparable elevations and on similar types of sediment but on different types of bedrock exhibit variation in $^{87}Sr/^{86}Sr$ values. For example, the Benson site ($^{87}Sr/^{86}Sr$=0.70893, S.D.=0.00033) is located on Middle Ordovician limestone while the comparable Gunby site ($^{87}Sr/^{86}Sr$=0.70982, S.D.=0.00029), is located on Middle/Lower Silurian sandstone (see Table 6.2). A statistically significant difference is present (p =0.0070) thereby showcasing the importance of bedrock in $^{87}Sr/^{86}Sr$ values.

8.7 Strontium isotope analysis and mobility in southern Ontario

Overall, there is minimal variation in bioavailable $^{87}Sr/^{86}Sr$ values in southern Ontario. Strontium from environmental sources including bedrock and sediment/soil, and to a lesser extent water and elevation, all combine to generate the observed $^{87}Sr/^{86}Sr$ values. Bedrock contributes the majority of strontium isotopes in a region; however, sediment and soil plays a role given the significant differences present between geological formations. As noted in Chapter Two, the environment is best viewed as a mixing system and therefore the overall minimal range in variation in observed $^{87}Sr/^{86}Sr$ values reflects this fact. This is compounded given the averaging effect observed when strontium isotopes from various areas are consumed and incorporated into mammalian tissues. The minimal difference between various areas in southern Ontario has implications for the interpretation of mobility using strontium isotope analysis.

It was hoped that strontium isotope analysis could help elucidate the extent of movement that occurred within Northern Iroquoian populations. Topics such as post-marital residence, coalescence and fission, all of which concern the movement of individuals in a single group, have been the focus of various studies (see Chapter Five) and remain of interest to researchers today. Strontium isotope analysis, which allows for the investigation of movement, represents a new approach to studying these phenomena in southern Ontario. However, given the minimal variation present in southern Ontario and the inability to distinguish not only between Northern Iroquoian populations (e.g., the Huron-Wendat versus the Neutral) but also between individual villages, the utility of strontium isotope analysis to answer questions about mobility within groups in this region appears limited.

On the other hand, investigating movement between groups originating in southern Ontario (e.g., the Huron-Wendat, Neutral) and those from outside of the region (e.g., Algonquian groups, Europeans) remains feasible. In fact, the minimal variation in bioavailable $^{87}Sr/^{86}Sr$ values present in this area encourages this avenue of study as it makes identification of immigrants (i.e., those people who fall outside of the local narrow range) to the region more straightforward. For example, identification of visitors who were interred in ossuaries is possible. By comparing the $^{87}Sr/^{86}Sr$ values obtained from the individuals recovered within an ossuary to bioavailable strontium values such as those obtained for this research, relationships between different populations (e.g., Northern Iroquoians, Iroquoians, Europeans, and Algonquians) can be inferred (assuming that foreign individuals come from areas with distinct $^{87}Sr/^{86}Sr$ values). Therefore, clarification of the socio-political relationships that existed between groups originating from southern Ontario versus those from Europe and the Canadian Shield using strontium isotope analysis appears possible.

The feasibility of investigating the origins of Northern Iroquoian populations using strontium isotope analysis, however, remains unknown. Bioavailable $^{87}Sr/^{86}Sr$ values from the proposed origin areas need to be available, as well as individuals to sample. More research is therefore needed before strontium isotope analysis can contribute to the *in situ* or migration debate. The contribution that strontium isotope analysis can make to the Pickering conquest debate similarly requires further samples.

In order for strontium isotope analysis to be a viable technique for the study of mobility in this area, mean $^{87}Sr/^{86}Sr$ values without overlapping standard deviations of two sigma would be ideal (e.g., discrete ranges of $^{87}Sr/^{86}Sr$ values). This would easily allow for identification of individuals who grew up on specific types of bedrock and sediment/soil with minimal chance of error. In southern Ontario in particular, it would enable identification of the extent of mobility and relationships present within Northern Iroquoian groups (e.g., the Huron-Wendat versus the Neutral). However, this is not visible in the current research thus contributing to the limited ability of strontium isotope analysis to address questions about mobility in southern Ontario.

8.8 Strontium isotope analysis and seasonality

The identification of seasonality in strontium isotope analysis is important as it may result in a range of values that characterize a single location rather than the traditional single value. This is because environmental factors that influence the release and transport of strontium isotopes (e.g., water movement, precipitation) can be dictated by seasonality. This is important because the mineralization rates of different types of teeth (e.g., incisor, canine, premolar, molar) may occur at specific times of the year or take more than a single season.

Additionally, the influence of seasonality on strontium isotope analysis may be visible through the acquisition of white-tailed deer. Local indigenous populations may be obtaining white-tailed deer in different locations depending on the time of year. This could be because of white-tailed deer behaviour (e.g., the deer are living in different areas depending on the time of year) or human behaviour (e.g., local groups change their hunting strategies depending on the weather, which is dictated by seasonality [Birch and Williamson 2013]). These and other factors combine to provide the range in values observed in southern Ontario in different types of bedrock, sediment/soil, and archaeological sites.

With respect to individual samples, the influence of seasonality on $^{87}Sr/^{86}Sr$ values is not visible in the majority of sampled teeth. However, some statistically significant differences, perhaps as a result of seasonality, have been noted between teeth from the same individual (e.g., M1 versus M2). Furthermore, the small difference in $^{87}Sr/^{86}Sr$ values visible between enamel taken from the top of the crown versus the CEJ could be a result of seasonal differences and the timing of tooth mineralization. Although minimal information is available on this topic, the data suggest that teeth mineralize at different times of the year. If white-tailed deer are moving around southern Ontario depending on the time of year, the strontium isotopes that they consume will reflect this movement. These isotopes will end up in different teeth according to the season that the tooth forms. Further research on the influence that seasonality wields on strontium isotope analysis is merited.

8.9 Environmental and cultural influences on strontium isotope analysis

Strontium isotope analysis can provide researchers with an indication of how Northern Iroquoian populations interacted with their environment. Although a body of literature exists on this topic, since strontium originates from the environment, it can inform us about this relationship from a different perspective.

Firstly, insight on where white-tailed deer were obtained can be ascertained by establishing where the strontium in white-tailed deer teeth originated. By comparing the obtained values from white-tailed deer enamel to the predicted ones based on theoretical and proxy models, an idea of whether the observed values are representative of the region can be ascertained. Therefore, it is possible to know whether the white-tailed deer are living and being hunted from the local area. Despite some limitations with the predicted and proxy models as discussed previously, and the narrow range in observed variation between different types of bedrock, the experimentally obtained values suggest that white-tailed deer were, for the most part, obtained locally with few exceptions (e.g., tooth MCTRE5, obtained at the Trent site). This can then be used in conjunction with other lines of evidence to provide researchers with information on both human and white-tailed deer behaviour.

Similarly, how white-tailed deer were obtained will dictate observed $^{87}Sr/^{86}Sr$ values. For example, people who lived in hamlets may have been obtaining white-tailed deer, which were hunted principally as a source of food and hide, differently than those who lived at palisaded and unpalisaded villages with site type influencing $^{87}Sr/^{86}Sr$ values. These different acquisition strategies can reflect the number of individuals present at the site, the purpose of the site and/or the socio-political climate present when the deer were obtained. Similarly, the single tooth recovered at the Trent site (MCTRE5) that provided outlying data can suggest something about either the extent of hunting territories or trading at that site. In this way, researchers can supplement existing data on these topics with strontium isotope analyses to create a more nuanced interpretation of what was occurring when the white-tailed deer remains were obtained and subsequently discarded.

Conversely, the influence of the environment on the Northern Iroquoians is visible, as they would adapt their hunting strategies to better take advantage of white-tailed deer availability. Local populations would have an idea of where white-tailed deer are more likely to be located and would hunt accordingly. Similarly, it may be that climate dictated when local groups engaged in hunting and how far they would go from their homes to obtain white-tailed deer. These hunting areas can have different $^{87}Sr/^{86}Sr$ values depending on the local geological and sediment composition, as well as elevation. The local environment can dictate the strontium isotopes available for consumption by humans and animals.

This illuminates the complex relationship that exists between strontium isotope analysis, the environment and humans. Both environmental and cultural factors influence strontium isotope data and together they dictate the observed values. Therefore, strontium obtained from archaeological fauna can be used to investigate the two sides of this relationship: human behaviour with respect to obtaining white-tailed deer in the environment and the behaviour of white-tailed deer as influenced by humans and the environment. The environment and culture, as well as white-tailed deer behaviour were considered throughout the course of this research while attempting to understand the observed $^{87}Sr/^{86}Sr$ values obtained from white-tailed deer teeth.

8.10 Predicted versus observed $^{87}Sr/^{86}Sr$ values

There are a number of differences between the observed $^{87}Sr/^{86}Sr$ values and the predicted values, both theoretical and proxy. Overall, there is more variation in the predicted values than in the experimentally obtained strontium values. This is expected, however, given the biological nature of the samples used to obtain the experimental data. Although the theoretical values were obtained using equations that are designed to predict bioavailable $^{87}Sr/^{86}Sr$ values, unpredictable variation unique to individual animals wields an influence on strontium isotope analysis. For example, individual dietary preferences and environmental conditions (e.g., local food availability) cannot be accounted for in predictive models. Furthermore, when considering the proxy model, the predicted values represent solely bedrock, while the experimental values reflect bioavailable strontium. As such, some degree of mixing as the strontium is released into the environment and incorporated into the food chain is expected. Therefore, the values obtained from the deer teeth are averages of everything the deer ate and drank while the tooth that was sampled was developing. These, by the nature of how strontium is released (see Chapter Two), are likely to be different from the strontium still bound in the bedrock. Therefore, the narrower range in the observed values reflects the averaging effect of mammalian tissues on $^{87}Sr/^{86}Sr$ values.

Furthermore, the observed values include strontium from the sediments and soils of a location. As discussed in Chapter Two, Section 2.3.2, sediments and soils do not always derive from the bedrock on which they sit. They can be mobile and therefore add different strontium values to the food chain that are independent from the strontium contributed by the bedrock of a location. Therefore, these values will differ from the previously documented values that solely reflect the bedrock.

Additionally, the model itself has limitations, which will influence the resulting predicted values. Although the equations proposed by Bataille (2014) consider rock type, hydrology, climate and aerosols, there are still generalizations within the equations with the grouping of similar rock types (e.g., sedimentary, carbonate, etc.). Furthermore, the equations proposed by Bataille (2014) do not consider recycling minerals within a single type of rock. The deposition of a rock may not reflect its actual age, as a rock deposited in the Ordovician time period may contain minerals from the Silurian. This may explain why the proxy values are closer to the observed values than the predicted values.

Finally, bedrock in Ontario is composed of layers of different types of rock. For example, limestone is often deposited with dolomite, shale and arkose while sandstone is mixed with shale, dolomite and siltstone. These different types of rock will erode at different rates contributing different strontium isotopes. Therefore, the $^{87}Sr/^{86}Sr$ values obtained experimentally in southern Ontario will not reflect a single type of rock but rather a mixture of different types of bedrock.

8.11 Summary

Overall, the observed $^{87}Sr/^{86}Sr$ values are impacted by various factors including sampling methods (e.g., where on the tooth the sample originates from, which tooth is sampled, and how the tooth was collected), white-tailed deer biology and behaviour, the local environment where the tooth was recovered (e.g., type of bedrock, sediment or soil, elevation, environmental heterogeneity) and cultural influences (e.g., the type of site, white-tailed deer acquisition and disposal of white-tailed deer remains). The archaeological context of the tooth also needs to be considered (e.g., surface collection versus *in situ* collection) so as to ensure minimal error from modern contaminants. These all combine to give the observed $^{87}Sr/^{86}Sr$ values. The resulting values can then characterize the local bioavailable strontium (i.e., create an isotopic baseline), as well as be used in conjunction with additional lines of evidence to explore topics such as the socio-political and economic relationships present between different indigenous groups.

In southern Ontario specifically, there is minimal variation in bioavailable isotopes from white-tailed deer teeth limiting the utility of strontium isotope analysis to investigate mobility among the local indigenous populations of Huron-Wendat and Neutral. However, investigating movement between groups from southern Ontario and those from outside of the region (e.g., Algonquian groups, Europeans) is feasible. Additionally, strontium isotope analysis represents an alternative method to investigate the relationships between Northern Iroquoian populations and their environment. Further research is required to establish the potential of strontium isotope analysis to address the origins of Northern Iroquoian populations. Finally, the influence of cultural factors on strontium isotope analysis needs to be taken into consideration in studies making use of archaeological faunal samples.

Chapter Nine: Conclusions

This research was designed to investigate the possibility of using strontium isotope analysis to investigate archaeological migration events and associated phenomena in southern Ontario, Canada. Using 104 white-tailed deer teeth recovered at 31 different archaeological sites in the study area, strontium isotopes representing the pool of bioavailable isotopes in southern Ontario were obtained from 321 samples of enamel. Questions about variation within and between white-tailed deer teeth were considered before strontium isotope data were organized by environmental variables such as type of bedrock, sediment and soil, and elevation, as well as by cultural factors such as archaeological site. The influence of the environment, white-tailed deer behaviour and ecology and culture were all considered throughout the analysis as possible explanations for the variation (or lack thereof) in observed strontium isotope ratios. These were compared to two additional models created using previously published research: a proxy model based on $^{87}Sr/^{86}Sr$ in bedrock and a theoretical model based on mathematical modeling in ArcGIS. In this chapter, a summary of the findings is presented followed by a discussion of limitations with this research and future avenues of study.

9.1 Summary of findings

The data resulting from this study suggest that there is limited $^{87}Sr/^{86}Sr$ variation within a single white-tailed deer tooth. Of the minimal variation that is present, a statistically significant difference was noted between the top and bottom of the lophs in a single tooth (although other teeth show a similar trend but cannot be tested statistically). There is more variation present in $^{87}Sr/^{86}Sr$ between different types of teeth (e.g., M1, M2, and M3) from the same individual. This has implications for how samples are taken for strontium isotope analysis, as well as the study of seasonality and the characterization of bioavailable strontium in an area.

Likewise, there is minimal variation in $^{87}Sr/^{86}Sr$ values obtained from white-tailed deer teeth recovered from the different types of bedrock and sediments/soils in southern Ontario. The limited variation in bedrock strontium could be a reflection of environmental aspects such as similar mineral compositions within the different types of bedrock, heterogeneity within bedrock, the sediment and soil overlaying an area, and overlapping types and layers of different types of bedrock. Cultural aspects such as white-tailed deer acquisition and methodological concerns (e.g., number of samples, sample material), as well as deer behaviour and ecology also interact with the environmental factors to provide the similar mean $^{87}Sr/^{86}Sr$ values with wide overlapping ranges of values.

Strontium values in sediment and soil are similarly impacted by environmental factors such as a range of different types of minerals and overlapping sediments/soils as well as atmospheric deposition and sediment and soil depth. The relationship between elevation and $^{87}Sr/^{86}Sr$ could be the result of age differences or different types of bedrock at different elevations, the movement of sediment, soil, and water between different elevations, and the ecological niches present at different altitudes. All of these are also impacted by white-tailed deer behaviour (grazing and territory preferences) and cultural influences such as white-tailed deer acquisition.

Statistically significant differences are present between different archaeological sites with the type of site, and by association socio-political aspects (e.g., whether warfare was a concern, trade, population numbers), exerting an influence on the amount of $^{87}Sr/^{86}Sr$ variation present in addition to local environmental factors. Ethnicity (e.g., Huron-Wendat, Neutral) and time of occupation (e.g., pre- and post-European contact), however, do not appear to influence $^{87}Sr/^{86}Sr$ values.

The differences between the three models created (proxy model using previously published bedrock $^{87}Sr/^{86}Sr$ values; theoretical model using previously published mathematical equations; and experimental bioavailable model using white-tailed deer enamel) are somewhat unexpected at first glance. However, with consideration of the assumptions and limitations built into each (e.g., white-tailed deer ecology, recycling of minerals, use of bedrock with no mixing), the differences between the three can be understood.

9.2 Limitations with this work

As with any study making use of isotope analysis, some limitations are inevitable. Factors such as sample availability, information on sample context, methodological concerns (e.g., sample size, diagenesis), representativeness, and how the Northern Iroquois have been interpreted in the past minimize the amount of interpretation and research that can be conducted.

Although samples from 31 archaeological sites situated on different types of bedrock present in southern Ontario are included in the study, many of these are clustered together in the southeastern part of southern Ontario around the tip of Lake Ontario. As such, sample availability represents a limiting factor. Samples from sites located in the Western Basin area, as well as a greater distribution of sites further north would have filled the gaps in sampled regions and enabled different research problems to have been addressed (e.g., the Pickering conquest hypothesis). Similarly, samples from northern Ontario on the Canadian Shield would have provided an interesting contrast to the more uniform bedrock composition present below the Trent-Severn waterways, as well as been useful in the identification of visitors to the Northern Iroquoian region. Therefore, where the samples are originating represents a limiting factor. However, this can be mitigated with future research.

Additionally, the provenience information for samples and sites is often incomplete. As was discussed in Chapter Six, inconsistencies between Borden numbers and site names, as well as limited information about specific sites and excavations all complicate interpretation of strontium isotope data, particularly given the influence of cultural activity on strontium isotope analysis. Unfortunately, there is little that can be done to minimize the influence of this limitation. As such, this must be kept in mind when considering any interpretations made using these data.

Methodologically, the amount of required sample for analyses is a limiting factor. A minimum of five grams of enamel using Faraday detectors is required for MC-ICP-MS. This means that the amount of serial sequencing that can be done using a single loph is restricted. Enamel thickness of white-tailed deer teeth varies depending on where on the crown the sample is taken. For example, enamel is thinner closer to the CEJ of a tooth relative to the apex of the crown. Therefore, samples are smaller longitudinally when taken from the top of a tooth relative to the bottom. This restricts the number of samples that can be taken. Sampling the same tooth in the same area using laser ablation may be able to mitigate this particular limitation, as laser ablation does not require the same amount of sample (although the limited precision associated with laser ablation may minimize its ability to resolve this issue).

The process of diagenesis may also influence local $^{87}Sr/^{86}Sr$ values. Although tooth enamel is more resistant to post-mortem chemical alteration than other tissues, the potential still exists that diagenetic material is present. This material would reflect local $^{87}Sr/^{86}Sr$ values of the environment in which the tooth was deposited, which could be valuable in the creation of an isotopic baseline. However, the addition of modern anthropogenic strontium is a concern, particularly given the agriculture industry that is present in southern Ontario. Therefore, steps were taken to minimize the amount of diagenetic material present in the samples (e.g., removal of the top layer of enamel). The possibility remains, however, that some diagenetic material was sampled and contributed to the observed values, which would differ from those present in the past.

Like any study making use of archaeological remains, how representative the sample population is of the whole population is a concern. This is true for both those studies making use of human remains (Wood et al. 1992; Waldron 1994; Roberts and Buikstra 2003) and faunal remains. Aspects such as cultural practices (e.g., hunting and gathering practices, disposal practices), sample size and individual behaviour in each animal can all influence the interpretations that can be made. As such, care has been taken to ensure neutral, representative samples whenever possible.

