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Population movements of the Huron-Wendat viewed through strontium isotope analysis

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A B S T R A C T

Environmental isotopes can provide information about the composition of groups and the movement of people across landscapes. The archaeological record of Huron-Wendat communities in south-central Ontario is one of numerous drainage-based sequences of small villages among which families or larger population segments moved. These villages amalgamated in the early to mid-sixteenth century into fewer, larger communities. Strontium isotope values ($^{87}Sr/^{86}Sr$) are used to test hypotheses about these early localized interactions and later amalgamations. There is little prior information about strontium values from this region which was recently glaciated and receives ample precipitation. From the late thirteenth century onward**,** ancestral Huron-Wendat communities had distinct burial practices of primary burial followed by secondary, collective ossuary burial. Strontium values from tooth enamel of 118 human first permanent molars from 15 archaeological contexts spanning four centuries are interpreted in a framework of archaeologically derived deer (N = 34), small (N = 35) and other large (N = 7) mammals. Reflecting their local origins, $^{87}Sr/^{86}Sr$ values of small mammals from three geological substrates differ significantly from one another. Each small mammal group clusters more tightly than those of deer. Most human $^{87}Sr/^{86}Sr$ values agree with small mammal values, by region. Three sites, out of six with more than 10 data points, show mean human $^{87}Sr/^{86}Sr$ values that differ significantly from the small mammal values of their geological substrate, signaling community movement and individual in-migration. Interpretation of individual human values outside local ranges is informed by information from dietary isotopes. Environmental isotopes substantiate and enhance our prior understandings of the ancestral Huron-Wendat.

1. Introduction

1.1. The setting

Decisions about who belongs to the group and where the group will live are central to the functioning of human societies. This research explores evidence for these decisions during an important period of cultural development among people living in the North American Lower Great Lakes region. The focus here is Northern Iroquoian communities. “Iroquoian” refers to both a cultural pattern and a linguistic family. The languages include those spoken by the Northern Iroquoians of the Great Lakes region as well as the more southerly Cherokee and Tuscarora languages. “Iroquoian” relates to, yet differs from, the term “Iroquois,” which was adopted by Europeans to refer to the Haudenosaunee, also known as the Five Nations Confederacy (see also Williamson and MacDonald, 2015:103-104).

As outlined extensively in the works of Bruce Trigger and others, the elements of Northern Iroquoian culture are horticultural subsistence; housing in often-palisaded longhouse villages, each longhouse usually shared by matrilineally defined extended families; clan membership

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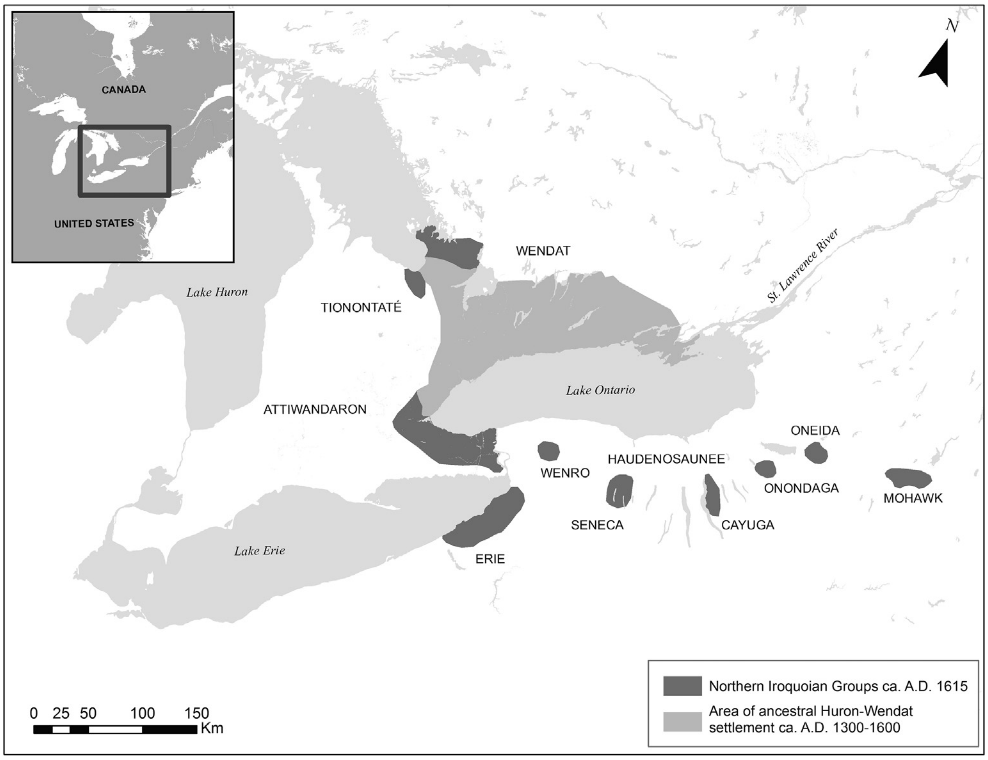

Fig. 1. Northern Iroquoian-speaking cultural areas in the North American Lower Great Lakes (Williamson, 2016:105).

that extended beyond villages to other communities, thus integrating villages within tribes and confederacies; shared governance structures, religious beliefs and practices; participation in ritualized warfare (Trigger, 1976:91-104); and secondary burial practices that created large ossuaries (Seeman, 2011; Trigger, 1976). Although it developed *in situ*, the full expression of this cultural complex is not identified archaeologically until the turn of the fourteenth century (e.g., Birch, 2015; Birch and Williamson, 2018; Engelbrecht, 2003; Warrick, 2000, 2008).

The Wendat, or Huron (as they were known by the French), were the northernmost of the Iroquoians. In the seventeenth century they lived in the area between Lake Simcoe and Georgian Bay that is known historically as Wendake (Fig. 1). Their confederacy consisted of four allied nations: the Attignawantan (Bear), Attigneenongnahac (Cord), Arendarhonon (Rock), and Tahontaenrat (Deer) (Trigger, 1976:30).

Their Iroquoian-speaking neighbours included the Tionontaté, who lived immediately to their southwest; the Neutral Confederacy (Attiwandaron), who lived farther south, on the Niagara peninsula that separates Lakes Erie and Ontario; the Erie, who lived south of Lake Erie; the Wenro (Oneronon), another group living south of the Great Lakes and associated with the Neutral; and the Haudenosaunee (Iroquois Confederacy), who lived in clustered tribal groupings across what is now central New York State (Fig. 1). The Haudenosaunee included (from west to east) the Seneca, Cayuga, Onondaga, Oneida, and the Mohawk.

Iroquoian speakers were encountered by Jacques Cartier in CE 1534 and 1535, living in the St. Lawrence Valley west of Quebec City, although they had moved elsewhere by the time Samuel de Champlain visited the region in CE 1603. The Wendat also had Algonquian-speaking neighbours, including the Odawa, who lived near the Tionontaté and beyond, the Nipissing who lived to the northeast of Georgian Bay, as well as numerous small bands along the eastern and northern shores of Georgian Bay and the Ottawa River.

These groups defined the geopolitical landscape of the lower Great Lakes at the time of initial and sustained European contact. Prior to that time, from CE 1300 to 1600, ancestral communities of the Wendat were most commonly located along the rivers that drain into the north shore of Lake Ontario. These communities later merged with others to settle in Wendake and Tionontaté country.

The prior summary is based not only on archaeology, but also on seventeenth-century European documents describing the Northern Iroquoians. Samuel de Champlain recorded his observations of Wendat (and Tionontaté) communities during the winter he spent with them, CE 1615-16 (Biggar, 1922-36). Gabriel Sagard, a Récollet friar, spent the winter of CE 1623–24 with the Wendat (Sagard, 1939). His description of that time has been called one of the world's first substantial ethnographies (Trigger, 1969:4). To these are added the annual accounts of the Jesuit priests who lived among the Wendat from CE 1634 until 1650 and among the Haudenosaunee from CE 1654 to 1667 (Thwaites, 1896-1901). These sources were written by outsiders with their own agendas (Trigger, 1976), but are nevertheless of great value.

By the turn of the fourteenth century, archaeological evidence documents a northward movement and expansion of ancestral Wendat populations. Smaller communities appear to have amalgamated, leading to diverse economic and sociopolitical changes throughout the broader region (Birch and Williamson, 2018). There is, as yet, no evidence for Wendat villages in Wendake prior to the late thirteenth century but several communities migrated into the region soon thereafter (Hart et al., 2016; MacDonald, 2002; Sutton, 1999). These post-coalescence villages averaged 1.5 ha in extent, about twice the size of earlier late Middle Woodland base settlements. While diverse hypotheses have been proposed for why people moved to the Simcoe Uplands (MacDonald, 2002; Sutton, 1999; Warrick, 2008:177-180), the most likely variables are population growth and the attraction of trade with Algonquians. Warrick (2008:141-142, 182) has suggested that a "population explosion" occurred between CE 1330 and CE 1420, when the ancestral Wendat population of south-central Ontario increased from 10,000 to 24,000, necessitating expansion and triggering movement into new lands. The nature and timing of this period of consolidation and growth have been subjects of considerable recent research (Birch, 2012; Birch et al., in press; Birch and Williamson, 2013; Manning et al., 2019). This period of coalescence also coincided with conflict (Jenkins, 2016; Williamson, 2007, 2014). This was a period of intensified maize production. Dietary stable isotope analysis of human remains from the early fourteenth century Moatfield ossuary indicate that maize may have provided about half of the food energy, compared to a much lower proportion in previous centuries (van der Merwe et al., 2003).

One of the most visible mechanisms for integrating people in the new, larger villages of this period was adoption of a form of secondary burial that is distinctive to the ancestral Wendat (Seeman, 2011; Williamson and Steiss, 2003). Wendat ossuaries are large, rather deep, pit features that contain the disarticulated and commingled remains of individuals who were interred during an important ceremony known as the "Feast of the Dead." One such ceremony was witnessed in CE 1636 by Jean de Brébeuf in historic Wendake (Thwaites, 1896-1901, 10:279–303). At a time determined by the decision to relocate a village, the remains of community members who had died - whose remains had been initially buried or stored - were disinterred and placed into the collective grave. The number of persons interred ranges from < 100 to several hundred (Williamson and Steiss, 2003). Dozens of ancestral Wendat ossuaries dating from the fifteenth through seventeenth centuries have been identified in historic Wendake (modern Simcoe County) and numerous sites – many of them earlier – are known from the region nearer to Lake Ontario (Williamson, 2014). Most of those in Wendake are known from reports of looting for anatomical collections and "race science" research that occurred in the late nineteenth and early twentieth centuries. Several ossuaries have been well-documented archaeologically (Williamson and Steiss, 2003). It is through the judicious and collaborative study of ancestors' remains from these ossuaries and other burial places that we are able most directly to generate new insights about their lives.

Although small scale movement of people had been the norm since the thirteenth century (Hart et al., 2016, Williamson, 2014), the sixteenth century was a period of increasing interaction with more distant communities (e.g. Williamson, 2016). The formation of locally based identities, the probable movement of individuals and groups, and the reorganization of regional networks were all happening concomitantly. This kind of fission, fusion, and movement of communities or segments of communities was recorded in CE 1639 by the Jesuit Paul Le Jeune in his description of the formation of the Huron-Wendat Confederacy. He noted that they "increase or diminish their numbers, however, by the adoption of other families, who join themselves now to some, now to others, and who also sometimes withdraw to form a band and a nation by themselves" (Thwaites, 1896-1901:16:227).

At about the same time, there is evidence of the formation of large, amalgamated villages on the lower St. Lawrence River, yet by the late sixteenth century, the lower St. Lawrence Valley was abandoned. Some people who had been living there had been incorporated into Huron-Wendat villages along the north shore of Lake Ontario (Williamson, 2016). Others were incorporated into communities in the Trent Valley and perhaps elsewhere among populations in northern New England and among the Mohawk, Onondaga and Oneida (Abel, 2016; Engelbrecht, 2004; Jamieson, 1990:403; Kuhn and Pendergast, 1993; Petersen et al., 2004; Ramsden, 1990a:383, 1990b; Warrick, 2000:454-457).

In sum, the political alliances that formed the Huron-Wendat confederacy, as documented by European observers, occurred in the late sixteenth and early seventeenth centuries. The northward movement of ancestral Huron-Wendat people that began in the thirteenth century was completed by around the turn of the seventeenth century, represented by communities situated in historic Wendake. At least two of the allied nations of the Huron-Wendat confederacy arose from communities that had previously lived on the north shore of Lake Ontario and in the Trent Valley. The other nations developed in historic Wendake subsequent to late thirteenth-century and fourteenth-century migrations (Trigger, 1976; Williamson, 2014).

Given the dynamic nature of this story, there is ample opportunity to test environmental isotope analysis as a vehicle for expanding our knowledge. There were many contexts for interaction among communities, both within and between language groups. Whatever the social context, linkages and movements across the landscape influenced group identities.

1.2. *This study*

In the past, it has only been possible to track the movement of people across the Lower Great Lakes landscape using settlement analyses and the examination of the material culture assemblages from them, especially ceramics (e.g., Hart et al., 2016). It is possible, however, to investigate population movements through evidence from strontium isotopes. In this study, strontium isotope values from human tooth enamel are interpreted in the context of tooth enamel values from archaeologically-derived small mammals (as per Bentley, 2006; Price et al., 2002) and white-tailed deer to explore possible human migration patterns. The small mammal enamel values should provide measures of the local biologically available strontium. These teeth, all from clear archaeological contexts, are from animals that were either pests or minor sources of food or skins obtained locally. The deer teeth provide isotope values representing a broader territory, both because of the species' ranging behavior and because of possible trading among communities. A recent dissertation explored various approaches to detecting past migration events in southern Ontario. It provides background on the complexity of using deer teeth as locational markers. The author suggests that the breadth of $^{87}Sr/^{86}Sr$ values from deer teeth, which may reflect the extent of hunting and trading territories, may decrease during times of unrest (Bower, 2017). We anticipated that small mammals would demonstrate the narrowest range of strontium isotope values, against which the ranges of deer and human values could be compared. Since very little strontium isotope research has been done in this region, a small number of non-deer large mammal values are included here for documentation (see Supplementary Documentation).