Finally, although different lines of evidence exist documenting life in the past for the Northern Iroquoians, there are, as noted previously, concerns with how these data have been obtained and subsequently interpreted. Since cultural aspects (e.g., white-tailed deer acquisition and disposal, cultural significance, etc.) can influence the interpretation of strontium isotope results, how these cultures have been studied and interpreted can impact strontium isotope analysis. Further research on indigenous populations as well as white-tailed deer may reveal any unknown aspects that influence the obtained $^{87}Sr/^{86}Sr$ values.

Overall, a number of limitations have been identified with this work. Although these have the possibility to impact the obtained values, solutions for minimizing their influence have been suggested. Furthermore, precautions to counteract their effects have been implemented whenever possible.

9.3 Future work

This research represents the first detailed evaluation of strontium isotope analysis using white-tailed deer teeth recovered at archaeological sites in Ontario, Canada. As such, it is a pilot study with numerous possibilities to expand on the original research. These include adding more animals to the dataset (from both archaeological and modern contexts), expanding the study region, investigating alternative methodology for obtaining strontium isotopes and adding additional isotopes. These can then contribute to the existing questions focusing on mobility in the area (e.g., origins of the Northern Iroquoians) as well as refine methodology for conducting strontium isotope analysis.

9.3.1 Addition of other species

Although white-tailed deer are a good option for investigating the variation in local bioavailable $^{87}Sr/^{86}Sr$ values, supplementing the data set with other animals could clarify the results from the original study (e.g., provide a distinction between sandstone and shale). Southern Ontario represents a vibrant landscape with a number of species that archaeological populations exploited for a number of reasons, both economic and ceremonial. As such, remains from species such as dog, beaver, raccoon, bear, moose, rabbit and red fox are all available from different archaeological sites throughout the region. Each species occupies a different ecological niche and has a unique relationship with local indigenous populations. Inclusion of these species would allow for better contextualization of the variation in bioavailable strontium isotopes that exists within a single location, as well as provide further information on the place that these animals hold within Northern Iroquoian society. In this way, a more complete isotopic baseline of southern Ontario, as well as a better understanding of how indigenous groups were interacting with their environment, would potentially be possible.

9.3.2 Addition of modern samples

The addition of anthropogenic strontium represents a concern in research that is focused on establishing the range in variation of strontium isotopes in the environment. In areas with agriculture, the addition of fertilizer obscures the naturally occurring $^{87}Sr/^{86}Sr$ values and so these values may change throughout time. By obtaining samples of enamel from modern-white-tailed deer of known provenience (e.g., known residence and mobility patterns) and comparing the resulting data to these archaeological data, a better understanding of the extent of the influence wielded by anthropogenic strontium in southern Ontario can be obtained. This would also enable for confirmation of the origins of the archaeological deer used in this study.

9.3.3 Increasing the study area

As noted previously, this study is limited in the area that was sampled (i.e., below the Trent-Severn waterway with the majority of sites located in the southeast of the region). The baseline data from this region that were obtained could easily be expanded with the addition of samples from more archaeological sites both within southern Ontario (e.g., the Western Basin area) but also in northern Ontario, as well as in other provinces and northeastern United States (Maine, New York, Vermont, New Hampshire, and Pennsylvania). This would increase the amount of interpretation that could be made and provide a better idea of the socio-political interactions that were occurring between different groups (e.g., the Northern Iroquoians, the Iroquoians, different Algonquian populations) throughout the area. It would also enable better consideration of the *in situ* versus migration debate with respect to the origins of the Northern Iroquois. Currently, samples from northern Ontario have been obtained for analysis and it is hoped that these are the first of many additional teeth to be sampled. This will provide a more nuanced isotopic baseline, which will allow for a better understanding of mobility and associated topics in local indigenous populations.

9.3.4 Methodological advancement

All of the strontium data in this project were obtained using MC-ICP-MS. Laser ablation coupled to a MC-ICP-MS is a different method for obtaining similar types of data; however, concerns have been expressed that it lacks the precision and accuracy recorded for solution chemistry (see Copeland et al. 2008; Horstwood 2008; Copeland et al. 2010). By conducting laser ablation on those teeth that already have MC-ICP-MS data available, the possibility for a better understanding of the precision and accuracy of laser ablation and strontium isotope analysis exists. Comparison between data obtained using solution chemistry and LA-MC-ICP-MS will enable tweaking of methods and settings used in LA-MC-ICP-MS, which will increase its accuracy and precision (see Lewis et al. 2014).

Furthermore, with increased methodological accuracy comes the ability to better serially sample teeth. Currently, a minimum of five grams of enamel is required for solution chemistry preparation of samples. However, this limitation is not present with LA-MC-ICP-MS, which requires much less enamel (micrograms rather than milligrams). This enables samples to be taken closer together, increasing the number of samples that can be taken from a single loph. This has implications for understanding the extent of variation within a single tooth and by association, seasonality.

9.3.5 Additional isotopes

Finally, strontium isotope analysis is not the only isotope that can be used to address questions about past mobility. The addition of alternative isotopes such as oxygen, lead (anthroscopic versus natural) and sulphur may be able to detect mobility within local indigenous populations, supplementing the strontium data. Although some strides have been made towards creating an isotopic baseline for oxygen (e.g., Schwarcz et al. 1991; Morris 2015), further research is required in southern Ontario. The combination of multiple isotopes will enable better interpretation of mobility in past populations.

9.4 Concluding thoughts

Strontium isotope analysis holds a lot of potential for the investigation of mobility in archaeological settings. A complex relationship exists between the environment, white-tailed deer and humans; however, when used in conjunction with multiple lines of evidence, strontium isotope analysis can facilitate the contextualization of this relationship, as well as mobility and associated topics (e.g., coalescence, fission, post-marital residence patterns, mortuary practices, etc.).

This study has presented new strontium isotope data for southern Ontario, Canada, as well as considered variation within samples of enamel obtained from white-tailed deer teeth. It has identified the utility of using strontium isotope analysis to investigate mobility in the study region and outlined its interpretive limits. It has also created and compared predicted and proxy models to observed experimental $^{87}Sr/^{86}Sr$ values obtained from white-tailed deer teeth in southern Ontario. Topics such as seasonality, the influence of culture on strontium isotope analysis in archaeology, and the interconnectedness of environmental and biological influences have all been considered throughout this dissertation. These have implications for how strontium isotope analysis has been conducted previously in other areas. There are several limitations with this study and strontium isotope analysis in general; however, there is also the possibility to improve its application. Strontium isotope analysis therefore represents a promising approach to address archaeological questions and provide a more nuanced understanding of past populations such as those who lived in southern Ontario, Canada.

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Appendix A

This appendix contains those data used to create the theoretical and proxy models for strontium isotopes available for consumption in southern Ontario presented in Chapter Three. The data for the theoretical model is presented first before those used in the proxy model.

$(Rb/Sr)_{parent}$ and $(Rb/Sr)_{lithology}$ values required for the creation of the predictive $^{87}Sr/^{86}Sr$ model for southern Ontario. All data are taken from Table 2S.1 in Bataille (2014:44-48). Blank spaces were left blank in the original.

Rock type	**$(Rb/Sr)_{parent}$**	**$(Rb/Sr)_{lithology}$**
Arkose	0.24	0.68
Clay or mud	24	0.74
Dolomite		0.37
Glaciolacustrine	0.24	0.5
Limestone		0.2
Sand	0.24	0.59
Sandstone	0.24	0.69
Shale	0.24	2.1
Siltstone	0.24	0.91
Till	0.24	0.5

Geological bedrock ages and $^{87}Sr/^{86}Sr$ seawater values required for the creation of the predictive $^{87}Sr/^{86}Sr$ model for southern Ontario. All data are taken from Table 2S.2 and Table 2S.3 in Bataille (2014:49-78).

Age	**Time (Mya)**	**$^{87}Sr/^{86}Sr_{seawater}$**
Quaternary	2.6	0.7089
Pleistocene- Upper Wisconsinian	2.6	0.7089
Late Mississippian	326	0.708
Late Devonian	385	0.7079
Middle Devonian	398	0.7085
Early Devonian	416	0.7085
Devonian	416	0.7085
Late Silurian	423	0.7082
Middle Silurian	428	0.7081
Early Silurian	444	0.7081
Silurian	444	0.7081
Late Ordovician	461	0.7080
Middle Ordovician	472	0.7082
Early Ordovician	488	0.7085
Ordovician	488	0.7085

Previously published strontium data for rock types and ages similar to those found in southern Ontario that were used in the creation of the proxy model. All geological substrates have been aged to the Paleozoic geological era before being subdivided further into geological periods. These geological periods have been divided into Early, Middle and Late whenever possible.

Geological Period	**Bedrock Geology**	**$^{87}Sr/^{86}Sr$**	**Country**	**Study**
Early Ordovician	Dolomite	0.70894	China	Wenhui et al. 2006
Early Ordovician	Dolomite	0.70902	China	Wenhui et al. 2006
Early Ordovician	Dolomite	0.70890	China	Wenhui et al. 2006
Early Ordovician	Dolomite	0.70883	China	Wenhui et al. 2006
Early Ordovician	Dolomite	0.70880	China	Wenhui et al. 2006
Early Ordovician	Dolomite	0.70973	China	Wenhui et al. 2006
Early Ordovician	Dolomite	0.70923	China	Wenhui et al. 2006
Early Ordovician	Dolomite	0.70936	China	Wenhui et al. 2006
Middle Ordovician	Dolomite	0.70852	United States	Min Yoo et al. 2000
Middle Ordovician	Dolomite	0.70856	United States	Min Yoo et al. 2000
Middle Ordovician	Dolomite	0.70833	United States	Min Yoo et al. 2000
Middle Ordovician	Dolomite	0.70897	United States	Min Yoo et al. 2000
Middle Ordovician	Dolomite	0.70902	United States	Min Yoo et al. 2000
Middle Ordovician	Dolomite	0.70833	United States	Min Yoo et al. 2000
Middle Ordovician	Dolomite	0.70858	Canada	McNutt et al. 1987
Middle Ordovician	Dolomite	0.70838	Canada	McNutt et al. 1987
Middle Ordovician	Dolomite	0.70889	Canada	McNutt et al. 1987
Middle Ordovician	Dolomite	0.70853	Canada	McNutt et al. 1987
Middle Ordovician	Dolomite	0.70851	Canada	McNutt et al. 1987
Middle Ordovician	Limestone	0.7088	China	Jiang et al. 2001
Middle Ordovician	Dolomitic limestone	0.70838	China	Wenhui et al. 2006
Middle Ordovician	Limestone	0.70826	Canada	Brand 2004
Middle Ordovician	Limestone, shale	0.70856	Canada	Brand 2004
Middle Ordovician	Limestone, shale	0.70831	Canada	Brand 2004
Middle Ordovician	Limestone, shale	0.70839	Canada	Brand 2004
Middle Ordovician	Limestone	0.708323	China	Wenhui et al. 2006
Late Ordovician	Shale, siltstone, limestone	0.71012	Canada	Brand 2004
Late Ordovician	Limestone	0.7081	China	Jiang et al. 2001
Ordovician	Shale	0.73434	United States	Stueber et al. 1987
Ordovician	Limestone	0.70793	United States	Stueber et al. 1987

Ordovician	Limestone	0.70823	United States	Stueber et al. 1987
Ordovician	Shale, sandstone	0.70807-70810	United States	Clark et al. 2004
Early Silurian	Shale	0.7862	Australia	Compston et al. 1962
Early Silurian	Sandstone	0.71292	United Kingdom	Chenery et al. 2010
Early Silurian	Sandstone	0.7111	United States	Sunwall and Pushkar 1979
Early Silurian	Siltstone	0.7101	United Kingdom	Chenery et al. 2010
Early Silurian	Siltstone	0.71206	United Kingdom	Chenery et al. 2010
Early Silurian	Dolomite limestone	0.70837	United States	Denison et al. 1997
Early Silurian	Dolomite limestone	0.708	United States	Denison et al. 1997
Middle Silurian	Dolomite	0.70845-0.70910	Canada	Coniglio et al. 2003
Late Silurian	Shale	0.7111	United States	Bottino and Fullhar 1966
Late Silurian	Salt	0.7087	Canada	Qing et al. 1998b
Silurian	Limestone	0.70826	United States	Stueber et al. 1987
Silurian	Limestone	0.70859	United States	Stueber et al. 1987
Silurian	Limestone	0.70885	United States	Stueber et al. 1987
Silurian	Limestone	0.70866	United States	Stueber et al. 1987
Silurian	Dolomite	0.70861	United States	Stueber et al. 1987
Silurian	Dolomite	0.7081	United States	Stueber et al. 1987
Silurian	Dolomite	0.70876	United States	Stueber et al. 1987
Silurian	Dolomite	0.70983	United States	Stueber et al. 1987
Silurian	Dolomite	0.70957	United States	Stueber et al. 1987
Silurian	Dolomite	0.709	United States	Stueber et al. 1987
Silurian	Sandstone	0.71258	China	Cai et al. 2001
Silurian	Sandstone	0.71057	China	Cai et al. 2001
Silurian	Sandstone	0.7115	China	Cai et al. 2001
Silurian	Sandstone	0.71183	China	Cai et al. 2001
Silurian	Sandstone	0.71145	China	Cai et al. 2001
Silurian	Sandstone	0.71072	China	Cai et al. 2001
Silurian	Sandstone	0.71101	China	Cai et al. 2001
Silurian	Sandstone	0.71161	China	Cai et al. 2001
Silurian	Sandstone	0.71111	China	Cai et al. 2001
Early Devonian	Limestone	0.70839	United States	Gao 1993
Early Devonian	Limestone	0.70853	United States	Denison et al. 1997
Early Devonian	Sandstone	0.71133	United Kingdom	Chenery et al. 2010

Early Devonian	Sandstone	0.71206	United Kingdom	Chenery et al. 2010
Early Devonian	Dolomite	0.7079	Canada	Mountjoy et al. 1992
Early Devonian	Dolomite	0.70812	Canada	Mountjoy et al. 1992
Middle Devonian	Dolomite	0.70822	Canada	Mountjoy et al. 1992
Middle Devonian	Dolomite	0.70833	Canada	Mountjoy et al. 1992
Middle Devonian	Dolomite	0.70871	Canada	Mountjoy et al. 1992
Middle Devonian	Dolomite	0.70812	Canada	Mountjoy et al. 1992
Middle Devonian	Dolomite	0.70846	Canada	Mountjoy et al. 1992
Middle Devonian	Dolomite	0.70829	Canada	Mountjoy et al. 1992
Middle Devonian	Dolomite	0.7088	Canada	Mountjoy et al. 1992
Middle Devonian	Dolomite	0.70816	Canada	Mountjoy et al. 1992
Middle Devonian	Dolomite	0.70866	Canada	Mountjoy et al. 1992
Middle Devonian	Dolomite	0.70804	Canada	Teare 1990
Middle Devonian	Dolomite	0.708	Canada	Teare 1990
Middle Devonian	Dolomite	0.70795	Canada	Teare 1990
Middle Devonian	Dolomite	0.708	Canada	Qing and Mountjoy 1994
Middle Devonian	Dolomite	0.7084	Canada	Qing and Mountjoy 1994
Middle Devonian	Dolomite	0.7093	Canada	Qing and Mountjoy 1994
Middle Devonian	Limestone	0.7078-0.7081	Canada	Qing 1998
Middle Devonian	Limestone	0.7072	United States	Whitney and Hurley 1964
Middle Devonian	Limestone	0.7058	United States	Whitney and Hurley 1964
Middle Devonian	Limestone	0.7039	United States	Whitney and Hurley 1964
Middle Devonian	Limestone	0.7075	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7237	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7403	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7457	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7147	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7316	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7542	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7505	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7316	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7322	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7127	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7348	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7134	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.736	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7547	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7407	United States	Whitney and Hurley 1964

Middle Devonian	Shale	0.7407	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7235	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7334	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.7487	United States	Whitney and Hurley 1964
Middle Devonian	Shale	0.727	United States	Whitney and Hurley 1964
Late Devonian	Shale	0.72	Australia	Bofinger et al. 1970
Late Devonian	Limestone	0.7082	Belgium	DeJohnghe et al. 1989
Late Devonian	Limestone	0.708285	United States	Brand 2004
Late Devonian	Dolomite	0.7085	Canada	Mountjoy and Halim-Dihardja 1991
Late Devonian	Dolomite	0.70961	Canada	Mattes and Mountjoy 1980
Late Devonian	Dolomite	0.70927	Canada	Mattes and Mountjoy 1980
Late Devonian	Dolomite	0.70921	Canada	Mattes and Mountjoy 1980
Late Devonian	Dolomite	0.7097	Canada	Mattes and Mountjoy 1980
Late Devonian	Dolomite	0.70951	Canada	Sharp et al. 2002
Late Devonian	Shale, limestone	0.70803-0.71064	United States	Clark et al. 2004
Late Devonian	Dolomite	0.7085	Canada	Mountjoy et al. 1992
Devonian	Sandstone	0.7123	Europe	Knudson et al. 2012
Devonian	Shale	0.75472	United States	Stueber et al. 1987
Devonian	Shale	0.73458	United States	Stueber et al. 1987
Devonian	Shale	0.72793	United States	Stueber et al. 1987
Devonian	Dolomite	0.71055	United States	Stueber et al. 1987
Devonian	Sandstone	0.70887	United States	Stueber et al. 1987
Devonian	Sandstone	0.71055	United States	Stueber et al. 1987
Devonian	Limestone	0.70832	United States	Stueber et al. 1987
Mississippian	Shale	0.739	United States	Steele and Pushkar 1973
Mississippian	Shale	0.7324	United States	Steele and Pushkar 1973
Mississippian	Shale	0.7335	United States	Steele and Pushkar 1973
Mississippian	Shale	0.745	United States	Steele and Pushkar 1973
Mississippian	Shale	0.741	United States	Steele and Pushkar 1973

Appendix B

This appendix summarizes available information on archaeological sites that provided samples for this research. Due to availability of records, the amount of information for each site varies. An effort has been made to be as thorough as possible, with identification of any limitations associated with individual sites. These data are summarized in Chapter Six.

Benson (BdGr-1)

The four and a half acre Benson site, dating to A.D. 1550-1580, is a palisaded village first excavated by J. Emerson in 1951 and again by P. Ramsden in 1976 and 1977 (Ramsden 1977:68; Ramsden 1979; Naismith 1981). Located on a hilltop at an elevation of 260 masl on the west bank of Talbot Creek near Raven Lake (Emerson 1954:203), the site sits on a Middle Ordovician limestone bedrock base (part of the Simcoe Group) covered with sand. A seven-row palisade, middens and longhouses were documented at the site (Emerson 1954; Ramsden 1979; Naismith 1981). No palisade extensions were noted at the site; however, several longhouses were expanded and two longhouses were constructed outside of the confines of the palisade (Ramsden 1979). Ramsden (1979) suggests that the village was divided into two different sections, based on the position and orientation of longhouses, as well as artifact distribution. Emerson did not document any burial features at the Benson site (Emerson 1954). The artifact assemblage includes lithics (e.g., projectile points, axes, chisels, pipes and beads), ceramics (e.g., gaming discs, pipes, body and rim sherds), worked faunal remains (awls, needles, tubular beads, pendants, harpoon points and beads) and European trade goods (e.g., copper beads, a small iron awl). Of note in this assemblage is the presence of effigy pieces, as well as atypical ceramic fragments indicative of the St. Lawrence Iroquois suggesting the influence of immigration (Emerson 1954; Ramsden 1979; Naismith 1981) or trade. Faunal remains resulting from both the fur trade (e.g., beavers) and food acquisition (e.g., white-tailed deer and dog) were both recovered at the Benson site (Ramsden 1979).

Bogle II (AiHa-11)

The Bogle II is a small 0.3 hectare Neutral hamlet dated to A.D. 1640-1651 (Lennox 1984). It is believed to represent a hamlet or satellite village that was occupied year round (Lennox 1984; Stewart 2000). Excavated by P. Lennox in 1979, it is located approximately 13 kilometers north of Hamilton, Ontario, on a low Middle and Lower Silurian sandstone rise in the Armabel Formation at an elevation of 265 masl covered with medium-coarse sandy loam to gravel sediments. A single row palisade, one midden, four longhouses and multiple pit features were recorded at the site (Lennox 1984; Stewart 2000). Lithics (scrapers, points, biface fragments, abraders, beads and pipes), ceramics (pipes, body and rim sherds), 13 pieces of worked shell (beads), six pieces of worked bone, and European trade goods (an iron knife fragment, a glass bead and brass scraps, kettle fragments, bangles, and beads) were all documented. Floral remains from maize, squash, beans, sunflower, butternut, raspberry and elderberry are represented while the faunal assemblage is 72.3% mammalian, 20.0% molluscs, 2.9% fish, 1.1 birds, 0.1% reptiles and 3.6% unknown. White-tailed deer was the most common mammal followed by raccoon, black bear, dog, beaver, muskrat, woodchuck, short-tailed shrew, and chipmunk (Lennox 1984:255). Species of fish include salmon, trout or sucker, sturgeon, walleye and catfish while birds include passenger pigeon and duck (Lennox 1984:255).

Boresma (AfHa-121)

The Boresma site is a Middle Woodland basecamp in the Thames River Valley of Middlesex County, approximately 34 kilometers south of Lake Erie and 50 kilometers southeast of Lake Huron (Wilson 1990). At an elevation of approximately 210 masl, the site is located on a Middle Devonian limestone bedrock in the Hamilton Group overlain by alluvial flats with sandy brown, silt sediments. J. Wilson excavated it in 1989 as a part of his Masters project, supervised by P. Ramsden of McMaster University. As a base camp, the Boresma site was occupied periodically throughout the year, acting as a focal point for local indigenous populations, with special purpose sites surrounding it. Wilson (1990) suggests that local populations would conduct specific activities at these surrounding sites, moving between them and Boresma, which was the hub of their yearly activities. Radiocarbon dates suggest that the site was occupied from A.D. 75-605 (calibrated by Wilson 1990:92). Although no clear house structure was documented, a number of poles suggesting continual construction of some type of residential structure were present (see Wilson 1990). Additionally eleven hearths, ten pit features and a midden were all noted. A number of different artifacts were recovered in the midden, including lithics such as bifaces, scrapers, knives, and ceramic sherds. The bulk of the faunal assemblage was also recovered in the midden. 65.0% of this faunal assemblage was fish, primarily walleye or sauger, and 29.9% were mammals with 80.2% of these from white-tailed deer (Wilson 1990:34-35). There were also beaver (9.4%), raccoon

(1.3%), bear (0.8%) and dog (0.6%) (Prevec 1990 in Wilson 1990). Birds (goose, duck, grouse), reptiles such as turtle, amphibians and clams were also recovered (Wilson 1990:36-37). Of these, fish followed by deer, bear, beaver and raccoon provided the bulk of the meat consumed by the local population. These were all consumed at the site rather than just processed for consumption at another location (Wilson 1990).

Boys (AlGs-10)

The Boys site is a palisaded village that has been dated to approximately A.D. 975 (Reid 1974:73). Located in an easily defensible location with freshwater close by, approximately 18 kilometers east of Toronto, the site was discovered by Dr. C.H.D. Clarke in 1954 and later excavated in the 1970's by Clarke and Ridley (Ridley 1958). Two longhouses and two middens were excavated. It is an irregularly shaped site at an elevation of 131masl and sediments in the area are sandy loams with a bedrock base of Upper Ordovician shale in the Blue Mountain Formation. Its irregular shape may be a result of the site's location, as it has ravines on two sides. The irregular shape of the Boys site is not the only oddity at the site. Unlike the defensive palisades found at contemporaneous sites such as Van Besien, the palisade at Boys may not be defensive in nature but rather a windbreak or snow fence (Reid 1975). Furthermore, the interior layout of individual houses at the site differs between longhouses (Reid 1975). Pottery, lithics, worked bone artifacts, pipes, a native copper awl, a small piece of hammered native silver and faunal remains were all recovered at the site (Ridley 1958; Reid 1975). Of the faunal remains, white-tailed deer, fish, red fox, beaver, black bear, raccoon, dog, woodchuck, porcupine otter and bird were all identified (Ridley 1958). Fish appear to be the dietary preference, as they comprise the bulk of the assemblage (Reid 1975). Rozel (1979) suggests that this indicates a seasonal occupation.

Cahaigue (BdGv-1)

This particular site is interesting in that it has two names associated with the same Borden number. This is because it has been suggested that the archaeological Warminster site is actually the village called Cahiague, which was visited by Champlain during A.D. 1615-1616 (Sykes 1983; McIlwraith 1946; Ramsden 1977:75; Fitzgerald 1986). However, Fitzgerald (1986; 1990:212-219) believes that this is not true and Champlain's Cahaigue could be the Ball site instead. In this research, it will be referred to as Cahaigue, as that is the name that it was assigned by Sustainable Archaeology at Innovation Park, McMaster University who provided the samples for this study.

Andrew F. Hunter first recorded the Cahaigue site, dating it to A.D. 1620-1630 (Fitzgerald 1986:6), in 1902 as containing both a village and an ossuary (Sykes 1983). The site was known to locals and as such was heavily looted prior to being excavated in 1946 and 1947 by the University of Toronto. In 1961, J. N. Emerson returned to the site and supervised excavations until 1969. An archaeological field school run by the University of Toronto excavated the site again in 1978 and 1979 (Sykes 1983).

The historic 15-acre site is located south of the town of Warminster, from which it derives one of its names, on a broad sandy plateau in the Medonte-Orillia Till Uplands at an elevation of 282 masl (Sykes 1983). It sits on a well-drained sandy sediment that overlies a Middle Ordovician limestone base in the Simcoe Group. Similar to other sites, it is bordered by two valleys with a source of fresh water nearby. A minimum of 172 longhouses, 19 middens and a palisade have been suggested as being present at the site, which is divided into two halves: north and south (Sykes 1983). The north village is approximately 3.4 hectares while the south village is approximately 2.6 hectares (Fitzgerald 1986), each separately palisaded and containing at least 86 longhouses (Sykes 1983). The palisades were composed of multiple rows (on average four rows) (Emerson and Russell 1965 in Sykes 1983). The ossuary, although heavily looted, included a plethora of grave offerings and individuals of all ages were represented, including children (McIlwraith 1946).

Substantial quantities of artifacts were recovered at the site of both indigenous and European origin. European goods include: copper kettle fragments, beads, tinklers (i.e., ornaments), pendants, bracelets, and rings, projectile points, and edge tools; spoons; iron kettle fragments, a bracelet, buttons, axes, adzes, chisels, celts, a scraper, knives, harpoons, projectile points, and awls; pewter plate fragments; 452 glass beads; and stone pipes (Fitzgerald 1982; Sykes 1983). Additionally, lithics, worked shell, pipes, and assorted pottery were recovered (McIlwraith 1946; Sykes 1983). With respect to subsistence, elements from deer, beaver, dog, bear, groundhog, hare fish, and bird, as well as maize were all documented (McIlwraith 1946).

Christianson (AiHa-2)

The three and a half acre Christianson site, dating to A.D. 1615-1630 (Noble 1970; Fitzgerald 1981), is located near Spencer Creek in Beverly Township in the municipality of Hamilton-Wentworth, Ontario (Fitzgerald 1981). Located on a Middle and Lower Silurian sandstone plain in the Guelph Formation covered by a thin layer of diamicton, gravel and sandy sediments, the site is on a hill (265 masl) with sharp drops located on its west and south sides (Fitzgerald 1981:11). I. Kenyon and D. Stothers first excavated it in 1968, and W. Noble returned in 1969. P.N. Christianson undertook surface collections before excavation in 1979 by W. Fitzgerald (Fitzgerald 1981). Eight longhouses, middens, pit features, a burial feature containing a single infant and exterior activity areas were all documented in the area. A cemetery, Shaver Hill, located nearby is associated with the Christianson site (Fitzgerald 1982; Fitzgerald 1990:285). The site was placed to take advantage of natural resources, including soils preferable for agriculture and wildlife acquisition, and had a three-row palisade in some areas for defense (Fitzgerald 1981). However, other palisade configurations (e.g., single and double row) at the same site suggest defense may not have been a primary concern (Fitzgerald 1981:35).

An extensive artifact collection is associated with the Christianson site. Ceramics include pipes, body and rim sherds while lithics include pipes, projectile points, flakes, drills, bifaces, scrapers, beads, pestles, a net sinker, a sharpening stone and a smoother (Fitzgerald 1981). Worked faunal remains such as bone beads, needles, flakers, awls/punches, harpoon fragments, rattle, fishhooks and a spoon fragment were recovered as well as shell beads and pendants. European trade goods including bracelet fragments, beads, tinkling cones, rings, knife blades, kettle fragments, axe fragments, awls, and a fish hook were documented at the site, despite extensive 19th century intrusions which may have influenced researchers' abilities to identify European trade goods (Fitzgerald 1981; Fitzgerald 1982). This may explain the low frequency of occurrence (0.3%) of artifacts of European origin (Fitzgerald 1982).

Prevec (1980) documented 8,426 faunal elements from the excavations conducted in 1979. The assemblage was 80.8% mammalian, of which 41.6% were white-tailed deer (Fitzgerald 1981:21). Following mammals, fish comprised 7.1% of the collection, molluscs, 6.4%, birds, 1.7%, amphibians 0.5% and reptiles, 0.4% (Fitzgerald 1981:22 Table 1). Beaver (19.1%), *Canis* sp. (12.5%), and raccoon (9.1%) were the most prevalent after white-tailed deer in the mammalian assemblage. Black bear, woodchuck, squirrel, fox and elk were also recovered at the Christianson site. Fitzgerald (1981:22) suggests that the presence of almost every element in a white-tailed deer indicates that these animals were killed nearby, brought back whole and butchered onsite. Fish species represented are brown bullheads, lake sturgeon, yellow walleye, catfish and suckers (Fitzgerald 1981:27, Table 5) while birds include passenger pigeons, wild turkeys and goose (Fitzgerald 1981:24, Table 3). Molluscs, both freshwater and marine bivalves, as well as snails, frogs, turtles and snakes were all found at Christianson (Fitzgerald 1981:29-30).

Cleveland (AhHb-7)

The Cleveland site is a protohistoric Neutral site that was occupied around A.D. 1540 +/- 90 (Burns 1973; Fitzgerald 1990:305). Located in Brantford Township in Brant County, next to Fairchild Creek (Mannen 1974), the site covers approximately four acres (Fitzgerald 1990:304) and is located on a Middle and Lower Silurian sandstone bedrock base in the Guelph Formation overlain with a sandy sediment. It has an elevation of approximately 219 masl (Fitzgerald 1990:304). W. Noble, with McMaster University, first excavated it in June 1971 (Noble 1972). A number of features were documented including three longhouses and middens. No human burials were recovered in the village; however, dog remains were recovered in formal burial contexts (Bathurst and Barta 2004). One of these dogs, found in a ceramic cauldron, was found to have tuberculosis (Bathurst and Barta 2004). A large collection of artifacts was recovered including ceramics (e.g., rims, castellations, pipes), lithics (e.g., projectiles, scrapers), European trade goods (e.g., brass beads and rings, iron celt and an iron pot), worked faunal remains, and floral and faunal remains (e.g., maize and acorns) (Noble 1972; Mannen 1974; Fitzgerald 1990). A number of faunal species are represented in the collection including white-tailed deer, elk, moose, passenger pigeon, bear, dog, raccoon, beaver, grey squirrel, muskrat, porcupine, marten, freshwater fish and clams, turtles and amphibians (Noble 1972).

Coulter (BdGr-10)

The Coulter site, located in Bexley Township, Victoria, approximately two kilometers northwest of West Bay on Balsam Lake, is dated to approximately A.D. 1550 (Damkjar 1982). It is located on Middle Ordovician limestone in the Simcoe Group with a thin layer of glacial drift overlying the bedrock (Damkjar 1982) at an elevation of approximately 279 masl. Sediments in the region are described as being Brown Forest Great Soil, composed of calcareous gravel and glacial drift (Damkjar 1982). Excavated in 1977 and 1978 by P. Ramsden as a part of the Upper Trent Valley Archaeological Project, the palisaded site spans approximately eight acres (Naismith 1981) with 26 houses, 28 middens, as well as numerous hearths and pits (Damkjar 1982). Five unexpected expansions attributed to coalescence resulting from either warfare or the fur trade, were noted at the site (Ramsden 1979; Damkjar 1982). The site is located close to several rivers facilitating aquatic travel and trade. Various faunal remains were recovered at the site including white-tailed deer, beaver, wolf, black bear, red fox, porcupine, and woodchuck. Moose originating from 15 kilometers north on the Canadian Shield was found at the site, as well as freshwater fish from the local streams. Artifacts that were recovered at the site include pottery, lithics and European trade goods such as metal beads (Ramsden 1979; Damkjar 1982).

Crawford Lake (AiGx-6)

The Crawford Lake site is one of a number of sites that are found approximately 65 kilometers west of Toronto around Crawford Lake (Finlayson and Byrne 1975) on a Middle and Lower Silurian sandstone bedrock base in the Clinton Group overlain by diamicton at an elevation of 305 masl. Established in A.D. 1280 in the Middleport cultural period, the population in this area peaked between A.D. 1360-1613 (Clark and Royall 1995). The site itself was occupied between A.D. 1350-1400 (Finlayson et al. 1975). This particular site was identified by Byrne in 1972, and is located approximately half a kilometer north northwest of Crawford Lake. In 1973, excavation revealed the presence of six longhouses with no palisade (Finlayson and Byrne 1975; Finlayson et al. 1975), as well as some features that have been interpreted as being sweat lodges (MacDonald 1988). Four of these longhouses were oriented in a north-south direction while the remaining two were in a WNW-ESE direction (Finlayson et al. 1975). It has been suggested that approximately 74 families occupied the Crawford Lake site based on the size of the documented longhouses (Finlayson and Byrne 1975). Pollen analysis suggests that maize, bean, sunflower, and squash were all cultivated in the area (McAndrews and Turton 2010). A variety of faunal remains were recovered at the site including white-tailed deer, elk, dog, muskrat, squirrel and freshwater fish (Burns and Heathcote 1974 in Finlayson and Byrne 1975). Floral remains from raspberry seeds, elderberry seeds, sumac seeds, amaranth seed, blueberry seeds, hawthorn apple seeds, nut fragments, maize, squash and beans were also recovered (Finlayson and Byrne 1975; Finlayson et al. 1975). Human remains from individuals of varying ages were documented at the site (Kapches 1976).

Donovan/Snyder (AhHa-3)

The Donovan/Snyder site is interesting in that there are two names associated with the same Borden number, AhHa-3. The samples for this site were found in a box labeled "Donovan AhHa-3" at Sustainable Archaeology at Innovation Park, McMaster University. A similar association between this name and Borden number is found in multiple reports created by local cultural resource management firms (e.g., ASI, Archaeological Assessments). However, when the Ontario Ministry of Tourism, Culture and Sport was contacted for information about the site, the paperwork provided the name "Snyder" for this specific Borden number. This is further complicated as there are different spellings for Snyder, with literature referring to it as the "Snider" site. This complicates any background research available for this site. However, one aspect that all reports and research agree on is the location of the site.

The Donovan/Snyder/Snider site is a historic Neutral village located on a plateau near Big Creek on the north shore of Lake Erie in Norfolk County, Ontario (Fitzgerald

1990). Located on a Middle and Lower Silurian sandstone bedrock base in the Guelph Formation overlain with sand and gravel, the site sits at an elevation of approximately 235 masl (Fitzgerald 1990:314:312-313). Occupied at approximately A.D. 1580-1600, I. Kenyon formally researched the 1.5-hectare site in 1971 (Fitzgerald 1990; Ontario Ministry of Tourism, Culture and Sport 2014a); however, it was the focus of looting from 1829 onwards (Smith 1987:33 in Lennox and Fitzgerald 1990:406). Donovan/Snyder is associated with a cemetery, which is located just north of the site itself (Fitzgerald 1990). Various artifacts were recovered at the site including lithics, ceramics, indigenous copper and European trade goods, in addition to faunal remains. Items such as copper and glass beads, groundstone celts, iron knives, axes, copper tinkling cones, bracelets and rings have all been the focus of study (Fitzgerald 1982; Fitzgerald 1990). Faunal elements recovered at Donovan/Snyder include white-tailed deer mandibles, from which the samples for this research originated.

Fonger (AhHb-8)

The 0.8-hectare Fonger site (Fitzgerald 1990:305), which dates to A.D. 1580-1600, is a late pre-contact Neutral site (Fitzgerald 1982:32; Prevec and Noble 1983). First discovered in the 1880's, it was excavated by G. Warrick in 1978 and 1979 (Warrick 1984 in Holterman 2007). The site is located along the headwaters of the Spencer and Bronte creeks, in Brant County near the Bogle II, Hood and Hamilton sites (Fitzgerald 1981). It is situated on a hill at an elevation of 207 masl near a tributary off Fairchild creek (Mannen 1974; Holterman 2007:13-14) on a Middle and Lower Silurian sandstone bedrock base in the Guelph Formation overlain by sandy gravelly sediments. A palisade composed of three to four rows surrounds 18 longhouses, six middens, and pit features (Warrick 1984 in Holterman 2007). Ceramics (pipes, body and rim sherds), lithics (projectile points, scrapers, bifaces, drills, celts, hammer stones, anvils, whetstones, pestle and mortars, manos, metates, and smoothing stones), worked bone and antler (awls, needles, harpoons, scrapers, and beads), along with minimal European trade goods made of copper, brass and iron (0.4% of the entire assemblage, including an iron needle, knife and celt, and brass beads and rings) were recovered at the site (Mannen 1974; Fitzgerald 1981; Fitzgerald 1982; Holterman 2007). The presence of artifacts of European origin at Fonger despite the lack of European contact suggest that it was engaged in trade with other villages that had access to European trade goods at this time. Floral remains from wild plum, raspberries, beans, squash and maize were recovered at Fonger (Holterman 2007:14), as were elements from various fauna. Of these species, mammals dominate the faunal assemblage (82.4%), with elements from fish and birds also documented (Prevec and Noble 1983). White-tailed deer, elk, beaver and bear compose the bulk of the identified fauna; however, raccoon, squirrel, *Canis* sp., woodchuck, chipmunk, weasel and muskrat are also represented (Prevec and Noble 1983; Holterman 2007:14). Fish (catfish, sucker, sturgeon, and freshwater drum) and birds (passenger pigeon, geese, wild turkey, grouse, hawk, swan, duck falcon and crane) comprise the remainder of the collection (Holterman 2007:14-15).