1.3. *Radiogenic strontium*

Strontium is an element commonly found in rocks of the earth's crust, with elemental abundances varying with the geological history of the rocks. Natural radioactive decay of ^{87}Rb to ^{87}Sr over geological timescales of billions of years results in strontium isotope values, expressed as a ratio of $^{87}Sr/^{86}Sr$ relative to the stable isotope ^{86}Sr, potentially varying across geologies with different ages and Rb/Sr ratios underlying a region. This feature can therefore be used for detecting geographical signatures of animal bioapatite. Dental enamel retains strontium that was integrated into the enamel prisms during tooth formation, as strontium readily substitutes for calcium. Enamel is much less subject to diagenesis than the bioapatite in bone (Bentley, 2006). The $^{87}Sr/^{86}Sr$ values in dental enamel, obtained from the plant and animal foods eaten and the water ingested during tooth formation, reflect the biologically available strontium in the environment. This ratio can be used to assess the animal's locale during tooth formation, contrasting it with the locale in which the tooth was later found. Study of this isotope ratio has become an important tool for studies of human and animal mobility (Bentley and Knipper, 2005; Coelho et al., 2017; Makarewicz and Sealy, 2015; Price et al., 2002; Slovak and Paytan, 2012). Many immigrants will remain invisible, because of the geographic redundancy of isotope ratios (Grupe, 2016) and the "astonishing compression in the range of human ratios" caused by variable patterns of strontium bioavailability (Burton and Hahn, 2016).

Radiogenic strontium ($^{87}Sr/^{86}Sr$) values have been used for the exploration of residence patterns across regions (Ericson, 1985) and other patterns of population diversity, most effectively in contexts linked to genomic information (Krzewinska et al., 2018). Other themes include the spread of agriculture (Bentley et al., 2005), identification of non-local individuals in cemeteries related to differences in burial patterns (Buzon et al., 2007; Müller-Scheeßel et al., 2020), socio-cultural practices related to gender roles (Bentley et al., 2012; Bentley et al., 2005; Bentley et al., 2018), identification of exotic faunal remains (Laffoon et al., 2016) and intrinsic versus extrinsic population growth (Cox et al., 2011; Sjögren et al., 2016). Interpretation of strontium values can be enhanced by combining results with those from stable isotope analyses (Gregoricka et al., 2020).

Strontium derived from older, igneous-origin rocks generally has higher (more radiogenic) $^{87}Sr/^{86}Sr$ values than younger, marine-origin rocks. In environments where the surficial geology is well characterized and annual precipitation is limited, an animal's geographic range as represented by its enamel can be deduced from its $^{87}Sr/^{86}Sr$ value (for example, Lehmann et al., 2018). However, constraints to the application of this method are numerous. Growing animals take up strontium from food and water, but uptake of strontium from underlying geological deposits can be compromised in regions with substantial rainfall, which dilutes the groundwater, or regions where the composition of the crustal layer has been mixed by glaciation. Both these factors are in play in south-central Ontario. Although there is interregional variability in annual precipitation, the mean annual precipitation for our study area, as measured between CE 1840 and 1980, is between 800 and 1040 mm/year (Canada, 2010). The soils of the region reflect the complex dynamics of glacial progression and retreat, with the post-glacial landscape dating from only 12,500 years ago (MacDonald, 2008:15). There are no maps of $^{87}Sr/^{86}Sr$ values of south-central Ontario rocks or soils. Contemporary surface water from streams in Ontario has a range of $^{87}Sr/^{86}Sr = 0.70869$ to 0.71646 (Bower, 2017:37-38). Our study provides an opportunity to explore the feasibility of using $^{87}Sr/^{86}Sr$ values for archaeologically framed human mobility studies in this region.

Most of the archaeological sites considered here are from a region that includes bedrock formations of shale and dolomite (Armstrong and Dodge, 2007) including the Ordovician-origin Georgian Bay Formation shales and the Paleozoic Shadow Lake Formation dolomites. Study of plant uptake from diverse rock types found in the Sterkfontein Valley of South Africa suggests that there should be a systemic difference in $^{87}Sr/^{86}Sr$ values between such areas (Sillen et al., 1998), if the bedrock geology is providing the nutrient base. To explore regional variation, this analysis also includes five small mammals from two sites and one human from one site located on rocks of Middle Paleozoic marine formations, the constituents of which are the Cataract, Guelph, and Onondaga formations, several hundred kilometers southwest of the other two formations (Fig. 2).

1.4. Dental development and ecology

Most of the animal teeth used in this study are from rodents (*Sciurus carolinensis* and *Tamiasciurus hudsonicus*), *Leporidae*, and white-tailed deer (*Odocoileus virginianus*), primarily anterior teeth (incisors and premolars) in the rodents and molars in the deer. Developmental timing, including the continuous growth of rodent incisors (Catón and Tucker, 2009) and formation of deer molars during the first year of life (Rivera-Araya and Birch, 2018) assure that strontium values reflect a substantial portion of the animals' lives. While it is known that these small mammals have typical home ranges in rich habitats of one to five hectares (Smith, 1975) and thus lived and died very near where their teeth were found during archaeological excavations, the seasonal movements of white-tailed deer in this part of North America have been observed to extend up to 20 km (Rivera-Araya and Birch, 2018) and can range over 1000 ha (Lesage et al., 2000).

Most of the human teeth in this study are mandibular first permanent molars. The first permanent molar crown formation begins at ~30 weeks' gestation and is completed by ~3.5 years (Hillson, 2014:64-65). Enamel does not remodel once it is formed (Hillson, 2014); thus the strontium values observed reflect the environment of the mother and the young child in the first years of life. Prior research on the diet of ancestral and contact period Huron-Wendat people (Pfeiffer et al., 2017; Pfeiffer et al., 2016; van der Merwe et al., 2003) supports the assumption that their diet was based on maize, fish and meat, all of which could be obtained locally. One of these studies explored weaning and childhood diets. It reports differences in dietary protein sources between girls and boys, possibly related to their involvement in gendered roles which may have included boys traveling with the men (Pfeiffer et al., 2017). This observation, based on tooth root dentine samples, relates to life experiences that occurred post-weaning, after crown completion.

2. Materials and methods

2.1. The archaeological sites

The teeth measured in this study come from 44 archaeological sites (Fig. 2; Supplementary Table). Most sites provided only one type of tooth (small mammal, deer or human). Seventeen sites provided only deer teeth, ten provided only small mammal teeth, nine provided only human teeth. The other eight provided combinations of human and deer (4), deer and small mammal (1), small and large mammal (1), human and small mammal (1) and deer, human and small mammal (1). Collective sample sizes are 118 human teeth from 15 sites, 34 deer from 23 sites, 35 small mammal teeth from 14 sites and 7 large (non-deer) mammals from one site.

Of the 15 sites from which human teeth were obtained, seven were ossuaries, three were occupational sites on which loose teeth were found, one was a primary burial, two were occupation sites that included primary burials, one was a funerary preparation site, and one was a primary cemetery. Three sites represent the fourteenth century, two of which have a unique relationship: the Hutchison site appears to have been used to prepare interments for the Staines Road ossuary (Robertson, 2004). The sites are reported separately here. Three sites come from the fifteenth century, and four from the sixteenth. The late sixteenth century Mantle (also known as Jean-Baptiste Lainé) site represents a situation in which a cemetery with primary interments adjoined the village (Birch and Williamson, 2013). This study treats the loose human teeth found within the village (Supplementary Table – Mantle Loose) as a different archaeological context from those of the cemetery (Supplementary Table – Mantle Cemetery). The single primary burial from the Wainfleet site could only be dated to the fourteenth through mid-seventeenth centuries and likely represents an ancestral or historic Neutral person.