Gunby (AiGx-5)

B. Newman excavated the Gunby site, dating to A.D. 1300-1320, in 1977 (Rozel 1979). It is located approximately 20 kilometers north of Hamilton, Ontario, on the

Niagara escarpment with a Middle and Lower Silurian sandstone base in the Armabel Formation covered with sand. The site is on a steep hill at an elevation of 259 masl, with the only level approach facing west and northwest (Rozel 1979). Comprised of 10 longhouses of variable lengths, evidence of a palisade at the 1.1 hectare site was inconclusive (Rozel 1979). These longhouses were arranged in different orientations, with some facing into the wind and others against it. Rozel (1979) suggests that the site may have been expanded once during its occupation. Several large refuse pits were excavated, providing a plethora of artifacts. These include (but are not limited to): lithics such as scrapers, projectiles, drills, wedges, and bifaces; groundstone artifacts such as hammer stones, net sinkers, celts, gaming stones, and anvil stones; worked bone artifacts such as awls, flakers, beads, points, punches, pegs, hair pins and scrapers; pipes; native copper artifacts; and 5,194 analyzable sherds of pottery (Rozel 1979). An additional 1000 carbonized seeds representing maize, beans, sunflowers, tobacco, sumac, strawberry, blackberry, pin cherry, and elderberry were recovered. Finally, 12,895 faunal elements were documented, from species such as deer, black bear, beaver, dog, fox, squirrel, raccoon, eastern chipmunk, and muskrat, as well as fish, bird, amphibians, turtles and shells. 70.7% of these were from deer, with the suggestion that the bulk of the butchering took place at the village itself, implying that they were obtained close by (Rozel 1979).

Hamilton (AiHa-5)

The six-acre Hamilton site, dating to A.D. 1638-1650, is a double-palisaded Neutral village (Lennox 1977; Fitzgerald 1990:289). Located north of Hamilton, Ontario, on a low sandy loam rise (268 masl) five kilometers from the Christianson site on the southwest corner of Crawford Lake (Stewart 2000), the site has a Middle and Lower Silurian sandstone base in the Armabel Formation covered by well-drained sandy loam sediments and diamicton. Unlike other Neutral sites in the area (e.g., Cleveland and Walker), it is not located in an easily defended location but rather is situated in an area preferable for taking advantage of local natural resources (Lennox 1977). As such, a double palisade with interior cordons was constructed at the site, creating cul-de-sacs and alleyways, ostensibly for protection (Lennox 1977; but see Ramsden 1988). W.C. Noble excavated the Hamilton site in 1970 and 1972 and P. Lennox returned in 1976, using the site as the basis of his MA research. Middens, pit features and five longhouses were documented at the site. One of these longhouses, longhouse two, shows evidence of having been expanded (Lennox 1977). Exterior activity areas, as well as a circular roofed area were also recorded. However, no burial features were documented at the Hamilton site.

A large artifact assemblage was recovered at the Hamilton site, including lithics, ceramics, European trade goods, worked shell, bone and antler, and a single modified bark fragment. Of the 6,859 lithics that were documented, projectiles, scrapers, whetstones and abraders, anvils, serrates, drills, beads, spokeshaves, net sinkers, hammerstones, adzes, mortars, pestles and a hoe are all present. 5,833 pieces of ceramic were also recovered, including body and rim sherds, as well as pipes. Shell beads, pendants, and a single scraper comprise the worked shell assemblage while examples of tubes, needles, awls and punches, pendants, combs, and a flute fragment compose the worked bone collection. Modified antler artifacts include flakers, harpoons, a projectile point, pendant, and human effigy pin. A variety of well used and recycled European trade goods were recovered from the Hamilton site, including glass beads, brass items (kettles, beads, knives and blades, projectile points, needles, awls, pendants, rings, earrings, bracelets, clothing fasteners, fish hook, pipe, and a picture frame) and iron items (axes, knives, awls, and dagger). Floral remains include maize, squash, sunflower, bean, hickory, butternut, and wild plum. Finally, 20,481 faunal specimens were recovered, of which 60.0% are mammalian, 17.8% are fish, and 10.2% are bird. Raccoon was the most common species (71 individuals), followed by deer (59 individuals). Chipmunk, squirrel, dog, muskrat, woodchuck, beaver, deer mouse, rabbit, vole, and black bear are all represented in the assemblage. Common fish species at the site are brown bullhead, drum walleye sucker and largemouth bass, while bird species are dominated by turkeys, geese, swans, and cranes (Lennox 1977:177-180, tables 48-51; Prevec and Noble 1983). Mussels, turtles and frogs were also documented.

There are some interesting phenomena occurring at the Hamilton site, leading Lennox (1977) to suggest that this village was the site of a Jesuit mission. For example, the presence of a brass picture frame indicates European involvement at the site. This is supported by the late occupation of the site, possibly right up until the dispersal of the Neutral around A.D. 1651. The pottery recovered at the site is also interesting as it is atypical of the types common at Neutral sites. Lennox (1977) explores this idea, suggesting that foreign female potters were present at the Hamilton site due to either adoption from the *Mascouten* or from alliances with other local populations such as the

Wenroe or Erie. He also argues that Hamilton was a principal village in the Neutral confederation, surrounded by satellite communities such as the Hood site.

Hood (AiHa-7)

Local collectors first discovered the Hood site in the late 1800's (Lennox 1984). Measuring 2.7 hectares, the site is located approximately 15 kilometers north of Hamilton, Ontario and dates to A.D. 1630-1641 (Lennox 1984). With minimal natural defenses, the site sits on a low rise approximately 274 masl (Fitzgerald 1990:291) composed of Middle and Lower Silurian sandstone in the Armabel Formation covered with sandy loam and coarse gravel. The excavators noted some limestone boulders in the area (Lennox 1984). P. Lennox excavated the site in 1977 prior to development planned for the region. Due to the site's vulnerable location, a five-row palisade was discovered, as well as 15 longhouses, middens, pit features and six burial features containing seven individuals (Lennox 1984; Fitzgerald 1990:153). Based on the artifact assemblage, it is suggested that the Jesuit missionaries visited the site, specifically *Teotongiaton* (Fitzgerald 1990:292). This assemblage is typical of Neutral occupation with lithics, ceramics, worked faunal remains, and European trade items all present. Projectile points, bifaces, scrapers, serrates, whetstones, abraders, anvil stones, mortar, milling stone, catlinite beads and a gunflint are among the lithics recovered. Ceramic artifacts include pipes, body and rim sherds. Worked faunal remains were turned into beads, pendants, scrapers, needles, bone tools, and bone tubes while a single native copper pin was documented. European trade goods such as brass kettle fragments, rivets, projectile points, knives, an engraved harpoon, awl, needles, chisel, beads, pendants as well as

Jesuit rings and medallion were recovered as well as glass beads, iron axes, knives, awls, kettle fragments, buckles and nails (Lennox 1984; Fitzgerald 1990:95, 153). Floral remains such as maize, beans, squash, sunflower, wild plum, butternut, walnut, acorn, and cherry among others were documented. Elements from deer (75.2%), beaver (9.6%), dog (4.3%), raccoon (3.3%), and black bear (2.6%) dominate the faunal assemblage (Lennox 1984:180, Table 1). Small numbers of fish, birds and reptiles were also noted (Lennox 1984:180, Table 1; Stewart 2000).

Kirche site (BcGr-1)

The Kirche site (or Kerche site) is a 3.3 acre village located in traditional Huron-Wendat territory dating from A.D. 1495-1550 (Naismith 1981; Fitzgerald 1990:104). It is located on Middle Ordovician limestone and dolostone in the Simcoe Group, covered by sandy sediment (Naismith 1981) and diamicton at an elevation of 282 masl. It was discovered in 1976 and excavated in 1977-1978 by P. Ramsden of McMaster University. Located next to a spring in modern Fenelon Township, Victoria County, Ontario, Balsam Lake is approximately 1.5 miles north of the site (Naismith 1981). Twenty-nine longhouses, pits, middens, a sweat bath and interior fences were documented within the palisaded site (Naismith 1981). Similar to other Huron-Wendat sites, it is believed that the Kirche site was extended as a result of coalescence. Of additional interest at this site is the documentation of a pit with a complete but disarticulated dog skeleton with cut marks suggesting that it was butchered. This led researchers to suggest that the dog was consumed during a feast (Naismith 1981). Other faunal remains recovered at the Kirche site include white-tailed deer, black bear, dog, moose, beaver, red fox, snowshoe hare, woodchuck, red squirrel, vole, turkey, freshwater fish, and raccoon. Pottery sherds, pipes, ceramic gaming discs, ceramic beads, shell and bone artifacts, (awls, beads, needles, arm bands or wristlets, projectile points, knives, deer scapula pipe) lithics (ground stone celts, chisels, beads, flakes, projectile points, knives, scrapers), and artifacts composed of native copper were also retrieved at the site. Although there is a great deal of variation in the pipe forms and profiles, Naismith (1981) suggests that the similarities in ceramics between Benson and Kirche indicate some relationship between the two sites.

Knight-Tucker (AhHb-1)

The Knight-Tucker site is a village dating to approximately A.D. 1520-1540 (Lennox 1984; Fitzgerald 1990:548). Located on the eastern bank of Beaver Creek between Brantford and Hamilton, Ontario, 238 masl (Fitzgerald 1990) near the Fairchild and Big Creeks rivers, this site is similar to some others in that it is known to the Ontario Ministry of Culture, Tourism and Sport by a different, yet similar name (the Tucker site). The site is situated on Middle and Lower Silurian sandstone in the Guelph Formation covered by clay. I. Kenyon test-pitted the Knight-Tucker site in 1972, recovering a single European trade good, a copper alloy tinkling cone (Fitzgerald 1990). Fitzgerald (1990) believes that the Knight-Tucker site is contemporaneous with the McPherson site. The lack of European trade goods and faunal assemblage suggests that it was established prior to the widespread adoption of the fur trade. The faunal assemblage contains 602 individual mammals, of which the majority (73.6%) are white-tailed deer (Fitzgerald 2005).

Ludlow Vanderlip (AgHa-8)

The 1.4 acre Ludlow Vanderlip site represents a 17th century hamlet (Fitzgerald 1990:309; Lennox and Fitzgerald 1990:413, Table 13.1). Located on a Middle and Lower Silurian sandstone plateau in the Guelph Formation covered with sand at an elevation of 210 masl, the site is next to a fork of two steams that flow into Big Creek (Fitzgerald 1990:309). Specifically, the site is located in Brantford Township, Brant County, straddling the property line between farms owned by T. Ludlow and I. Vanderlip in 1903 (Waugh 1903:75). It is believed that the faunal remains sampled for this research are from an excavation conducted by I. Kenyon and W. Fox in 1971-1972 (Sustainable Archaeology at Innovation Park, McMaster University 2015a). The site was partially ploughed prior to being partially excavated (Ontario Ministry of Culture, Tourism and Sport 2014b). Ceramics, lithics and European trade goods were recovered at the site, including a hammerstone, projectile points and fragments from a brass kettle (Waugh 1903:75). Faunal remains include elements of white-tailed deer, turtle, and *Canis* sp., among "other animals" (Waugh 1903:75).

McPherson/Smith Seager Cemetery (AhHa-6)

Unfortunately, there is some degree of confusion surrounding this particular site. Stored at Sustainable Archaeology at Innovation Park, McMaster University as McPherson (AhHa-6), this particular site name is associated with a different Borden number, AhHa-21. According to the Ontario Ministry of Culture, Tourism and Sports, the Borden number AhHa-6 is associated with the name "Smith Seager Cemetery" rather than McPherson. Fitzgerald (1990) supports this in his doctoral dissertation, which mentions the Smith-Seager Cemetery. According to Fitzgerald (1990:306-307), the five-hectare Smith-Seager Cemetery, located at an elevation of 223 masl, has provided a European glass bead dating to the second glass bead period (A.D. 1600-1620; Hancock et al. 1994). It is located immediately south of the Smith-Hailey site (AhHa-5), on a sand ridge between two tributaries of Big Creek (Fitzgerald 1990:307).

There is more information available on the McPherson site (AhHa-21). The site, dating to A.D. 1530-1580 (Katzenberg 1993; Katzenberg et al. 1993), is located on Middle and Lower Silurian Sandstone in the Guelph Formation, covered with clay at an elevation of 223 masl. Excavated by W. Fitzgerald in 1987 as part of a salvage attempt (Katzenberg 1993), the site is located 11 kilometers west of Hamilton, Ontario on a tributary of Big Creek (Katzenberg et al. 1993). The village, which was originally a hamlet surrounded by a double palisade, experienced two separate expansions, increasing from 0.25 hectares to 0.8 hectares before reaching its final size of 1.25 hectares (Fitzgerald 1990:284; Katzenberg et al. 1993). With each expansion, the palisade was rebuilt to accommodate the increased size (Fitzgerald 2005). Katzenberg and colleagues (1993) believe that the visible expansions represent the incorporation of individuals from either migration or adoption via warfare rather than natural population increase, with the arrival of several waves of people over the decades that the site was occupied. At its largest, it is estimated that approximately 725 people lived in 20 longhouses at the palisaded site, with 30 burial features and six refuse deposits documented (Katzenberg et al. 1993; Fitzgerald 2005). These burial features contained the remains of 31 complete and partial skeletons, some of which were adult in-house burials (Sutton 1988;

Katzenberg et al. 1993). Stable isotope analyses of these remains show that the individuals were consuming maize, and age differences in carbon and nitrogen isotopes attributed to weaning have been documented (Katzenberg 1993; Katzenberg et al. 1993). Artifacts recovered from the site include ceramics (Fitzgerald 2005), as well as native copper, European copper and brass beads; however, these are in limited quantities (Hancock et al. 1992) suggesting the presence of minimal trade at the McPherson site. Of the faunal remains recovered, 291 were mammals, of which 78.4% were white-tailed deer, thus dominating the assemblage (Fitzgerald 2005).

Mannen (AhHb-8)

The two-hectare Mannen site, located east of Brantford, Ontario close to the modern day town of Onondaga, is a Neutral village (Fitzgerald 1990:304). It is situated on a Middle and Lower Silurian sandstone bedrock base in the Guelph Formation covered with sand, close to the Cleveland and Fonger sites, on a promontory (235 masl) overlooking Fairchild Creek (Mannen 1974; Fitzgerald 1990:304). Dating to A.D. 1585-1600, it was excavated by D. Mannen and W.C. Noble, possibly in the 1970's (Sustainable Archaeology at Innovation Park, McMaster University 2015b). Ceramics, pipes, lithics, groundstone tools, and worked antler and bone tools in addition to European trade goods (an iron knife, brass beads, a brass ring, and a glass bead) were all documented at the site (Noble 1972; Mannen 1974; Sustainable Archaeology at Innovation Park, McMaster University 2015b). The faunal assemblage contains the remains of white-tailed deer, beaver and *Canis* sp.

McMurray (AgGw-1)

The McMurray site, located on Middle and Lower Silurian sandstone in the Guelph Formation covered by silt, is a part of what Lennox and Fitzgerald (1990) call the Upper Twenty Mile Creek cluster. Twenty Mile Creek runs from Hamilton, Ontario, across the Niagara escarpment and ends in Lake Ontario. The 2.5-hectare McMurray site, which is at an elevation of 209 masl, is located just outside of Smithville, Ontario, just north of Twenty Mile Creek (Fitzgerald 1990:322). A historic Neutral village, it was excavated by R. Smith in 1947 and again in 1971 by W.A. Fox (Ontario Ministry of Culture, Tourism and Sport 2014c). Based on the presence of a European glass bead, the site has been dated to A.D. 1600-1620 (Hancock et al. 1994; Little 2010). Ceramics, lithics and worked faunal remains comprise the artifact collection associated with McMurray while the faunal assemblage includes remains from white-tailed deer, *Canis* sp. and beaver.

Nedelko Orct (AhHa-20)

Unfortunately, limited information is available for the 2.3-acre Nedelko Orct site (Fitzgerald 1990:304), possibly spelled Nadelko Orct (Archaeology at McMaster University 2015). Fitzgerald (1990:304) believes that only limited surface excavations have been conducted at the site; however, Sustainable Archaeology at Innovation Park, McMaster University (2015c), who curate the artifact collection associated with the site, state that it was excavated by I. Kenyon in 1971. According to the Ontario Ministry of Culture, Tourism and Sport (2014d), the site is a Neutral Woodland village located on a knoll next to a tributary of Fairchild Creek, northeast of Lynden, Ontario. It is situated on

Upper Ordovician shale in the Queenston Formation, covered with diamicton at an elevation of 235 masl (Fitzgerald 1990:304). Lithics, ceramics, cultigens such as berries and bark, and faunal remains, including white-tailed deer and *Vulpes* sp. are all attributed to Kenyon's 1971 excavation (Sustainable Archaeology at Innovation Park, McMaster University 2015c).

Nursery (AhGx-8)

The Nursery site, also known as the Arboretum site, is located on the shore of Cootes Paradise in Hamilton, Ontario with a number of other sites located close by including Princess Point (AhGx-1) (Burchell 2010; 2012). With a swamp at its western end, the site is located on flat terrain next to Spencer Creek (Martin 2011) and is situated on Upper Ordovician shale in the Queenston Formation covered with sand at an elevation of approximately 100 masl. The site has been known locally for at least four decades, with individuals, such as G. Gee and D. Gilmour, collecting artifacts in the late 1950's (Martin 2011; Burchell 2010; Burchell and Cook 2012). D. Stothers and I. Kenyon formally excavated the site in 1969 before McMaster University resumed excavations in 2006 and 2009 under the direction of S. Martin, and again from 2010-2012 under the direction of M. Burchell. Excavation is ongoing; however, the site has been disturbed due to horticultural activities as the site is currently on land owned by the Royal Botanical Garden (Burchell and Cook 2012). The site exhibits signs of occupation from the Archaic to post-European contact, with intense occupation around A.D. 1275 with the establishment of a basecamp, hamlet or village (Burchell 2010; Burchell and Cook 2012). As excavation is ongoing, the full extent of the site is yet unknown; however, Smith and

Crawford (1997) believe that it is smaller than the nearby Princess Point site. A number of artifacts were recovered at the site during the various excavations, including lithics (flakes, scrapers, bifaces, projectile points, a drill), and ceramics from both pre- and post-European contact (body sherds, rim sherds, pipe fragments). Glass artifacts, including European beads, and metal fragments have all been documented (Martin 2011; Burchell 2010; Burchell and Cook 2012). Floral remains from Martin's 2009 excavation include bramble, black walnut, hickory, wood sorrel, purslane, and acorn. Faunal remains from both mammals and birds have been recovered from multiple excavations (Burchell 2010; Burchell and Cook 2012).