Because ossuaries were constructed at some distance from their associated villages, it is difficult to link an ossuary with the village(s) in which the decedents had lived. In this study, it is assumed that the human teeth from the Kleinburg ossuary represent people who lived in the Skandatut village (Williamson, 2014:25), from which we have teeth from large and small mammals. This combination therefore provides values for humans, small and large mammals from an associated village and ossuary dating to the late sixteenth to early seventeenth century. Two sites date to the seventeenth century only, as determined by modeling of new radiocarbon dates and the kinds of European items within the ossuaries. The Warminster site almost certainly represents the historically recorded village of Cahiagué, which Samuel de Champlain visited in CE 1615 (Heidenreich, 2014; Manning et al., 2019); new radiocarbon analyses and glass beads from the site indicate it was occupied after that time as well (Fitzgerald, 1986). Glass beads from the Maurice ossuary place it to between CE 1630 and 1650 (Motykova, 1969).

2.2. Methods for isotope determination

Permanent teeth were removed from mandibles prior to the reburial of the human remains with permission of the Huron-Wendat Nation of

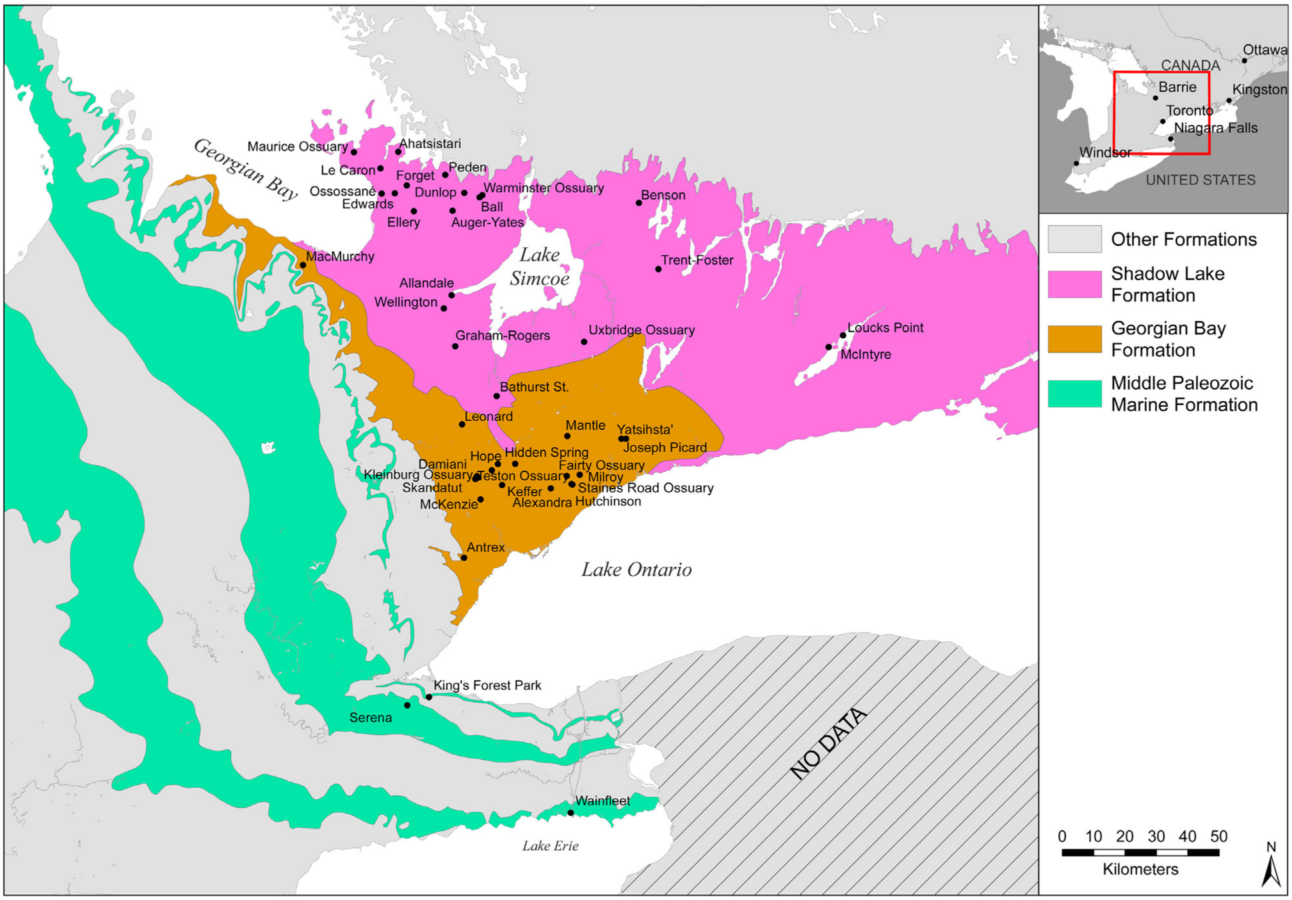

Fig. 2. Archaeological sites providing enamel strontium values in this study, plotted on a 1:250 000 scale bedrock geology map of Ontario. Credit: Eric Beales. Source: Ministry of Energy, Northern Development and Mines, Ontario Geological Survey. Published February 1, 2011, Retrieved from https://www.mndm.gov.on.ca/en/mines-and-minerals/applications/ogsearth/bedrock-geology.

Wendake, Quebec. Loose teeth found on occupational sites were retained, also with permission. With the exception of some of these loose teeth, the sampled human teeth were fully formed (adult) mandibular first molars. The dental health traits of these communities were quite similar, with relatively light tooth wear and numerous caries, reflecting their maize-oriented diets (Pfeiffer and Fairgrieve, 1994). The fragmentary and co-mingled nature of the human remains precludes the attribution of sex to any of the teeth. The minimal wear precludes classification into age-at-death categories.

The non-human teeth were provided by many curators who we approached during a period from 2013 through 2017. The identification of deer teeth was a matter of consulting documented archives and following protocols for destructive testing. The identification of small mammal teeth first required colleagues to search unsorted or partially sorted faunal remains and make species identifications, specifically in support of this project.

The crown of each tooth was cleaned and abraded slightly, if necessary, to remove contaminants. The enamel used for strontium isotope determination was removed by grinding with a diamond-tipped dental drill bit attached to a Dremel device. The same protocol was used for all teeth, regardless of species or tooth type. For many of the human teeth, the analyzed enamel powder was an aliquot of that used previously to measure carbon isotope ratios (Pfeiffer et al., 2017; Pfeiffer et al., 2016). All strontium isotope analyses were performed on a Nu Instruments NuPlasma HR in the MC-ICP-MS facility, housed in the Department of Geological Sciences, University of Cape Town, Rondebosch, South Africa, following established preparatory protocols (Copeland et al., 2016). Following enamel dissolution in concentrated HNO_3, Sr elemental separation for each sample followed the methods of Pin et al. (1994). Strontium isotope ratio analyses used SRM987 as bracketing standard, and all sample $^{87}Sr/^{86}Sr$ values are referenced to a value of 0.710255 for this standard. Isobaric interference by ^{87}Rb at 87 amu was corrected using the measured ^{85}Rb signal and the natural $^{87}Rb/^{85}Rb$ ratio. Instrumental mass fractionation was corrected using the measured $^{86}Sr/^{88}Sr$ values, a known value of 0.1194 for this ratio and the exponential law. An in-house, carbonate reference material NM95 processed as unknown with batches of samples returned $^{87}Sr/^{86}Sr$ results (0.708909 ± 0.000038 2σ; n = 8) in agreement with long-term data for this material from this facility (0.708911 ± 0.000040 2σ; n = 414). The internal 2σ errors for individual $^{87}Sr/^{86}Sr$ analyses presented here were similar or better than the external 2σ error obtained from the repeat analyses of NM95 listed above, therefore < 0.000040 for some and typically < 0.000020 for the majority. No values have been removed.

2.3. Methods for pattern assessment

Various approaches have been proposed for the identification of migrants within a community. The human values that fall outside the range of baseline animal values can be flagged as possible migrants, comparing values to the fourth decimal point (Grow Allen et al., 2019; Knudson et al., 2016). Another approach for comparing strontium values is to characterize those that are ± 2 standard deviations from the mean as outside values (Gregoricka et al., 2020; Price et al., 2002). It has been argued that the flaw in this approach is the absence of normal distributions in $^{87}Sr/^{86}Sr$ values (Müller-Scheeßel et al., 2020). Another approach is to consider the normal variability within a local population as approximately +/- 0.00015, and the $^{87}Sr/^{86}Sr$ difference among

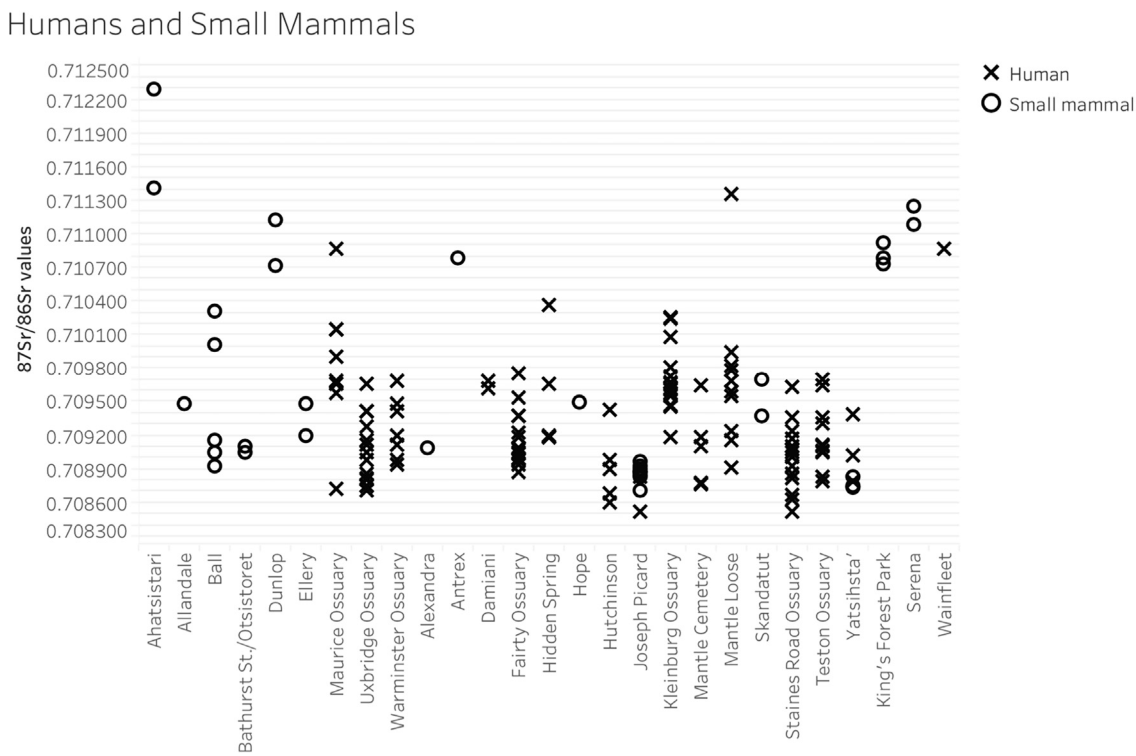

Fig. 3. All $^{87}Sr/^{86}Sr$ values included in this study, plotted by archaeological site.

humans from a single location to be about 0.0003 (Burton and Price, 2013). This analysis will explore these approaches, with interpretations informed by consideration of the region's physical geography and culture history and human dietary stable isotope values derived from prior studies.

3. Results

3.1. Overview

The average $^{87}Sr/^{86}Sr$ value for the 194 teeth included in this study is 0.709443 (SD = 0.051071), with a range of 0.708308 to 0.712295. The upper portion of this range is considerably less enriched than modern values of Ontario surface water (Fig. 3).

Small mammal $^{87}Sr/^{86}Sr$ values were compared for the three distinct geological substrate regions (Table 1). The group from the Middle Paleozoic Marine Formations is the most tightly clustered and is distinct from the other two groups ($t = 3.486$, $p = 0.001$). The groups from the Georgian Bay Formation shale and Shadow Lake Formation dolomite regions are also statistically different from one another ($t = 2.799$, $p = 0.009$). The small mammal teeth from the Shadow Lake Formation have the largest range. Divergent values include a rabbit and red squirrel from Ahatsistari and two rabbits from Dunlop.

Deer and human enamel values are available from all three areas but are most numerous from the Georgian Bay and Shadow Lake formations. Human values range from 0.708510 to 0.711358 (Table 2). Considered by site, the human values do not cluster tightly. Sites with five or more human values show ranges of at least 0.0005. Only one human tooth from the Niagara formations has been measured. When all values from within each region are combined, the deer $^{87}Sr/^{86}Sr$ values do not differ between Georgian Bay and Shadow Lake regions ($t = 0.47$), nor do the human $^{87}Sr/^{86}Sr$ values ($t = -0.285$). The mean $^{87}Sr/^{86}Sr$ value for all 34 deer enamel samples is 0.709540 (SD = 0.000692). The mean $^{87}Sr/^{86}Sr$ value of all 118 human enamel samples is 0.709308 (SD = 0.000493).

Values for the associated sites of Hutchinson and Staines Road are indistinguishable, consistent with the archaeological evidence that they represent the same community. The group of ten loose teeth from the Mantle occupation site do not differ significantly from the five teeth from the Mantle cemetery ($t = 1.88$, $p = 0.08$).

Table 1
$^{87}Sr/^{86}Sr$ values of tooth enamel from small mammals, deer and humans from south-central Ontario archaeological sites, grouped by different geological substrates.

	N	Mean	Range	S.D.
Small Mammals				
Niagara Formations	5	0.710949	0.710724–0.711249	0.000217
Shadow Lake Formation	14	0.709948	0.708928–0.712295	0.001066
Georgian Bay Formation	16	0.709104	0.708709–0.710783	0.000532
Deer				
Shadow Lake Formation	13	0.709469	0.708470–0.711377	0.000831
Georgian Bay Formation	21	0.709584	0.708771–0.711130	0.000609
Humans				
Shadow Lake Formation	29	0.709316	0.708700–0.710863	0.000514
Georgian Bay Formation	88	0.709287	0.708510–0.711358	0.000462

3.2. Community values

The expected fit between the $^{87}Sr/^{86}Sr$ values of human communities and that of their environment can be explored by comparing the mean $^{87}Sr/^{86}Sr$ values for each human sample with the small mammal value for their geological region (Figs. 4 and 5; Table 2). This is because the mean small mammal values are thought to represent the values of that particular geological substrate and therefore if people originated in that geological substrate, their values should be similar. Most human samples fit within the expected ranges.