Princess Point (AhGx-1)

The Princess Point site holds a lot of significance for archaeologists in southern Ontario. Dated from A.D. 500-1000 in the early Late Woodland Period, Princess Point represents one of the earliest sites with maize in the area (Crawford and Smith 1996; Crawford et al. 1997). As such, many studies have been conducted on the premise that Princess Point introduced maize to the region, initiating a subsistence switch from hunting and gathering to agriculture by A.D. 1000 via migration, diffusion or assimilation (Smith and Crawford 1997; Dieterman 2001). Furthermore, Princess Point is the starting point for a cultural complex originally defined by Stothers in 1977 spanning from A.D. 500-900 between the Middle and Late Woodland (Smith et al. 1997). Maize horticulture and a semi-sedentary lifestyle, with ceramics exhibiting cord-wrapped stick decorations, and bifacial chert tools characterize this complex (Fox 1990). There are a number of archaeological sites surrounding Princess Point that exhibit stylistic similarities in recovered artifacts and settlement patterns (Haines et al. 2011), including the Nursery site (AhGx-8).

D. Stothers, I. Kenyon and W. Noble first excavated the Princess Point site in the late 1960's (Smith 1997). The site is located on Upper Ordovician shale in the Queenston Formation overlain by grey-black sandy silt and sandy-gravel fill at an elevation of 73 masl. They documented the presence of cultural pits, a midden and what they termed as being a habitation site representing a small seasonal camp occupied during the spring and summer (Stothers 1977). The site was left alone for the next forty years until the 2000's when D. Smith oversaw a field school in the area (Martin 2009; Haines et al. 2011). Since that time, J. Curtis and H. Haines have directed the excavations in the area. Ceramics, faunal material and debitage have all been recovered at Princess Point, including awls, beads, net sinkers, ground stone objects, projectile points and a bone harpoon (Haines et al. 2011). Remains including teeth from white-tailed deer were also recovered and subsequently stored at Sustainable Archaeology at Innovation Park, McMaster University in Hamilton, Ontario.

Reid (AdHc-5)

The Reid site spans an acre and is located north of Long Point, Lake Erie. It represents a double-palisaded village with six longhouses of variable sizes. Within this village are numerous corridors and cul-de-sacs, similar to what is seen at Van Besien (Wright 1978). No middens were documented at the site; however, over 700 pits yielded large quantities of artifacts and faunal and floral remains. T. Lee originally documented its presence in 1949 before it was excavated in 1976 (Wright 1978). It is dated to approximately A.D. 1300. The Reid site is located on a sandy knoll, similar to others in the area, on Middle Devonian limestone in the Dundee Formation covered with clay at an elevation of approximately 176 masl. Two burials containing nine people were documented at the site in addition to the other structures. One of these burials is interpreted as being an ossuary while the second contained bundle burials (Wright 1978; Wright 1986). Of the artifacts recovered, ceramics, pipes, lithics, and worked faunal remains were all present. These include projectile points, drills, scrapers, whetstones and net sinkers, groundstone, awls, beads, cups and gaming pieces. Faunal remains from the site are comprised primarily of fish followed by deer, bear, turtle and other small mammals. Floral remains from maize, sumac, hawthorn, butternut, wild cherry, walnut and acorn were also present (Wright 1978).

Savage (AdHm-29)

The Savage site, dating to approximately A.D. 1350, is located 2.4 kilometers south of the Thames River in Howard Township, Kent County (Fraser 2001; Marson 2011). It is situated on an Upper Devonian shale bedrock base in the Kettle Point Formation covered with glacially deposited sand over top of clay at an elevation of 189 masl. The areas adjacent to the site are composed of black shale, while the Savage site itself is on a sand ridge, which is part of the Bothwell Sand Plain (Fraser 2001). Erosion is a large concern in this region, with researchers commenting on the influence that it has had on the site over time (Murphy 1986 in Fraser 2001). The site is named after the landowner of the property, Glen Savage (Murphy 1986 in Fraser 2001). Stanley Wortner first discovered it in the 1960's after it was disturbed by agricultural activities before being excavated by C. Murphy in 1982 (Fraser 2001). A single longhouse with a midden and refuse pits, as well as a single burial feature containing multiple individuals were recorded at the site (Fraser 2001; Marson 2011). Ceramics, lithics and worked faunal remains were all recovered, as well as both floral and faunal remains. Floral remains include elm, black ash, sugar maple, beech, sycamore, white oak, as well as seeds from butternut, black walnut, and hickory (Fraser 2001). Hawthorn, raspberry, blackberry, strawberry, elderberry sumac, maize, beans, squash, sunflower and acorn were also represented. Faunal remains were dominated by mammals (72.3%) followed by fish (19.5%), reptiles (1.6%), clams (1.2%), birds (0.6%) and amphibians (0.4%) with a total of 15489 elements analyzed (Prevec 1986 in Fraser 2001). White-tailed deer and gray squirrel were the principal species represented; however, snake and red fox were also present. Based on the faunal assemblage Prevec (1986, in Fraser 2011) believes that the site was occupied year-round.

Slack-Caswell (AfHa-1)

Slack-Caswell is a hamlet dated to approximately A.D. 1380 (Lennox and Kenyon 1984; Jamieson 1986). Located approximately one kilometer southeast of Rockford, Ontario on a wooded plateau at an elevation of 216 masl on the edge of the Norfolk Sand Plain, the site is on the Onondaga Formation, which has a geological base of Middle Devonian limestone and chert. These rocks were actively quarried and may have been the motivating factor for the founding of the site (Jamieson 1986) with archaeological evidence for the acquisition and refinement of local cherts suggesting that the hamlet was a special purpose site (Jamieson 1979 in Jamieson 1986). Sediments in the region are black clay or loam. A single large longhouse and two middens were documented at the site; however, there may be another structure located close by (Jamieson 1986). Both floral and faunal remains were recovered at the site. Floral remains include maize, beans, sunflower, squash, sumac, wild plum, walnut, and hawthorn while faunal remains include woodchuck, white-tailed deer, snowshoe hare, squirrel, dog, beaver, muskrat, long-tailed weasel, porcupine, fox and raccoon. Remains from birds, fish, reptiles and molluscs were also documented (Jamieson 1986).

Thorold (AgGt-1)

The ten-acre Thorold site, dating to A.D. 1615-1630, is located 168-172 masl on Middle and Lower Silurian sandstone in the Lockport Formation covered with a thick grey clay (Noble 1980; Fitzgerald 1990:329). Located on an easily defensible location on top of an outcrop overlooking the Niagara escarpment, the unpalisaded site is surrounded by ravines next to Dick's Creek approximately 0.4 kilometers away from the modern day town of Thorold, Ontario (White 1972; Noble 1980). The location of the Thorold site has been known since 1895, with local individuals M. McComb and C. Case surface collecting artifacts affiliated with the site (Noble 1980). Their private collection was donated to McMaster University in 1955 (Noble 1980), where it resides today. W.C. Noble returned to the site and conducted excavations discovering five longhouses, 26 middens, pits and a burial feature containing a single adult (Noble 1980). The longhouses at the site are tapered at the ends, which is unique relative to other contemporary sites. Furthermore, Noble (1980) notes some stylistic differences in recovered ceramic sherds and lithic design, suggesting that this reflects the tribal affiliation of the village. Noble

(1980) believes that this site represents the capital village of the Onguiarahronon, one of the documented nations in the area at the time of European contact. Exotic material at the site (e.g., chert, marine shells) suggests that the occupants of Thorold were engaged in trade with a number of other groups. In addition to ceramics and lithics, worked bone (e.g., needles, awls, punches, beads, and a rattle) and European trade goods (e.g., iron axes, knives, spearheads, copper kettle frags, glass beads) compose the artifact assemblage (Noble 1980). The faunal collection is primarily mammalian (55.0%), with elements from white-tailed deer, raccoon, beaver and *Canis* sp. (Prevec and Noble 1983), followed by birds and fish (Stewart 2000). Stewart (2000) notes that a large number of reptiles have been recovered at the Thorold site relative to other sites.

Trent/Thornbury (BcGr-2)

The Trent site is another site where an inconsistency between the site name and Borden number exists. According to Sustainable Archaeology at Innovation Park, McMaster University, the site was known as the Trent site; however, the Borden number BcGr-2 is associated with the name “Thornbury” according to the Ontario Ministry of Culture, Tourism and Sport (2014e). Similar to other scenarios where this issue has been noted, the site will be referred to as the Trent site, following Sustainable Archaeology at Innovation Park, McMaster University who are in possession of the artifact collection associated with the site.

The small 63 square-meter Trent site is located near Lindsay, Ontario in Eldon Township, Victoria County, on a knoll next to a creek (Burger and Pratt 1973; Ontario Ministry of Culture, Tourism and Sport 2014e) at an elevation of 280 masl. Situated on a

Middle Ordovician limestone base in the Simcoe Group overlain by a layer of clay, all of which is covered by a layer of stony silt (Ontario Ministry of Culture, Tourism and Sport 2014e), the Ontario Ministry of Culture, Tourism and Sport (2014e) believes that the artifact collection associated with the site was collected by D.K. Hakas in 1967 while under the supervision of K.E. Kidd. The protohistoric site has been dated to A.D. 1550 based on the presence of three brass scraps, one of which has been turned into a bead and another into a ring (Burger and Pratt 1973). A single longhouse with over 350 features, three of which are human burials were documented at the "heavily fortified" site (Burger and Pratt 1973:14). The artifact collection is dominated by ceramics, of which 35.0% are of St. Lawrence Iroquois design, (Burger and Pratt 1973). Faunal remains include teeth from white-tailed deer, which were sampled for this research.

Uren (AfHd-3)

The Uren site represents a pivotal site in Ontario archaeology, as it is the inspiration for a cultural sub stage, the Uren horizon. The Uren horizon is one of the subdivisions of the Middle Iroquoian, spanning A.D. 1300-1330 (Wright 1986; Warrick 2000). It was during this time that Wright (1966) suggested that the Pickering and Glen Meyer branches united as one, as described by the Pickering conquest hypothesis (see Chapter Four). The Uren horizon was a time of rapid culture change, with alterations in pottery manufacture, settlement patterns, and social organization. For example, pottery decoration became more similar between groups with universal decorating motifs (Warrick 2000). Additionally, the average size of houses and villages increased (Dodd et al. 1990), indicating the start of coalescence in the region (Warrick 2000:439). The presence of sweat lodges in larger longhouses and the occurrence of ossuaries have been suggested as being indicative of these processes, both of which become more common during the Uren phase. Furthermore, it is hypothesized the concept of clans was created during this time, with the goal of unifying a disparate population (Wright 1986).

The 1.1 hectare Uren site is located two kilometers northeast of Otterville, Ontario at an elevation of 245 masl. Bounded by a ravine on two sides, the site is situated on a Middle Devonian limestone base, part of the Onondaga Formation, overlain by sand. The soil is composed of grey-brown podzols (Wright 1986). The site was occupied at approximately A.D. 1250 and represents eleven longhouses surrounded by a palisade (Wright 1986). W.J. Wintemberg excavated the Uren site in 1920 and M. Wright continued excavating in 1977.

Of the two primary excavations, Wintemberg's 1920 dig focused on the middens located at the site, identifying 20 refuse areas. He recovered a large quantity of faunal remains and artifacts, as well as some floral remains (e.g., maize kernels, a sunflower seed and a fragment of butternut squash). Upwards of 3,600 faunal remains were documented at the site by Wintemberg (1928b). These include snail and clamshells, fish (catfish, pike, sand pickerel and sheepshead), frog, turtle, birds (primarily passenger pigeon) and mammals. Of the mammalian remains, most are deer, followed by squirrel, black bear, woodchuck, red fox, beaver, raccoon, dog and 12 other species, all obtained locally (Wintemberg 1928b). Artifacts such as pottery, lithics, and worked bone were all documented. These include knives, axes, scrapers, projectiles, awls, needles, hammers, pestles, combs, bone ornaments, stone pendants, beads, rattles, pipes and a bone whistle.

Wintemberg recovered minimal human remains during this time but those present represent a wide range of ages.

Wright's 1977 excavations complemented those completed by Wintemberg, exposing a multiple row palisade and eleven longhouses. He notes the long occupation of the site, with the suggestion that separate community segments existed, possibly as a result of coalescence (Wright 1986). Similar to Wintemberg, Wright also recovered human remains, as well as a surplus of artifacts including lithics, worked bone, pottery, and pipes. The faunal remains documented by Wright are similar to those recovered by Wintemberg, with the same species noted.

Van Besien (AfHd-2)

The Van Besien site is a palisaded Neutral village dating to approximately A.D. 900-940 located on the Norfolk Sand Plain in the township of Norwich (Noble 1973; Schumacher 2013). W.C. Noble excavated it in 1971 and 1972; however, local collectors looted the site before it was formally excavated. Located on a sandy knoll in the Onondaga Formation with Middle Devonian limestone overlain with silt at an elevation of approximately 247 masl, there are ravines with water located on two sides. The site was expanded three times during its occupation, increasing from 1.2 hectares to 1.5 hectares to 3.0 hectares (Noble 1973), with changing settlement patterns indicating some degree of social turbulence. Noble (1973) notes that defense was a concern for the occupants of Van Besien, with strong palisades and thick defensive walls in at least one of the three longhouses present at the site. Furthermore, there was an interior fence added between the second and third expansion (Noble 1973; Naismith 1981), potentially as an added defensive structure (but see Ramsden 1988). Each of the three longhouses was constructed differently with variation noted in the interior design (Noble 1975; Schumacher 2013). Large amounts of pottery, lithics, worked faunal remains (e.g., bone, antler, teeth, shell), pipes, cultigens, faunal remains and human remains were all recovered at the site in middens and near the houses (Noble 1973; Reid 1975). These include (but are not limited to): rim and body sherds, as well as flakes, scrapers, projectiles, bifaces, celts, drills, anvils, pestles, hammerstones, net sinkers and whetstones. Worked faunal remains include bone awls, worked rodent incisors, worked deer phalanges, bone beads and punches, drilled turtle bones and a whistle created from the long bone of a bird (Noble 1973; Reid 1975).

Faunal remains were well preserved with 3,181 elements identified beyond class, representing a minimum of 58 species (Burns 1973 in Noble 1973). Of these, white-tailed deer comprised the bulk of the assemblage, providing the local population with a minimum of one ton of meat (Burns 1973 in Noble 1973). Every element of the deer's skeleton is represented in the collection, thereby suggesting that the deer were obtained very close by and butchered on site (Noble 1973:40). After deer, dog, beaver, woodchuck, grey squirrel, eastern cottontail, raccoon, black bear, and porcupine dominate the assemblage (Noble 1973:38-39, Table 29). Fish, including suckers, catfish, pickerel/sauget, bass and whitefish, birds, turtles and molluscs were also recovered (Noble 1973:39). Maize kernels, plum pits, a hazelnut and walnut, all charred were documented on site. Furthermore, there is a suggestion of cannibalism, with charred human remains recovered in midden contexts (Noble 1973). The varieties of subsistence remains suggest a year round occupation of the site (Schumacher 2013).

Walker (AgHa-9)

The Walker site is a Neutral village that has been dated to A.D. 1620-1645 (Wright 1981). It has a long archaeological history with excavations starting in the late 1800's with the first systematic excavation conducted by D. Boyle and F. Waugh. Later in the early 20th century, W. J. Wintemberg continued excavations before J. Steele worked with the disturbed ossuary areas in 1944 (Wright 1977; Lennox and Fitzgerald 1990). In 1973 and 1974, W.C. Noble resumed excavations in a salvage attempt. The 4.05 hectare site is located on a sandy knoll at an elevation of 220 masl (Wallace 2015; but see Fitzgerald 1990:311 who states the site is only 2.3 hectares) with a Middle and Lower Silurian sandstone bedrock base in the Guelph Formation covered with sand. Twelve longhouses and seven middens were the focus of excavation, with over 9,000 artifacts recovered (Wright 1977; Wright 1981). Human burial features, including five burial pits and an ossuary, were documented within the limits of the village; however, they were extensively disturbed. Remains from individuals of all ages were recovered from the burial features (Wright 1977).

No palisade was present at the site, which is uncommon when the site is compared to similar contemporary Neutral sites (Lennox and Fitzgerald 1990). Further contributing to the unique nature of the site, there has been a suggestion that this site represents the Neutral capital city of *Ounontisaston* (Wright 1977; Noble 1978:162). Wright (1977) also believes that this site represents the main Jesuit mission in Neutral territory, established by Jean de Brebeuf and Joseph Chaumanot in A.D. 1640-1641.

Recovered artifacts include lithics (e.g., flakes, scrapers, projectile points, whetstones, anvil stones, drills, gaming stones, manos, hammerstones and pestles), ceramics (both body and rim sherds), worked bone and shell (e.g., beads, awls, punches, bodkins, toggles, harpoons, chisels, combs, and rattles), pipes, cultigens, faunal and floral remains, and European trade goods (e.g., beads, iron axes and knives, brass kettles, rings, metal projectile points and saws, and iron spears) (Wright 1977; Wright 1981:52, Table 1). The species represented by the floral remains include raspberry seeds, maize, hawthorn, black cherry, acorn, squash, beans, and hickory (Wright 1977). Of the faunal remains, 73.1% are mammalian with elements from white-tailed deer, raccoon, beaver and *Canis* sp. (Wright 1977; Prevec and Noble 1983). Deer represent the most common species with 70.2% of all identified mammalian remains originating from deer and the remains from 82 individual animals documented (Wright 1977:161). The variety of elements suggests that the entire deer was brought back to the village for butchering (Wright 1977:162), indicating that they were obtained from a location close by. Following deer, squirrel, raccoon and beaver are the most populous. Fish, bird, molluscs, amphibians and reptiles comprise the remaining faunal collection (Wright 1977).

Appendix C

This appendix contains an inventory of those teeth that were sampled for strontium isotope analysis. NA indicates that those data are unavailable. Contextual information is provided by Sustainable Archaeology at Innovation Park, McMaster University who are currently in possession of the faunal collections.

ID	Site	Side	Maxillary/ Mandibular	Type	Recovery Location
MCBEN7	Benson	Right	Mandibular	M3	House 18
MCBEN11	Benson	Left	Mandibular	M1	Midden 56
MCBEN13	Benson	Right	Maxillary	M2	House 14
MCBEN13	Benson	Right	Maxillary	M2	House 14
MCBOG4	Bogle II	NA	Mandibular	M3	MA7
MCBOG5	Bogle II	NA	Maxillary	M	MA7
MCBOG10	Bogle II	NA	Maxillary	M	MA1, 6(5)
MCBOG11	Bogle II	Left	Maxillary	M3	MA13
MCBOG13	Bogle II	Right	Mandibular	M3	House 5
MCBOR1	Boresma	Left	Mandibular	M1	Square 180-70
MCBOR5	Boresma	Right	Maxillary	M3	Square 175-70, sub square 18 Level 1
MCBOR7	Boresma	Left	Mandibular	M3	Square 175-75, subsquare 22 Level 1
MCBOY2	Boys	Right	Maxillary	M1	House 1 feature 21
MCBOY5	Boys	Right	Maxillary	M1	West midden unit A
MCBOY6	Boys	Right	Maxillary	M1	West midden unit A
MCCAH1	Cahaigue	Right	Maxillary	M3	Case collection
MCCHR36	Christianson	Right	Mandibular	M1	Midden area 13 -3,4,5 PZ
MCCHR37	Christianson	Left	Maxillary	M1	Area C
MCCHR38	Christianson	Right	Maxillary	M1	Area C
MCCHR41	Christianson	Left	Maxillary	M1	House 1 feature 33
MCCLV11	Cleveland	Right	Maxillary	M2	NA
MCCLV13	Cleveland	Right	Mandibular	M2	NA
MCCLV15	Cleveland	Right	Maxillary	M1	NA
MCCOU4	Coulter	Left	Mandibular	M3	Midden 55
MCCOU5	Coulter	Right	Maxillary	M1	Midden 55
MCCOU6	Coulter	Left	Maxillary	M1	Midden 55
MCCRL1	Crawford Lake	NA	Maxillary	M	NA

MCDON1	Donovan	NA	Mandibular	PM3	NA
MCDON2	Donovan	NA	NA	M	NA
MCDON3	Donovan	Left	Mandibular	M1	NA
MCFON1	Fonger	Right	Maxillary	M1	NA
MCFON2	Fonger	Right	Maxillary	M3	NA
MCFON3A	Fonger	Left	Maxillary	M1	NA
MCFON3B	Fonger	Left	Maxillary	M3	NA
MCFON4	Fonger	Left	Maxillary	M1	NA
MCFON5	Fonger	Left	Maxillary	M1	NA
MCGUN1	Gunby	NA	Maxillary	M	NA
MCGUN5	Gunby	Right	Maxillary	M3	NA
MCGUN9A	Gunby	Right	Maxillary	M1	NA
MCGUN9C	Gunby	Right	Maxillary	M3	NA
MCGUN10	Gunby	Left	Mandibular	M1	NA
MCHAM1	Hamilton	Right	Maxillary	M3	House 3 P15
MCHAM2	Hamilton	Right	Maxillary	M1	House 3 P15
MCHAM3A	Hamilton	Right	Maxillary	M1	House 3 P15
MCHAM3B	Hamilton	Right	Maxillary	M2	House 3 P15
MCHAM3C	Hamilton	Right	Maxillary	M3	House 3 P15
MCHAM7	Hamilton	Right	Maxillary	M1	House 3 P15
MCHOO1	Hood	Right	Mandibular	M2	Feature 347
MCHOO2	Hood	Left	Maxillary	M2	Feature 347
MCHOO5	Hood	Right	Maxillary	M1	Feature 373
MCHOO6	Hood	Right	Maxillary	M2	Feature 373
MCHOO7A	Hood	Right	Mandibular	M2	Feature 373
MCHOO7B	Hood	Right	Mandibular	M1	Feature 373
MCHOO7C	Hood	Right	Mandibular	PM3	Feature 373
MCKIR2	Kirche	Left	Maxillary	M3	House 1 midden 212 square 310-210
MCKIR4	Kirche	Right	Mandibular	M3	House 1 midden 213 square 275-235
MCKIR7	Kirche	Right	Mandibular	M3	Palisade square 330-210
MCKIR9	Kirche	Left	Maxillary	M1	Palisade(?) square 270-125
MCKNT2	Knight-Tucker	Right	Maxillary	M1	NA
MCKNT6	Knight-Tucker	Left	Maxillary	M1	Southwall unit 4
MCKNT7	Knight-Tucker	Left	Maxillary	M1	S15E3
MCLUD 1	Ludlow Vanderlip	Left	Mandibular	M3	NA
MCLUD2	Ludlow Vanderlip	Left	Mandibular	M1	NA

MCLUD3	Ludlow Vanderlip	Right	Mandibular	M2	NA
MCMAN1	Mannen	Right	Mandibular	M1	NA
MCMAN2	Mannen	Right	Maxillary	M1	NA
MCMAN3	Mannen	Left	Mandibular	M2	NA
MCMAN10	Mannen	Left	Mandibular	M3	NA
MCMCM1	McMurray	Left	Mandibular	M3	NA
MCMCM2	McMurray	Right	Maxillary	M1	NA
MCMCM3	McMurray	NA	Maxilary	M	NA
MCMCP1	McPherson	Left	Mandibular	M3	Surface
MCMCP2	McPherson	Right	Maxillary	M1	Surface
MCNDO1	Nedelko-Orct	NA	Maxillary	M	Area 4 and area 5
MCNDO2	Nedelko-Orct	NA	Mandibular	M	Area 4 and area 5
MCNUR8	Nursery	Left	Maxillary	M1	NA
MCNUR9	Nursery	Left	Maxillary	M2	NA
MCNUR10	Nursery	Left	Maxillary	M1	NA
MCPRI1	Princess Point	Right	Mandibular	M1	Area A
MCPRI2	Princess Point	Left	Maxillary	M3	Area A
MCPRI3	Princess Point	Left	Mandibular	PM4	Area A
MCPRI4	Princess Point	Left	Mandibular	M3	Area A
MCREI2	Reid	Right	Maxillary	M2	House 1 P712
MCREI4	Reid	Left	Mandibular	M3	House 1 P134
MCREI7	Reid	Right	Mandibular	M3	House 1 P32
MCREI8	Reid	Right	Mandibular	M3	House 1 P389
MCREI9	Reid	Right	Mandibular	M1	House 3 P317
MCREI10	Reid	Left	Mandibular	M3	House 3 P317
MCREI11	Reid	Right	Mandibular	M3	House 3 P317
MCSAV1	Savage	Left	Maxillary	M1	145 8W
MCSLC1	Slack-Caswell	Left	Mandibular	M1	NA
MCSLC2	Slack-Caswell	Left	Mandibular	M1	NA
MCSLC4	Slack-Caswell	Left	Maxillary	PM3	NA
MCTHO1	Thorold	Right	Maxillary	M1	Midden 3 square 27
MCTHO2	Thorold	Right	Mandibular	PM3	Midden 3 square 42
MCTHO3	Thorold	Right	Maxillary	M1	Midden 3 unit 9 square 2
MCTRE1	Trent	Left	Mandibular	M3	Surface NE quad
MCTRE4	Trent	Left	Maxillary	M1	Surface NE quad
MCTRE5	Trent	Left	Maxillary	M2	Surface SE quad
MCURE1	Uren	Left	Maxillary	M1	NA
MCURE2	Uren	Right	Mandibular	M3	NA

MCURE6	Uren	Left	Mandibular	M1	NA
MCVBE3	Van Besien	Right	Mandibular	M3	NA
MCVBE4	Van Besien	Right	Mandibular	M3	NA
MCVBE5	Van Besien	Left	Mandibular	M3	NA
MCWAL2A	Walker	Right	Maxillary	M1	NA
MCWAL2C	Walker	Right	Maxillary	M3	NA
MCWAL3A	Walker	Left	Maxillary	M1	NA
MCWAL3B	Walker	Left	Maxillary	M3	NA
MCWAL4	Walker	Right	Mandibular	M3	NA

Appendix D

This appendix details where samples were obtained from as well as their length and weights. All measurements are maximum lengths (i.e., from the apex of the crown to the base of the CEJ) measured using digital calipers. When data are unavailable, they are signified as such by NA. These could be because the sample is obtained from a fragment due to post-mortem damage or the measurement is obscured. The latter primarily occurs with samples obtained from the back section of enamel.

MARC	MAAS (g)	Tooth	Loph	Section	Sample size (mm)	Whole loph (mm)
2150	0.01605	MCCHR36	Back left	Front	top 2.06	10.8
2151	0.01755	MCCHR36	Back right	Front	top 2.1	8.4
2152	0.0164	MCCHR36	Front left	Front	top 2.1	10.9
2153	0.02113	MCCHR36	Front left	Front	middle 3.5	10.9
2154	0.01305	MCCHR36	Front left	Front	bottom 2.3	10.9
2157	0.05378	MCCHR36	Front right	Front	bottom 2.9	10.4
2158	0.0146	MCCHR36	Front left	Back	top 2.4	NA
2159	0.00839	MCCHR36	Back right	Back	NA	NA
2160	0.00546	MCREI10	Front right	Front	top 2.3	8.7
2161	0.01263	MCREI10	Front right	Front	middle 2.6	8.7
2162	0.01467	MCREI10	Front right	Front	bottom 2.0	8.7
2163	0.01387	MCREI10	Front left	Front	top 3.0	7.6
2164	0.01618	MCREI10	Front left	Front	bottom 3.4	7.6
2165	0.0229	MCREI10	Back left	Back	top 3.3	11.1
2166	0.0201	MCREI10	Back left	Back	middle 2.8	11.1
2167	0.02145	MCREI10	Back left	Back	bottom 3.2	11.1
2168	0.01579	MCREI10	Back right	Back	longitudinal	5.3
2169	0.02306	MCREI10	Front right	Back	top 3.2	NA
2175	0.00918	MCBOG10	Front left	Front	top 2.4	5.4
2176	0.01528	MCBOG10	Front left	Front	bottom 2.5	5.4
2177	0.00985	MCBOY5	NA	Front	longitudinal	7.2
2178	0.03223	MCBOY5	NA	Front	longitudinal	7.2
2179	0.01747	MCTHO1	Front left	Front	top 4.0	9.4
2180	0.02174	MCTHO1	Front left	Front	bottom 4.3	9.4
2181	0.01625	MCTHO1	Back right	Front	top 2.3	9.9

2182	0.01417	MCTHO1	Back right	Front	middle 3.4	9.9
2183	0.01673	MCTHO1	Back right	Front	bottom 4.2	9.9
2184	0.01062	MCBOG5	Front left	Front	top 2.8	8.2
2186	0.01062	MCBEN13	Front left	Front	top 1.8	4.2
2187	0.01626	MCBEN13	Front left	Front	bottom 2.4	4.2
2188	0.01481	MCBEN13	Front right	Front	longitudinal	3.6
2189	0.02195	MCKIR7	Back right	Front	top 2.5	10.4
2190	0.01447	MCKIR7	Back right	Front	middle 2.2	10.4
2191	0.01425	MCKIR7	Back right	Front	bottom 3.7	10.4
2192	0.0192	MCKIR7	Back middle	Front	top 4.2	10.6
2193	0.01232	MCKIR7	Back middle	Front	middle 2.7	10.6
2194	0.01284	MCKIR7	Back middle	Front	bottom 2.9	10.6
2195	0.0106	MCKIR7	Back left	Front	top 3.4	7.8
2196	0.01361	MCKIR7	Back left	Front	bottom 3.6	7.8
2197	0.01451	MCKIR7	Front left	Front	top 3.0	9.5
2198	0.03146	MCKIR7	Front left	Front	middle 2.6	9.5
2199	0.02942	MCKIR7	Front left	Front	bottom 3.0	9.5
2200	0.01335	MCKIR7	Front middle	Front	top 3.2	10.7
2201	0.01365	MCKIR7	Front middle	Front	middle 2.2	10.7
2202	0.02168	MCKIR7	Front middle	Front	bottom 4.5	10.7
2203	0.01178	MCKIR7	Front right	Front	top 3.4	8.9
2204	0.01611	MCKIR7	Front right	Front	middle 3.4	8.9
2205	0.01203	MCKIR7	Front right	Front	bottom 2.1	8.9
2206	0.02159	MCCLV13	Front left	Front	top 2.4	12.5
2207	0.01513	MCCLV13	Front left	Front	next 1.2	12.5
2208	0.02114	MCCLV13	Front left	Front	middle 2.1	12.5
2209	0.02766	MCCLV13	Front left	Front	next 2.9	12.5
2210	0.0262	MCCLV13	Front left	Front	bottom 4.1	12.5
2211	0.01161	MCCHR38	Front left	Front	top 2.7	8.2
2212	0.0151	MCCHR38	Front left	Front	middle 3.0	8.2
2213	0.01455	MCCHR38	Front left	Front	bottom 2.5	8.2
2214	0.00918	MCCHR38	Front left	Back	top 3.9	NA
2215	0.00944	MCCHR38	Front left	Back	middle 3.6	NA
2216	0.0131	MCCLV11	Front left	Front	top 1.8	7.8
2217	0.01765	MCCLV11	Front left	Front	middle 2.0	7.8
2218	0.02199	MCCLV11	Front left	Front	bottom 3.2	7.8
2219	0.0086	MCREI11	Front left	Front	longitudinal	10
2220	0.0152	MCREI11	Front left	Front	longitudinal	10
2221	0.00711	MCREI11	Front left	Front	longitudinal	10

2222	0.00928	MCKIR9	Front left	Front	top 3.2	7.8
2223	0.01118	MCKIR9	Front left	Front	bottom 2.6	7.8
2224	0.02988	MCTHO3	Front left	Front	top 3.1	5.1
2225	0.01442	MCTHO3	Front left	Front	bottom 2.0	5.1
2226	0.01718	MCTHO3	Front left	Front	longitudinal	5.1
2227	0.01053	MCBOR1	Front left	Front	top 3.3	9.5
2228	0.01092	MCBOR1	Front left	Front	middle 3.0	9.5
2229	0.01238	MCBOR1	Front left	Front	bottom 2.8	9.5
2230	0.00985	MCBOR5	Front left	Front	longitudinal	10.1
2232	0.01607	MCBOR5	Front left	Front	middle 3.4	10.1
2233	0.01254	MCBOR5	Front left	Front	bottom 3.7	10.1
2234	0.01324	MCBOY6	Front left	Front	fragment	NA
2235	0.01176	MCBOY6	Front left	Front	fragment	NA
2236	0.01319	MCBEN11	Front left	Front	top 4.1	9.2
2237	0.0083	MCBEN11	Front left	Front	bottom 4.1	9.2
2238	0.00774	MCURE6	Front left	Front	top 2.8	5.2
2239	0.00917	MCURE6	Front left	Front	bottom 3.2	5.2
2240	0.01623	MCURE1	Front left	Front	top 3.0	8
2241	0.02137	MCURE1	Front left	Front	middle 2.0	8
2242	0.01588	MCURE1	Front left	Front	bottom 3.0	8
2304	0.01693	MCGUN1	Front right	Front	top 1.5	12.8
2305	0.01645	MCGUN1	Front right	Front	next 1.5	12.8
2306	0.0138	MCGUN1	Front right	Front	next 1.5	12.8
2307	0.01384	MCGUN1	Front right	Front	next 2.0	12.8
2308	0.01407	MCGUN1	Front right	Front	next 2.0	12.8
2309	0.00477	MCGUN1	Front right	Front	middle 1.8	12.8
2310	0.00874	MCGUN10	Front right	Front	top 1.9	6.8
2311	0.01086	MCGUN10	Front right	Front	middle 2.8	6.8
2312	0.01173	MCGUN10	Front right	Front	bottom 1.9	6.8
2313	0.00773	MCGUN10	Back right	Front	top 2.3	7
2314	0.00673	MCGUN10	Back right	Front	middle 2.4	7
2366	0.00584	MCVBE4	Front left	Front	next 1.4	12.2
2367	0.0046	MCVBE4	Front left	Front	next 1.0	12.2
2368	0.00858	MCVBE4	Front left	Front	middle 1.3	12.2
2369	0.01322	MCVBE4	Front left	Front	next 1.6	12.2
2370	0.01434	MCVBE4	Front left	Front	next 1.8	12.2
2371	0.01225	MCVBE4	Front left	Front	bottom 2.4	12.2
2372	0.00314	MCVBE4	Back left	Front	middle 0.9	9.2
2373	0.0087	MCVBE4	Back left	Front	next 1.0	9.2

2374	0.00696	MCVBE4	Back left	Front	next 1.5	9.2
2375	0.00385	MCVBE4	Back left	Front	bottom 1.8	9.2
2376	0.00489	MCVBE4	Front right	Front	top 1.2	9.1
2380	0.00821	MCVBE4	Front right	Front	next 1.3	9.1
2382	0.00818	MCVBE4	Front middle	Front	top 1.3	12
2384	0.00495	MCVBE4	Front middle	Front	next 1.3	12
2385	0.00928	MCVBE4	Front middle	Front	next 1.4	12
2386	0.00713	MCVBE4	Front middle	Front	middle 1.2	12
2387	0.00668	MCVBE4	Front middle	Front	next 1.2	12
2389	0.00833	MCVBE4	Front middle	Front	next 1.1	12
2390	0.00902	MCVBE4	Front middle	Front	bottom 1.8	12
2391	0.0042	MCVBE4	Back middle	Front	top 1.7	13.3
2392	0.00777	MCVBE4	Back middle	Front	next 1.8	13.3
2393	0.00769	MCVBE4	Back middle	Front	next 1.6	13.3
2394	0.00531	MCVBE4	Back middle	Front	next 1.2	13.3
2395	0.00637	MCVBE4	Back middle	Front	next 1.5	13.3
2396	0.00523	MCVBE4	Back middle	Front	next 1.3	13.3
2397	0.00392	MCVBE4	Back middle	Front	bottom 1.6	13.3
2398	0.00425	MCVBE4	Back right	Front	top 2.0	13.6
2399	0.00451	MCVBE4	Back right	Front	next 1.1	13.6
2400	0.00396	MCVBE4	Back right	Front	next 1.0	13.6
2401	0.00713	MCVBE4	Back right	Front	middle 1.3	13.6
2402	0.00496	MCVBE4	Back right	Front	next 1.3	13.6
2403	0.00445	MCVBE4	Back right	Front	next 0.9	13.6
2404	0.00463	MCVBE4	Back right	Front	next 1.2	13.6
2405	0.00435	MCVBE4	Back right	Front	bottom 1.5	13.6
2406	0.00451	MCVBE5	Front left	Front	top 1.6	7.6
2407	0.0057	MCVBE5	Front left	Front	next 1.7	7.6
2408	0.00353	MCVBE5	Front left	Front	middle 1.2	7.6
2409	0.00542	MCVBE5	Front left	Front	next 1.3	7.6
2410	0.00583	MCVBE5	Front left	Front	bottom 1.8	7.6
2417	0.0043	MCHOO5	Front left	Front	longitudinal	6
2418	0.01159	MCHOO5	Front left	Front	longitudinal	6
2419	0.00711	MCTRE4	Front left	Front	top 1.7	5.9
2420	0.00525	MCTRE4	Front left	Front	middle 1.0	5.9
2421	0.00186	MCTRE4	Front left	Front	bottom 2.2	5.9
2422	0.00377	MCTRE4	Front left	Back	longitudinal	NA
2424	0.00832	MCKNT2	Front left	Front	top 1.7	5.2
2426	0.00998	MCKNT2	Front left	Front	bottom 1.8	5.2