Several of the archaeological sites provided very small numbers of human teeth. Among the six sites with ten or more human data points, three, Uxbridge, Kleinburg and the loose teeth from Mantle, show mean $^{87}Sr/^{86}Sr$ values that differ significantly from the mean value of small mammals from their geological substrate (Table 2). The Uxbridge value

Table 2
Human enamel $^{87}Sr/^{86}Sr$ values identified by archaeological site, statistically compared to $^{87}Sr/^{86}Sr$ values from small mammals of their respective geological substrates. Formation S = Shadow Lake, G = Georgian Bay, N = Niagara. Statistically significant t-values are bolded.

Site	Formation	N	Mean	Range	S.D.	t-value
14th–15th Centuries						
Fairty AlGt-3	G	15	0.709162	0.708868–0.709752	0.000247	0.38
Hutchinson AlGt-34	G	5	0.708912	0.708597–0.709427	0.000325	0.75
Staines Road AkGt-65	G	15	0.709006	0.708510–0.709622	0.000290	0.63
Uxbridge BbGs-3	S	15	0.709092	0.708700–0.709677	0.000329	**2.93, p = 0.01**
Joseph Picard AlGs-376	G	3	0.708755	0.708709–0.708958	0.000212	1.10
Teston AlGv-2	G	10	0.709192	0.708785–0.709693	0.000305	0.48
Yatsihsta’ AlGs-452	G	3	0.709066	0.708731–0.709390	0.000302	0.12
16th–17th Centuries						
Kleinburg AlGv-1	G	15	0.709699	0.709181–0.710249	0.000292	**3.73** ***p = 0.00***
Mantle Cemetery AlGt-334	G	5	0.709091	0.708765–0.709664	0.000361	0.05
Mantle loose AlGt-334	G	10	0.709701	0.708903–0.711358	0.000668	**2.52** ***p = 0.02***
Hidden Spring AlGu-368	G	5	0.709516	0.709179–0.710362	0.000516	1.52
Damiani AlGv-231	G	2	0.709646	0.709610–0.710275	0.000051	1.40
Warminster BdBv-1	S	6	0.709183	0.708933–0.709475	0.000223	1.72
Maurice BeHa-1	S	8	0.709836	0.708721–0.710863	0.000612	0.27
Date uncertain						
Wainfleet	N	1	0.710865			

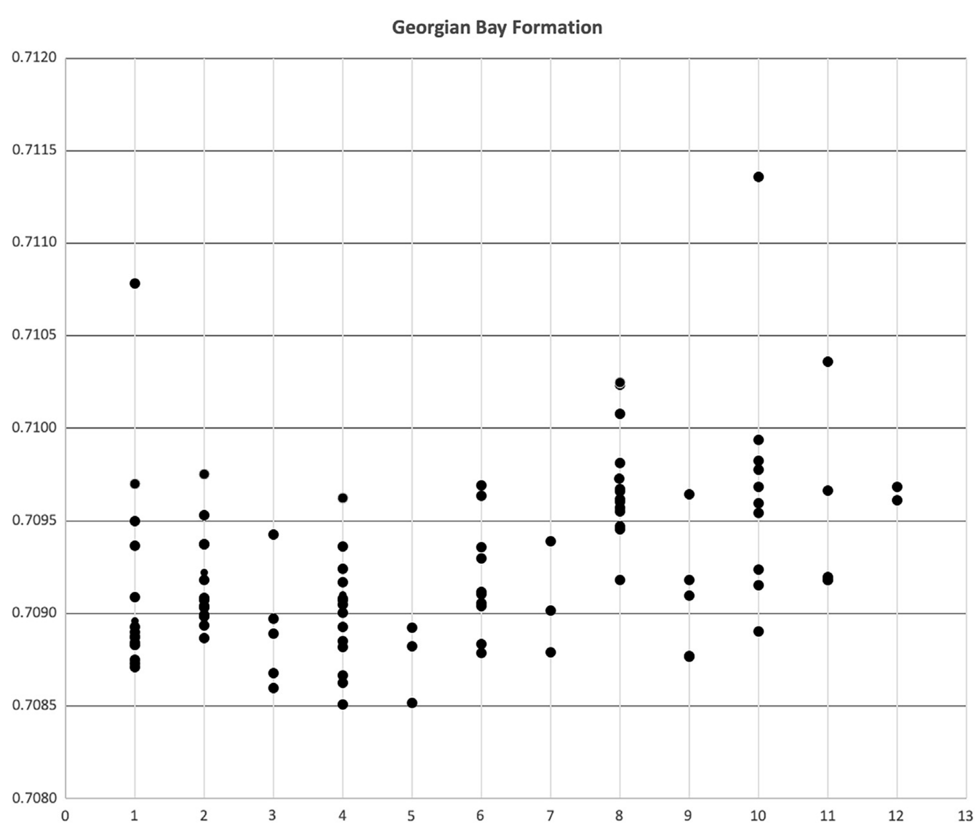

Fig. 4. 87Sr/86Sr values for Georgian Bay Formation small mammals (column 1) and humans from archaeological sites in that region. Key: column 2: Fairty; 3: Hutchinson; 4: Staines Road; 5: Joseph Picard; 6: Teston; 7: Yatsihsta’; 8: Kleinburg; 9: Mantle cemetery; 10: Mantle loose teeth; 11: Hidden Spring; 12: Diamiani.

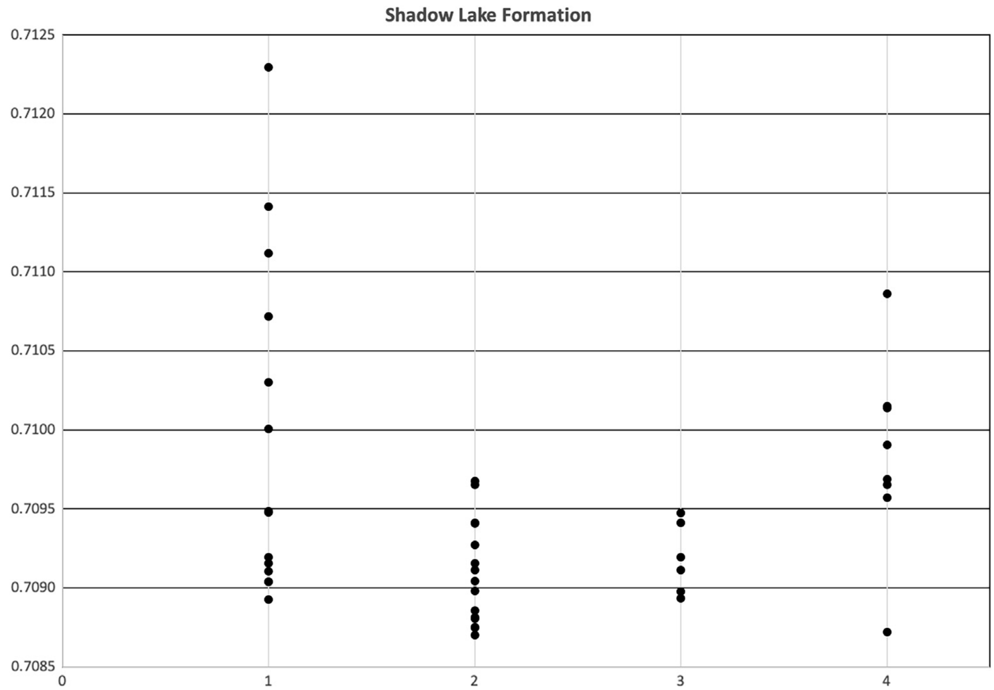

Fig. 5. 87Sr/86Sr values for Shadow Lake Formation small mammals (column 1) and humans from archaeological sites in the region. Key: column 2: Uxbridge; 3: Warminster; 4: Maurice.

is lower than the Shadow Lake reference group, the other two are higher than the Georgian Bay reference group. This suggests that some members of those communities began their lives in regions that differed isotopically from where they were buried. Georgian Bay Formation values are the lowest of the three regions measured, so the incomers to those two sites may have lived in either of the other regions when they were children. Both Uxbridge and the loose teeth from Mantle also have individual values outside the local range. The Kleinburg cluster of human values has significantly higher values than the Georgian Bay reference group. This may suggest movement of a larger group.