2427	0.00795	MCMAN1	Front left	Front	top 1.9	8.9
2428	0.00893	MCMAN1	Front left	Front	next 1.5	8.9
2429	0.00715	MCMAN1	Front left	Front	next 1.4	8.9
2430	0.00964	MCMAN1	Front left	Front	next 2.0	8.9
2431	0.00652	MCMAN1	Front left	Front	bottom 2.0	8.9
2647	0.0064	MCREI4	Front left	Front	top 2.3	11.5
2648	0.01017	MCREI4	Front left	Front	next 1.8	11.5
2649	0.01467	MCREI4	Front left	Front	next 2.1	11.5
2650	0.01176	MCREI4	Front left	Front	next 2.4	11.5
2651	0.00862	MCREI4	Front left	Front	bottom 2.2	11.5
2652	0.02675	MCVBE5	Front middle	Front	top 3.5	10
2653	0.0195	MCVBE5	Front middle	Front	middle 2.8	10
2654	0.01168	MCVBE5	Front middle	Front	bottom 3.5	10
2689	0.01116	MCCLV11	Front right	Front	top 1.5	9.8
2690	0.01133	MCCLV11	Front right	Front	next 1.4	9.8
2694	0.01945	MCMAN1	Back right	Front	top 2.5	8.5
2695	0.01312	MCMAN1	Back right	Front	next 2	8.5
2696	0.01012	MCMAN1	Back right	Front	next 2	8.5
2697	0.00358	MCMAN1	Back right	Front	bottom 1.5	8.5
2698	0.0053	MCLUD2	Front left	Front	top 2.0	8.2
2701	0.00527	MCLUD2	Front left	Front	next 1.2	8.2
2702	0.00736	MCLUD2	Front left	Front	next 1.3	8.2
2703	0.00341	MCLUD2	Front left	Front	bottom1.4	8.2
2704	0.00447	MCHAM7	Front left	Front	bottom 1.3	6
2705	0.00336	MCHAM7	Front left	Front	next 1	6
2706	0.00391	MCHAM7	Front left	Front	middle 1.2	6
2707	0.00368	MCHAM7	Front left	Front	next 1	6
2708	0.00424	MCHAM7	Front left	Front	top 1.5	6
2709	0.01186	MCGUN10	Front right	Front	top 2	6.8
2710	0.00875	MCGUN10	Front right	Front	next 1.5	6.8
2711	0.00579	MCGUN10	Front right	Front	next 1	6.8
2712	0.00304	MCGUN10	Front right	Front	bottom 0.9	6.8
2740	0.01588	MCKNT6	Front left	Front	top 2.28	11.28
2741	0.01459	MCKNT6	Front left	Front	next 1.62	11.28
2742	0.0152	MCKNT6	Front left	Front	next 1.38	11.28
2743	0.01642	MCKNT6	Front left	Front	next 1.67	11.28
2745	0.00783	MCKNT6	Front left	Front	next 1.12	11.28
2748	0.00446	MCMCP1	Front left	Front	top 0.77	9.64
2749	0.0027	MCMCP1	Front left	Front	next 1.15	9.64

2750	0.00446	MCMCP1	Front left	Front	next 1.23	9.64
2751	0.00869	MCMCP1	Front left	Front	next 1.45	9.64
2752	0.01209	MCMCP1	Front left	Front	next 0.95	9.64
2753	0.00972	MCMCP1	Front left	Front	next 1.06	9.64
2754	0.01369	MCMCP1	Front left	Front	next 1.43	9.64
2755	0.00759	MCMCP1	Front left	Front	bottom 1.37	9.64
2756	0.00467	MCMCP2	Front left	Front	top 1.41	8.62
2757	0.00956	MCMCP2	Front left	Front	next 1.82	8.62
2758	0.00454	MCMCP2	Front left	Front	bottom 1.32	8.62
2759	0.00539	MCMCP2	Front left	Front	top 1.7	8.62
2760	0.01068	MCMCP2	Front left	Front	bottom 2.44	8.62
2761	0.00731	MCPRI2	Front left	Front	top 4	9.81
2762	0.00998	MCPRI2	Front left	Front	middle 2.53	9.81
2763	0.00832	MCPRI2	Front left	Front	bottom 2.86	9.81
2764	0.00546	MCPRI2	Front left	Front	longitudinal	9.81
2765	0.00826	MCPRI2	Front left	Front	longitudinal	9.81
2766	0.00331	MCPRI3	Front left	Front	top 1.75	5.74
2767	0.00408	MCPRI3	Front left	Front	middle 1.82	5.74
2768	0.00411	MCPRI3	Front left	Front	bottom 1.63	5.74
2769	0.00716	MCPRI4	Front left	Front	longitudinal	8.34
2770	0.01003	MCPRI4	Front left	Front	longitudinal	8.34
2771	0.01489	MCPRI4	Front left	Front	longitudinal	8.34
2772	0.00423	MCMCP1	Front middle	Front	top 1.82	8.13
2773	0.0071	MCMCP1	Front middle	Front	middle 2.13	8.13
2774	0.0059	MCMCP1	Front middle	Front	bottom 2.86	8.13
2775	0.00658	MCMCP1	Front right	Front	top 1.17	12.73
2776	0.00848	MCMCP1	Front right	Front	next 1.21	12.73
2777	0.00573	MCMCP1	Front right	Front	next 1.21	12.73
2778	0.00804	MCMCP1	Front right	Front	next 1.49	12.73
2779	0.00638	MCMCP1	Front right	Front	next 1.64	12.73
2780	0.00459	MCMCP1	Front right	Front	next 1.68	12.73
2781	0.00288	MCMCP1	Front right	Front	bottom 1.57	12.73
2782	0.00437	MCMCP1	Back left	Front	top 3.19	10.71
2783	0.00897	MCMCP1	Back left	Front	middle 1.28	10.71
2784	0.00729	MCMCP1	Back left	Front	next 1.05	10.71
2785	0.0074	MCMCP1	Back left	Front	next 1.23	10.71
2786	0.00943	MCMCP1	Back left	Front	bottom 1.79	10.71
2787	0.00929	MCPRI1	Front left	Front	top 4.37	8.94
2788	0.0042	MCPRI1	Front left	Front	middle 1.23	8.94

2789	0.00811	MCPRI1	Front left	Front	bottom 3	8.94
2790	0.00679	MCSAV1	Front left	Front	top 1.87	7.41
2791	0.00683	MCSAV1	Front left	Front	next 1.90	7.41
2792	0.01015	MCSAV1	Front left	Front	next 2	7.41
2793	0.00752	MCSAV1	Front left	Front	bottom 1.38	7.41
2794	0.00521	MCTRE5	Front left	Front	top 1.66	5.48
2795	0.0118	MCTRE5	Front left	Front	middle 2	5.48
2797	0.00406	MCMCP1	Back right	Front	top 1.69	5.35
2798	0.00587	MCMCP1	Back right	Front	middle 1.49	5.35
2799	0.0026	MCMCP1	Back right	Front	bottom 1.66	5.35
2800	0.00334	MCHOO6	Front left	Front	longitudinal	5.82
2801	0.0139	MCHOO6	Front left	Front	longitudinal	5.82
2802	0.01029	MCHOO6	Front right	Front	top 1.53	7.9
2803	0.00854	MCHOO6	Front right	Front	next 1.29	7.9
2805	0.0151	MCHOO6	Front right	Front	bottom 2.71	7.9
2806	0.00577	MCHOO6	Front right	Front	longitudinal	7.9
2807	0.00411	MCBEN7	Front left	Front	top 1.71	7.01
2809	0.00935	MCBEN7	Front left	Front	next 1.37	7.01
2810	0.00987	MCBEN7	Front left	Front	bottom 1.78	7.01
2813	0.01067	MCHOO7A	Front left	Front	longitudinal	9.08
2814	0.00447	MCHOO7A	Front left	Front	longitudinal	9.08
2815	0.00503	MCHOO7B	Front left	Front	top 1.87	6.89
2816	0.00635	MCHOO7B	Front left	Front	middle 1.60	6.89
2817	0.00503	MCHOO7B	Front left	Front	bottom 2.12	6.89
2820	0.0063	MCHOO7C	Front left	Front	next 1.42	6.28
2821	0.0094	MCHOO7C	Front left	Front	bottom 2.13	6.28
2823	0.00751	MCMCP1	Back right	Front	top 5.94	9.06
2824	0.0072	MCMCP1	Back right	Front	bottom 3.05	9.06
2825	0.01801	MCMCP1	Back middle	Front	top 5.09	12.91
2826	0.01713	MCMCP1	Back middle	Front	next 2.72	12.91
2827	0.01883	MCMCP1	Back middle	Front	next 2.67	12.91
2828	0.01705	MCMCP1	Back middle	Front	bottom 2.29	12.91
2829	0.00104	MCMCP1	Front right	Back	top 4.94	4.94
2830	0.01151	MCMCP1	Back left	Back	top 3.96	9.92
2831	0.01385	MCMCP1	Back left	Back	bottom 4.16	9.92
2885	0.01884	MCREI2	Front left	Front	longitudinal	8.27
2886	0.02215	MCURE2	Front left	Front	longitudinal	8.8
2887	0.02546	MCCHR37	Front left	Front	longitudinal	10.24
2889	0.01076	MCREI9	Front left	Front	longitudinal	8.98

2900	0.02417	MCKIR2	Front left	Front	top 3.24	10.85
2901	0.01732	MCKIR2	Front left	Front	middle 3.84	10.85
2903	0.0137	MCSLC2	Front left	Front	top 2.23	10.01
2907	0.01519	MCBOG11	Front left	Front	longitudinal	12.93
2911	0.01244	MCHOO1	Front left	Front	longitudinal	11.58
2916	0.01867	MCBOG13	Front left	Front	middle 2.24	10.61
2920	0.01929	MCURE2	Front left	Front	longitudinal	8.8
2923	0.02135	MCCHR41	Front left	Front	longitudinal	12.78
2926	0.00471	MCLUD3	Front left	Front	top 2.7	8.52
2927	0.0063	MCLUD3	Front left	Front	middle 2.67	8.52
2929	0.01158	MCMAN3	Front left	Front	top 2.27	6.37
2934	0.01591	MCREI7	Front left	Front	longitudinal	8.87
2941	0.01192	MCBOG4	Front left	Front	longitudinal	7.43
2942	0.01654	MCSLC4	Front left	Front	middle 4.68	4.68
2943	0.01119	MCKNT7	Front left	Front	top 2.47	9.46
2944	0.00945	MCVBE3	Front left	Front	top 1.96	5.21
2945	0.02271	MCMAN10	Front left	Front	top 3.83	7.7
2946	0.01715	MCBOY2	Front left	Front	NA	16.7
2947	0.01237	MCWAL4	Front left	Front	top 3.24	8.02
2948	0.00765	MCDON2	Dentin	Front	NA	NA
2949	0.0193	MCDON2	Enamel	Front	NA	NA
2950	0.02005	MCDON3	Front left	Front	top 3.61	9.76
2951	0.01262	MCDON1	Front left	Front	longitudinal	5.52
2952	0.01356	MCNDO1	Front left	Front	NA	10.58
2953	0.00784	MCNDO2	NA	Front	longitudinal	10.36
2954	0.01081	MCCAH1	Front left	Front	longitudinal	10.36
2955	0.01824	MCCHR38	Front right	Front	longitudinal	9.7
2956	0.01993	MCLUD 1	Front right	Front	longitudinal	7.63
2960	0.01281	MCSLC1	Front left	Front	top 3.0	7.68
2961	0.02437	MCCRL1	NA	Front	top 4.09	9.39
2962	0.01121	MCBOR7	Front left	Front	top 3.81	9.24
2977	0.00498	MCCOU6	Front left	Front	longitudinal	9.73
2978	0.03103	MCMCM1	Front left	Front	top 5.95	10.83
2980	0.01544	MCHAM2	Front left	Front	top 4.02	7.07
2981	0.01798	MCHAM1	Front left	Front	top 4.56	10.5
2982	0.01565	MCHAM1	Front left	Back	top 4.56	NA
2983	0.01594	MCGUN5	Front right	Front	top 3.92	9.83
3122	0.0092	MCFON3A	Front left	Front	longitudinal	4.33
3124	0.00576	MCWAL3A	Front left	Front	top 2.39	7.19

3125	0.01508	MCHOO2	Front left	Front	longitudinal	9.56
3126	0.00983	MCCOU5	Front left	Front	top 3.19	8.95
3127	0.01921	MCKIR4	Front left	Front	top 4.5	10.76
3128	0.01826	MCWAL3B	Front left	Front	top 4.81	10.91
3129	0.00815	MCMCM2	Front left	Front	top 3.61	8.59
3130	0.00633	MCTHO2	Front left	Front	top 2.45	5.77
3131	0.01859	MCMAN2	Front left	Front	top 4.15	8.95
3132	0.01349	MCCOU4	Front left	Front	top 4..5	8.19
3133	0.01155	MCHAM3A	Front left	Front	top 3.31	6.99
3134	0.01476	MCHAM3B	Front left	Front	top 3.32	10.03
3135	0.01228	MCHAM3C	Front left	Front	top 3.82	9.3
3136	0.00406	MCWAL2A	Front left	Front	top 2.35	7.52
3137	0.00774	MCWAL2C	Front left	Front	top 2.11	8.61
3138	0.00768	MCGUN9A	Front left	Front	top 3.32	4.7
3139	0.01058	MCGUN9C	Front left	Front	top 2.60	6.75
3140	0.00642	MCFON5	Front left	Front	top 2.85	5.47
3141	0.00441	MCMCM3	Front left	Front	top 1.59	9.27
3330	0.00994	MCFON1	Front left	Front	top 2.87	5.41
3331	0.01181	MCTRE1	Front left	Front	top 3.34	6.51
3332	0.02584	MCCLV15	Front left	Front	top 6.42	12.25
3334	0.01464	MCFON2	Front left	Front	top 3.96	6.68
3336	0.01189	MCNUR10	Front left	Front	longitudinal	12.14
3361	0.0154	MCNUR8	Front left	Front	top 2.42	12.68
3363	0.01151	MCNUR9	Front left	Front	top 3.83	11.49

Appendix E

This appendix contains the $^{87}Sr/^{86}Sr$ data obtained from sampled white-tailed deer teeth recovered at archaeological sites in southern Ontario. Values were corrected using the data provided in Table 6.1. Starred values were diluted for analyses. Italicized samples are those data that are inaccurate and not included in the results. Sites in bold were analyzed at the MPI-EVI Archaeological Science Research Group in Leipzig, Germany. Sample concentrations of strontium were used to establish whether a value is acceptable (i.e., a sample with a concentration of zero or below indicates a sample that is not appropriate to include in analyses). Sample concentrations were established following the protocols outlined in Chapter Six.

MARC	Tooth	Uncorrected $^{87}Sr/^{86}Sr$	Corrected $^{87}Sr/^{86}Sr$	Sample conc (ppm)
2150	MCCHR36	0.71001	0.70998	12
2151	MCCHR36	0.70946	0.70943	12
2152	**MCCHR36**	**0.71012**	**0.71006**	**4**
2153	**MCCHR36**	**0.71016**	**0.71010**	**3**
2154	**MCCHR36**	**0.71017**	**0.71010**	**7**
2155	MCCHR36	0.70945	0.70942	6
2156	MCCHR36	0.70094	0.70097	11
2157	MCCHR36	0.71005	0.71002	10
2158	MCCHR36	0.71002	0.70999	11
2159	MCREI10	0.71136	0.71133	29
2160	MCREI10	0.71083	0.71080	8
2161	MCREI10	0.71101	0.71098	23
2162	MCREI10	0.71099	0.71096	9
2163	**MCREI10**	**0.71111**	**0.71105**	**12**
2164	**MCREI10**	**0.71093**	**0.71667**	**18**
2165	MCREI10	0.71100	0.71097	23
2166	MCREI10	0.71085	0.71082	20
2167	MCREI10	0.71067	0.71064	16
2168	MCREI10	0.71077	0.71074	23
2169	MCREI10	0.71093	0.71090	21

2175	**MCBOG10**	**0.71019**	**0.71013**	**16**
2176	**MCBOG10**	**0.71019**	**0.71013**	**3**
2177	**MCBOY5**	**0.70988**	**0.70962**	**10**
2178	**MCBOY5**	**0.70987**	**0.70961**	**4**
2179	**MCTHO1**	**0.71214**	**0.71208**	**5**
2180	**MCTHO1**	**0.71219**	**0.71213**	**8**
2181	MCTHO1	0.71205	0.71202	9
2182	MCTHO1	0.71210	0.71207	19
2183	MCTHO1	0.71211	0.71208	20
2184	**MCBOG5**	**0.70973**	**0.70967**	**2**
2185	***MCBEN13***	***0.70969***	***0.70962***	***0***
2186	**MCBEN13**	**0.70897**	**0.70891**	**30**
2187	**MCBEN13**	**0.70899**	**0.70892**	**10**
2188	MCBEN13	0.70897	0.70894	11
2189	MCKIR7	0.70892	0.70889	9
2190	MCKIR7	0.70889	0.70887	3
2191	MCKIR7	0.70889	0.70886	6
2192	MCKIR7	0.70885	0.70882	14
2193	MCKIR7	0.70881	0.70878	24
2194	MCKIR7	0.70882	0.70879	11
2195	MCKIR7	0.70874	0.70871	6
2196	MCKIR7	0.70876	0.70873	20
2197	**MCKIR7**	**0.70899**	**0.70893**	**5**
2198	**MCKIR7**	**0.70916**	**0.70909**	**3**
2199	**MCKIR7**	**0.70881**	**0.70875**	**5**
2200	MCKIR7	0.70883	0.70880	10
2201	MCKIR7	0.70883	0.70880	3
2202	MCKIR7	0.70881	0.70878	4
2203	MCKIR7	0.70858	0.70855	8
2204	MCKIR7	0.70883	0.70880	3
2205	MCKIR7	0.70882	0.70879	10
2206	**MCCLV13**	**0.71140**	**0.71134**	**3**
2207	**MCCLV13**	**0.71116**	**0.71110**	**20**
2208	**MCCLV13**	**0.71096**	**0.71090**	**6**
2209	**MCCLV13**	**0.71086**	**0.71080**	**8**
2210	**MCCLV13**	**0.71059**	**0.71054**	**7**
2211	**MCCHR38**	**0.70988**	**0.70983**	**9**
2212	**MCCHR38**	**0.70992**	**0.70987**	**4**
2213	**MCCHR38**	**0.70986**	**0.70981**	**6**

2214	MCCHR38	0.70986	0.70983	8
2215	MCCHR38	0.70920	0.70917	61
2216	**MCCLV11**	**0.71075**	**0.71070**	**27**
2217	**MCCLV11**	**0.71081**	**0.71076**	**20**
2218	**MCCLV11**	**0.71072**	**0.71067**	**21**
2219	**MCREI11**	**0.70983**	**0.70977**	**24**
2220	**MCREI11**	**0.70984**	**0.70978**	**24**
2221	**MCREI11**	**0.70982**	**0.70977**	**11**
2222	MCKIR9	**0.70876**	0.70870	5
2223	MCKIR9	**0.70855**	0.70850	7
2224	MCTHO3	0.71178*	0.71175	5
2225	**MCTHO3**	**0.71183**	**0.71177**	**35**
2226	**MCTHO3**	**0.71185**	**0.71179**	**56**
2227	**MCBOR1**	**0.70929**	**0.70924**	**20**
2228	**MCBOR1**	**0.70940**	**0.70935**	**18**
2229	**MCBOR1**	**0.70934**	**0.70929**	**29**
2230	MCBOR5	0.70979	0.70976	1
2232	**MCBOR5**	**0.70978**	**0.70973**	**12**
2233	**MCBOR5**	**0.70971**	**0.70966**	**6**
2234	**MCBOY6**	**0.70890**	**0.70884**	**24**
2235	**MCBOY6**	**0.70892**	**0.70886**	**19**
2236	**MCBEN11**	**0.70862**	**0.70855**	**11**
2237	**MCBEN11**	**0.70858**	**0.70852**	**18**
2238	MCURE6	0.70944	0.70941	17
2239	MCURE6	0.70965	0.70962	5
2240	MCURE1	0.70885	0.70882	9
2241	MCURE1	0.70902	0.70899	9
2242	MCURE1	0.70897	0.70895	48
2304	MCFON4	0.70989	0.70986	18
2305	MCFON4	0.70953	0.70950	6
2306	MCFON4	0.70981	0.70978	7
2307	MCFON4	0.70995	0.70992	7
2308	MCFON4	0.70992	0.70989	12
2309	MCFON4	0.70987	0.70984	19
2310	MCGUN10	0.70982	0.70979	11
2311	MCGUN10	0.70976	0.70973	11
2312	MCGUN10	0.70968	0.70965	8
2313	MCGUN10	0.70978	0.70975	9
2314	MCGUN10	0.70970	0.70967	3

2365	*MCVBE4*	*0.70945*	*0.70942*	*0*
2366	MCVBE4	0.70974	0.70971	6
2367	MCVBE4	0.70972	0.70969	8
2368	MCVBE4	0.70979	0.70976	4
2369	MCVBE4	0.70969	0.70966	1
2370	MCVBE4	0.70983	0.70980	4
2371	MCVBE4	0.70980	0.70977	15
2372	MCVBE4	0.70984	0.70981	4
2373	MCVBE4	0.70975	0.70972	16
2374	MCVBE4	0.70959	0.70956	2
2375	MCVBE4	0.70975	0.70972	3
2376	MCVBE4	0.70988	0.70985	14
2377	*MCVBE4*	*0.71000*	*0.70997*	*-3*
2378	MCVBE4	0.70974	0.70971	1
2379	MCVBE4	0.70972	0.70969	1
2380	MCVBE4	0.70985	0.70982	1
2381	*MCVBE4*	*0.70974*	*0.70971*	*-1*
2382	MCVBE4	0.70970	0.70967	17
2383	*MCVBE4*	*0.71001*	*0.70998*	*-2*
2384	MCVBE4	0.70972	0.70969	3
2385	MCVBE4	0.70980	0.70977	2
2386	MCVBE4	0.70982	0.70979	15
2387	MCVBE4	0.70980	0.70977	17
2388	*MCVBE4*	*0.70959*	*0.70956*	*-2*
2389	MCVBE4	0.70978	0.70975	25
2390	MCVBE4	0.70968	0.70965	8
2391	MCVBE4	0.70968	0.70965	17
2392	MCVBE4	0.70981	0.70977	18
2393	MCVBE4	0.70984	0.70980	25
2394	MCVBE4	0.70984	0.70980	20
2395	MCVBE4	0.70974	0.70970	29
2396	MCVBE4	0.70975	0.70971	25
2397	MCVBE4	0.70975	0.70972	16
2398	MCVBE4	0.70961	0.70958	14
2399	MCVBE4	0.70968	0.70965	24
2400	MCVBE4	0.70958	0.70954	16
2401	MCVBE4	0.70977	0.70974	18
2402	MCVBE4	0.70979	0.70976	12
2403	MCVBE4	0.70984	0.70980	11

2404	MCVBE4	0.70976	0.70973	23
2405	MCVBE4	0.70943	0.70940	24
2406	MCVBE5	0.70999	0.70996	14
2407	MCVBE5	0.70968	0.70965	17
2408	MCVBE5	0.70945	0.70942	12
2409	MCVBE5	0.71022	0.71019	10
2410	MCVBE5	0.70925	0.70922	20
2416	*MCHOO5*	*0.71011*	*0.71008*	*0*
2417	MCHOO5	0.70975	0.70972	9
2418	MCHOO5	0.70981	0.70978	8
2419	MCTRE9	0.70885	0.70882	21
2420	MCTRE9	0.70903	0.70900	4
2421	MCTRE9	0.70873	0.70869	18
2422	MCTRE9	0.70876	0.70873	5
2423	*MCTRE9*	*0.70936*	*0.70933*	*0*
2424	MCKNT2	0.71075	0.71072	7
2425	*MCKNT2*	*0.71158*	*0.71155*	*0*
2426	MCKNT2	0.71053	0.71050	3
2427	MCMAN1	0.71028	0.71025	8
2428	MCMAN1	0.71029	0.71026	31
2429	MCMAN1	0.71031	0.71027	9
2430	MCMAN1	0.71020	0.71017	3
2431	MCMAN1	0.71031	0.71027	3
2647	MCREI4	0.70948	0.70945	228
2648	MCREI4	0.70945	0.70942	548
2649	MCREI4	0.70945	0.70942	41
2650	MCREI4	0.70945	0.70942	82
2651	MCREI4	0.70950	0.70947	196
2652	MCVBE5	0.71041	0.71039	20
2653	MCVBE5	0.71020	0.71018	46
2654	MCVBE5	0.10070	0.71005	6
2689	MCCLV11	0.71053	0.71051	62
2690	MCCLV11	0.71075	0.71072	78
2694	MCMAN1	0.7103*	0.71027	4
2695	MCMAN1	0.71034*	0.71031	4
2696	MCMAN1	0.71026	0.71024	13
2697	MCMAN1	0.71028	0.71026	33
2698	MCLUD2	0.70914	0.70911	31
2701	MCLUD2	0.70898	0.70896	72

2702	MCLUD2	0.70898	0.70896	77
2703	MCLUD2	0.70955	0.70953	68
2704	MCHAM7	0.71040	0.71038	60
2705	MCHAM7	0.71045	0.71043	21
2706	MCHAM7	0.71039	0.71036	527
2707	MCHAM7	0.71047	0.71044	527
2708	MCHAM7	0.71043	0.71041	18
2709	MCGUN10	0.70985	0.70983	28
2710	MCGUN10	0.70991	0.70989	16
2711	MCGUN10	0.70997	0.70995	8
2712	MCGUN10	0.70989	0.70987	8
2740	MCKNT6	0.71001*	0.70998	3
2741	MCKNT6	0.71007	0.71004	36
2742	MCKNT6	0.71002	0.70998	624
2743	MCKNT6	0.71002	0.70999	43
2745	MCKNT6	0.70999	0.70996	128
2748	MCMCP1	0.71036	0.71033	65
2749	MCMCP1	0.71039	0.71036	36
2750	MCMCP1	0.71046	0.71043	60
2751	MCMCP1	0.71039	0.71036	74
2752	MCMCP1	0.71036	0.71033	29
2753	MCMCP1	0.71027	0.71024	36
2754	MCMCP1	0.71011	0.71009	80
2755	MCMCP1	0.70998	0.70995	54
2756	MCMCP2	0.71116	0.71114	110
2757	MCMCP2	0.71114	0.71112	113
2758	MCMCP2	0.71097	0.71094	1105
2759	MCMCP2	0.71114	0.71111	505
2760	MCMCP2	0.71115	0.71113	98
2761	MCPRI2	0.71029	0.71026	952
2762	MCPRI2	0.71006	0.71003	592
2763	MCPRI2	0.70995	0.70992	45
2764	MCPRI2	0.71000	0.70997	78
2765	MCPRI2	0.71031	0.71028	402
2766	MCPRI3	0.71011	0.71008	85
2767	MCPRI3	0.71004	0.71001	388
2768	MCPRI3	0.71056	0.71053	100
2769	MCPRI4	0.71039	0.71037	102
2770	MCPRI4	0.71040	0.71038	140

2771	MCPRI4	0.71045*	0.71042	3
2772	MCMCP1	0.71041	0.71038	50
2773	MCMCP1	0.71035	0.71032	40
2774	MCMCP1	0.71010	0.71007	30
2775	MCMCP1	0.71020	0.71017	40
2776	MCMCP1	0.71029	0.71026	89
2777	MCMCP1	0.71039	0.71036	57
2778	MCMCP1	0.71044	0.71041	14
2779	MCMCP1	0.71043	0.71040	52
2780	MCMCP1	0.71037	0.71034	82
2781	MCMCP1	0.71028	0.71025	59
2782	MCMCP1	0.71031	0.71028	51
2783	MCMCP1	0.71045	0.71041	45
2784	MCMCP1	0.71044	0.71042	40
2785	MCMCP1	0.71039	0.71036	31
2786	MCMCP1	0.71038	0.71035	70
2787	MCPRI1	0.71053	0.71051	81
2788	MCPRI1	0.71061	0.71059	19
2789	MCPRI1	0.71062	0.71060	159
2790	MCSAV1	0.70986	0.70984	16
2791	MCSAV1	0.70977	0.70975	14
2792	MCSAV1	0.71004	0.71002	28
2793	MCSAV1	0.71004	0.71002	9
2794	MCTRE5	0.71099	0.71096	106
2795	MCTRE5	0.71156*	0.71153	3
2797	MCMCP1	0.71041	0.71038	8
2798	MCMCP1	0.71018	0.71015	46
2799	MCMCP1	0.71010	0.71008	16
2800	MCHOO6	0.71067	0.71064	877
2801	MCHOO6	0.71068*	0.71065	4
2802	MCHOO6	0.71056	0.71053	893
2803	MCHOO6	0.71062	0.71059	140
2805	MCHOO6	0.71075*	0.71072	16
2806	MCHOO6	0.71069	0.71066	109
2807	MCBEN7	0.70921	0.70919	190
2809	MCBEN7	0.70934*	0.70931	7
2810	MCBEN7	0.70956*	0.70953	3
2813	MCHOO7A	0.71081	0.71078	90
2814	MCHOO7A	0.71070	0.71067	147

2815	MCHOO7B	0.70983	0.70980	74
2816	MCHOO7B	0.70972	0.70969	95
2817	MCHOO7B	0.70972	0.70969	99
2820	MCHOO7C	0.71001	0.70998	92
2821	MCHOO7C	0.71006	0.71003	95
2823	MCMCP1	0.71045	0.71042	47
2824	MCMCP1	0.71009	0.71006	60
2825	MCMCP1	0.71034	0.71031	46
2826	MCMCP1	0.71043	0.7104	42
2827	MCMCP1	0.71036	0.71033	62
2828	MCMCP1	0.71024	0.71021	57
2829	MCMCP1	0.71022	0.71019	50
2830	MCMCP1	0.71037	0.71034	52
2831	MCMCP1	0.71046	0.71043	69
2885	MCREI2	0.71034	0.71031	460
2886	MCURE2	0.70951*	0.70948	11
2887	MCCHR37	0.70952	0.70949	187
2889	MCREI9	0.70988	0.70985	68
2900	MCKIR2	0.70895	0.70892	59
2901	MCKIR2	0.71197*	0.71194	27
2903	MCSLC2	0.71037	0.71034	585
2907	MCBOG11	0.71007	0.71004	451
2911	MCHOO1	0.71024	0.71021	262
2916	MCBOG13	0.70955*	0.70952	11
2920	MCURE2	0.70935	0.70932	428
2923	MCCHR41	0.71006*	0.71003	15
2926	MCLUD3	0.71147	0.71144	50
2927	MCLUD3	0.71143	0.7114	337
2929	MCMAN3	0.71027	0.71024	162
2934	MCREI7	0.70895	0.70892	300
2941	MCBOG4	0.70971	0.70968	204
2942	MCSLC4	0.70977	0.70974	277
2943	MCKNT7	0.71015	0.71012	103
2944	MCVBE3	0.70931	0.70928	163
2945	MCMAN10	0.71052	0.71049	191
2946	MCBOY2	0.71033	0.71030	27
2947	MCWAL4	0.70857	0.70854	66
2948	MCDON2	0.71105	0.71102	167
2949	MCDON2	0.71079	0.71076	199

2950	MCDON3	0.71085	0.71082	31
2951	MCDON1	0.71042	0.71039	57
2952	MCNDO1	0.71070	0.71067	57
2953	MCNDO2	0.70955	0.70952	55
2954	MCCAH1	0.70911	0.70978	37
2955	MCCHR38	0.70963*	0.70960	15
2956	MCLUD 1	0.70895	0.70892	72
2960	MCSLC1	0.70918	0.70915	76
2961	MCCRL1	0.70955	0.70952	11
2962	MCBOR7	0.70959	0.70956	499
2977	MCCOU6	0.70859	0.70856	64
2978	MCMCM1	0.71307*	0.71304	8
2980	MCHAM2	0.70958	0.70955	30
2981	MCHAM1	0.70980	0.70977	79
2982	MCHAM1	0.70976	0.70973	78
2983	MCGUN5	0.71039	0.71036	112
3122	MCFON3A	0.71011	0.71008	30
3124	MCWAL3A	0.70916	0.70913	141
3125	MCHOO2	0.71077	0.71074	60
3126	MCCOU5	0.70862	0.70859	21
3127	MCKIR4	0.70862	0.70859	8
3128	MCWAL3B	0.70929*	0.70926	40
3129	MCMCM2	0.71172	0.71169	89
3130	MCTHO2	0.71172	0.71169	47
3131	MCMAN2	0.71012	0.71009	26
3132	MCCOU4	0.70857	0.70854	38
3133	MCHAM3A	0.71005	0.71002	22
3134	MCHAM3B	0.70944	0.70941	9
3135	MCHAM3C	0.71003	0.71000	16
3136	MCWAL2A	0.71086	0.71083	28
3137	MCWAL2C	0.71107	0.71104	94
3138	MCGUN9A	0.70954	0.70951	32
3139	MCGUN9C	0.70965	0.70962	34
3140	MCFON5	0.71002	0.70999	49
3141	MCMCM3	0.71048	0.71045	65
3330	MCFON1	0.70997	0.70994	31
3331	MCTRE1	0.70858	0.70855	35
3332	MCCLV15	0.70952	0.70949	17
3334	MCFON2	0.70991	0.70988	10

3336	MCNUR10	0.71027	0.71024	25
3361	MCNUR8	0.70989	0.70986	10
3363	MCNUR9	0.71016	0.71013	11

Values for SRM987 obtained throughout mass spectrometry that were used to correct resulting data. These are summarized in Table 6.1.

Date	**$^{87}Sr/^{86}Sr$**	**Voltage**
July 22, 2014	0.71026	14.5
July 22, 2014	0.71027	14.5
July 22, 2014	0.71027	14.5
July 22, 2014	0.71027	14.5
July 23, 2014	0.71027	16
July 23, 2014	0.71028	15
July 23, 2014	0.71026	15
July 23, 2014	0.71027	15
July 23, 2014	0.71027	15
July 23, 2014	0.71027	14.5
July 23, 2014	0.71027	14
July 23, 2014	0.71026	14
July 24, 2014	0.71027	15
July 24, 2014	0.71026	15
July 24, 2014	0.71027	15.5
July 24, 2014	0.71025	15
July 24, 2014	0.71029	14
July 24, 2014	0.71028	14.5
July 24, 2014	0.71029	15.5
April 1, 2015	0.71024	15
April 1, 2015	0.71025	15
April 1, 2015	0.71027	15
April 1, 2015	0.71027	15
April 1, 2015	0.71027	15
April 1, 2015	0.71026	15
April 1, 2015	0.71026	15
April 1, 2015	0.71028	15
April 1, 2015	0.71026	15
April 1, 2015	0.71025	15
April 1, 2015	0.71026	15
April 1, 2015	0.71026	15
April 2, 2015	0.71025	13
April 2, 2015	0.71027	14
April 2, 2015	0.71027	15
April 2, 2015	0.71027	15
April 2, 2015	0.71029	15
April 2, 2015	0.71027	15
April 2, 2015	0.71026	15

April 2, 2015	0.71028	15
April 2, 2015	0.71026	15
April 2, 2015	0.71027	16
April 2, 2015	0.71027	15
April 2, 2015	0.71025	15
April 2, 2015	0.71027	16
July 27, 2015	0.71025	13
July 27, 2015	0.71026	14
July 27, 2015	0.71030	14
July 27, 2015	0.71027	14
July 27, 2015	0.71027	14
July 27, 2015	0.71025	14
July 27, 2015	0.71027	14
July 27, 2015	0.71026	14
July 27, 2015	0.71027	14
July 27, 2015	0.71029	14
July 28, 2015	0.71028	17
July 28, 2015	0.71027	17
July 28, 2015	0.71027	17
July 28, 2015	0.71027	16
July 28, 2015	0.71027	16
July 28, 2015	0.71026	16
July 28, 2015	0.71027	16
July 28, 2015	0.71026	16
July 28, 2015	0.71027	16
July 28, 2015	0.71027	16
July 29, 2015	0.71027	17.6
July 29, 2015	0.71026	17.4
July 29, 2015	0.71028	17.3
July 29, 2015	0.71028	16.7
July 29, 2015	0.71028	16.5
July 29, 2015	0.71027	15.9
July 29, 2015	0.71027	16.3
July 29, 2015	0.71027	15.6
July 29, 2015	0.71028	15.5
July 29, 2015	0.71025	16
July 29, 2015	0.71028	15.4
July 29, 2015	0.71027	15.2
July 29, 2015	0.71028	14
December 17, 2015	0.71026	16
December 17, 2015	0.71028	16
December 17, 2015	0.71026	16
December 17, 2015	0.71028	16
December 17, 2015	0.71029	16
December 17, 2015	0.71027	16
December 17, 2015	0.71025	16

SRM987 values used to calculate concentrations of samples. Data were plotted to obtain regression equations, which were then used in conjunction with the mass of the sample and dilution factor to establish the concentration of strontium in each sample (see Chapter Six).

Date	**Concentration (ppb)**	**Voltage**
July 22, 2014	199	11
July 22, 2014	404	24
July 22, 2014	600	35
July 22, 2014	199	14
July 22, 2014	404	28
July 22, 2014	600	43
July 23, 2014	199	16
July 23, 2014	404	33
July 23, 2014	600	48
July 23, 2014	199	14
July 23, 2014	404	27
July 23, 2014	600	40
July 24, 2014	199	16
July 24, 2014	404	33
July 24, 2014	600	47
July 24, 2014	199	14
July 24, 2014	404	29
July 24, 2014	600	42
April 1, 2015	199	13
April 1, 2015	404	26
April 1, 2015	600	39
April 1, 2015	199	15
April 1, 2015	404	31
April 1, 2015	600	46
April 2, 2015	199	13
April 2, 2015	404	25
April 2, 2015	600	40
April 2, 2015	199	16
April 2, 2015	404	32
April 2, 2015	600	48
April 2, 2015	199	15
April 2, 2015	404	29
April 2, 2015	600	44
July 27, 2015	201	13
July 27, 2015	385	26
July 27, 2015	588	40
July 27, 2015	201	14
July 27, 2015	385	28
July 27, 2015	588	42
July 28, 2015	201	16
July 28, 2015	385	31

July 28, 2015	201	16
July 28, 2015	385	30
July 29, 2015	201	17
July 29, 2015	385	33
July 29, 2015	201	14
July 29, 2015	385	27
December 17, 2015	194	16
December 17, 2015	400	32
December 17, 2015	194	15
December 17, 2015	400	32