Another way that outsiders can be identified is through comparison of human values and those from small mammals obtained from the same archaeological site. For the Joseph Picard site, three humans can be compared to eight small mammals. From the Yatsihsta' site, three human values can be compared to three small mammals. In the former case, one human value falls outside the range of the local small mammals. At Yatsihsta', two human values are outside the range. Both Yatsihsta' molars are maxillary, and one is fragmentary, so both teeth could represent the same person, although they were not near one another when discovered. No dietary isotope values are available from these three teeth.

3.3. Individuals beyond the local range

There are various ways in which individual values can stand out from the collective pattern. The human values that lie outside the range of regional small mammals are listed in Table 3 (see also Figs. 3 and 4). All outside values in the Shadow Lake formation have values below those of the small mammals, consistent with migration from the Georgian Bay formation. The Uxbridge site, which lies near the boundary of the two formations, has a cluster of five persons with values lower than expected for the Shadow Lake formation. The Maurice ossuary, located further north, has one. Among sites on the Georgian Bay formation, six individuals from five sites have values that are lower than those of the small mammals, and one person is higher. Three of the six are from the affiliated sites of Hutchinson and Staines Road, which are thought to represent the same ossuary-creation event. There is one outside value each from Fairty, Joseph Picard and Mantle loose teeth. Since the Georgian Bay formation has the lowest range of $^{87}Sr/^{86}Sr$ values within this swath of Ontario, people with lower values may represent the natural range in the region, or they may have come from a region not yet characterized for $^{87}Sr/^{86}Sr$. The person with the higher value, from the loose teeth at Mantle, may have originated in the Niagara or Shadow Lake region, or elsewhere. In three instances, from Fairty and Staines Road as well as the dramatic outside value from among the loose teeth at Mantle, $^{87}Sr/^{86}Sr$ values for single individuals differ by more than 2 standard deviations from others who were buried or found at the same site (Table 4).

Table 3
Human 87Sr/86Sr values that fall outside the range of regional small mammals. Dietary isotope values were previously published (Pfeiffer et al., 2016; Pfeiffer et al., 2014).

Site	Sample ID	$^{87}Sr/^{86}Sr$ value	$\delta^{13}C_{enamel}$ (‰)	$\delta\ ^{15}N_{dentin}$ (‰)
Shadow Lake				
Uxbridge	UCT 14,182	0.708700	−1.4	11.7
Uxbridge	UCT 16,054	0.708748	−2.1	10.6
Uxbridge	UCT 16,051	0.708749	N/A	N/A
Uxbridge	UCT 14,175	0.708807	−1.5	11.7
Uxbridge	UCT 16,060	0.708813	N/A	N/A
Maurice	UCT 16,025	0.708721	−2.3	10.8
Georgian Bay				
Fairty[1]	UCT 16,046	0.709752	−3.9	12.3
Hutchinson	UCT 13,711	0.708597	−2.5	13.2
Staines Road	UCT 13,679	0.708510	−1.9	12.0
Staines Road	UCT 13,688	0.708626	−3.5	11.7
Joseph Picard[1]	UCT 24,079	0.708517	N/A	N/A
Mantle loose[1]	UCT 13,668	0.711358	−7.4	10.5

[1] Also listed in Table 4.

The dietary isotope ratios of all these individuals may provide further information about the communities in which their early lives were spent (Table 3 and 4). Like the values for $^{87}Sr/^{86}Sr$, values for $\delta^{13}C_{enamel}$ provide information about the content of overall diet during the years when the tooth was forming. While there are relatively few studies reporting $\delta^{13}C_{enamel}$ for past peoples of this region, the profile of

Table 4
Individual human enamel $^{87}Sr/^{86}Sr$ values that deviate by more than two S.D. from means of relevant reference groups. Dietary isotope values were previously published (Pfeiffer et al., 2016; Pfeiffer et al., 2014).

Site	Sample ID	$^{87}Sr/^{86}Sr$ value	$\delta^{13}C_{enamel}$ (‰)	$\delta\ ^{15}N_{dentin}$ (‰)	Provenience
Differs from the human reference group					
Fairty[1]	UCT 16,046	0.709752	−3.9	12.3	
Staines Road	UCT 13,677	0.709622	−5.9	11.8	
Mantle loose[1],[*]	UCT 13,668	0.711358	−7.4	10.5	
Differs from the site-specific small mammal reference group					
Joseph Picard[1]	UCT 24,079	0.708517	N/A	N/A	11 EA-158 519-237 topsoil midden lower premolar
Yatsihsta'	UCT 24,081	0.709390	N/A	N/A	13EA-158 509-146 Layer 3 upper M3
Yatsihsta'	UCT 24,082	0.709017	N/A	N/A	13EA-158 513-142 L3 upper molar incomplete

[1] Also listed in Table 3.
[*] This value also exceeds that of the Shadow Lake Formation baseline but falls within two S.D. of the Niagara Formations value.

$\delta^{13}C_{collagen}$, as measured in bone and dentine, is better known. The $\delta^{13}C_{dentine}$ value for the populations described here is −10.86‰ (SD = 1.18). By comparison, human bone collagen from prior to the introduction of maize has been reported at −20.8‰ (Schwarcz et al., 1985). Values for $\delta\ ^{15}N_{dentin}$ reflect protein sources during that same period of childhood (Pfeiffer et al., 2016; Pfeiffer et al., 2014). Five of the $^{87}Sr/^{86}Sr$ outside values have $\delta^{13}C_{enamel}$ isotope values like those of other Huron-Wendat ancestors (mean $\delta^{13}C_{enamel}$ = -3.57‰, SD = 1.45, n = 167 (Pfeiffer et al., 2016)). Outside values from Uxbridge and Staines Road have exceptionally positive $\delta^{13}C_{enamel}$ values of −1.4, −1.5 and −1.9‰, suggesting exceptionally high proportions of dietary maize in childhood. Outside values from Staines Road and the loose teeth from Mantle have more negative values of −5.9 and −7.4‰, suggesting that they had childhood diets that included a lower proportion of maize. Based on the offsets noted above, these are analogous to collagen values of about −13 to −14‰. Such values are not in the range of maize-free diets but are less enriched than is typically seen. None of the values for $\delta\ ^{15}N_{dentin}$ differ from expected for this geographic region (mean $\delta^{15}N_{dentin}$ = 11.9‰, SD = 0.98, n = 167) (Pfeiffer et al., 2016).

4. Discussion and conclusions

This research has established preliminary strontium isotope benchmarks for the study of fourteenth through early seventeenth century human mobility in south-central Ontario. This is a relatively new approach for examining human mobility in the past, certainly for the Great Lakes Region, and we hope that future studies will expand on this work. Larger samples of small mammals from secure archaeological contexts would be especially helpful. To that end, all the primary data generated for this study, including values from a small number of large mammals other than deer, is provided as supplementary information. The lack of correspondence between the range of $^{87}Sr/^{86}Sr$ values from archaeologically derived enamel and strontium values measured in modern water sources illustrates the importance of using materials from the past to explore questions about the past. This observation contributes to ongoing discussions (see for example Frei et al., 2020) regarding the suitability of using surface water run-off as sources of bioavailable signatures in provenance studies.

The ranges of strontium isotope values among site- and region-specific animal and human groups reported in this study are generally wider than has been suggested as normative for local communities (Burton and Hahn, 2016). We conclude that in this part of North America, as in other parts of the world, strontium isotope studies must be locally framed.

Our results provide possible examples of mobility of community segments and of individuals. Corroborating evidence from dietary isotopes shows that some incomers came from other agricultural communities, but at least two incomers came from communities less reliant on maize. Since most of our deer teeth come from the sixteenth century, we were unable to explore Bower's hypothesis (2017) that deer may have been harvested from a more narrowly defined territory in later times, as compared to earlier times. Refinement of this and other hypotheses presented here will have to await data from further samples.

Our results can be interpreted relative to population dynamics known to have occurred during the period of each site's occupation. For those three communities that show $^{87}Sr/^{86}Sr$ values that differ significantly from the mean value of small mammals from their geological substrate, it appears that a substantial number of community members originated in one or more regions that differed isotopically. The human mean Uxbridge $^{87}Sr/^{86}Sr$ value is less enriched than expected, suggesting that incomers may have come to the Shadow Lake Formation site from the nearby Georgian Bay Formation. The movement of community segments to join with others at this and other periods should be regarded as a common decision taken by Huron-Wendat or more broadly by Iroquoians. This is both consistent and concomitant with, for example, the fifteenth into sixteenth century movement of segments of Saint Lawrence Iroquoian communities, perhaps families or clan segments. These groups had moved from the upper Saint Lawrence Valley and/or Jefferson County, New York, to among other Iroquoian-speaking nations, pre-coalescent and coalescent period ancestral Huron-Wendat communities such as the Joseph Picard or Yatsihsta' sites, situated about one kilometer apart on the Lynde Creek system, about thirty kilometers south of Uxbridge (Williamson, 2016:116). The ultimate disposition of the Joseph Picard population is unknown, but it would not be unreasonable to suggest that they moved to the region around Uxbridge and eventually into the upper Trent River Valley to help form communities such as Benson and Trent-Foster (Williamson, 2016:116). Those communities in turn moved around CE 1580 to historic Wendake and likely became the Arendaronon (Rock) nation of the Huron-Wendat Confederacy (Trigger, 1976:156-157).

In the other two instances, Kleinburg Ossuary and the loose teeth from the Mantle occupation site, human mean $^{87}Sr/^{86}Sr$ values are more enriched than the local baseline. The Georgian Bay Formation values are the lowest of the three regions measured. The Kleinburg ossuary is associated with the Skandatut site. Based on initial survey and test excavations, it was suggested that Skandatut had ties to the Neutral of the Hamilton-Niagara region (Birch and Williamson, 2013:38), a suggestion long made for certain communities on the Humber River, on which Skandatut is also situated (Williamson et al., 1998:9). Thus, the values from Kleinburg could reflect individuals originating from the middle Paleozoic marine formation region we tested, portions of which are situated within the historic Neutral territory.

The Mantle site is a large, late-sixteenth century community that had formed initially by the merging of several smaller communities. Its archaeology revealed evidence of people moving in and out of the village along with long-distance contacts with Saint Lawrence Iroquoian, Haudenosaunee and even Ohio populations (Birch and Williamson, 2013:141, 162). The cosmopolitan nature of the site is entirely consistent with some inhabitants having been born in regions other than the Georgian Bay formation lands.

Since the outside values identified in Table 3 all tend to be higher Sr values than their reference group, it is plausible that they also came from the Niagara formations; this is the most parsimonious interpretation, given the known cultural affiliations with communities in that region. The Mantle value, while most disparate, lies within 2 standard deviations of the reference value for the Niagara Formations. Hence, while acknowledging that we have no comparative data for geological formations nor archaeological sites in eastern Ontario, Quebec, New York and beyond, there is currently no isotopic evidence that any person entered these south-central Ontario communities from outside the region of interest here.

The individual outside values from Staines Road Ossuary and Mantle occupation sites have more negative $\delta^{13}C_{enamel}$ values than those of the communities within which they were found. This suggests that they had childhood diets that included a lower proportion of maize, which would not be consistent with the Neutral populations of the Niagara region. These values suggest that they were individuals from Algonquian nations that were visiting or living in these communities. The Huron-Wendat's neighboring Algonquian nations are known to have traded hides and other items in return for maize. Indeed, the Huron-Wendat territory was known as the "granary of most of the Algonquians" (Tooker, 1964:25). While analyses of plant microfossils on pottery (Boyd and Surrette, 2010) indicate that Algonquian communities in the boreal forest of central Canada consumed significant quantities of maize by this period, their childhood diets were unlikely to have been as strongly based on maize as those of their southern agricultural neighbors.

Relations between Huron-Wendat and Algonquian communities led to diverse interactions. Models of hide requirements for sixteenth century sites like Mantle suggest that once community populations reached numbers for which needs exceeded 7,000 hides annually, as at Mantle, it was essential to acquire hides from northern Algonquian neighbors (Birch and Williamson, 2013:111-117). Substantial numbers of Algonquian neighbors are said to have wintered with the Huron-Wendat. In the winter of CE 1615–16, 700–800 Nipissing people wintered among the Huron-Wendat in the lower Wye Valley, in a separate village. Other Algonkians who lived in the Ottawa River region – perhaps as many as 1000 - wintered among the Arendarhonon on the outskirts of Cahiagué (Warminster) between CE 1608 and 1616 (Fox and Garrad, 2004; Pendergast, 1999). The presence of two native copper beads on the Mantle site, mined from deposits along the north shore of Lake Superior in Algonquian territory, plus the presence of similar artifacts on contemporaneous villages in the immediate vicinity of the Staines Road Ossuary, suggest the likely presence of Algonquian traders at those sites. Thus, it is possible that either or both individuals from Staines Road Ossuary and Mantle village were Algonquian. No strontium values are available from the Nipissing Lake region, the Ottawa Valley, or other northern Ontario locales where Algonquians resided, so this hypothesis cannot be tested further at this time. Individuals who were included in ossuaries are thought to have been community members, so the Staines Road individual may have married into the community and thereby become Huron-Wendat.

The seventeenth century Maurice Ossuary has one outsider, with a value that aligns with the Georgian Bay formation. The Maurice ossuary is associated with the northern Bear clan who were established in that region since the mid-fifteenth century or longer (Williamson, 2014: 15). The glass beads recovered from that ossuary date to the late historic period, ca CE 1630–50 (Motykova, 1969). This was a period of considerable social and political unrest as well as population disruption resulting from unrelenting attacks by the Haudenosaunee as well as the effects of diseases introduced by Europeans (Trigger, 1976:725-782). The adoption of prisoners and refugees from other areas was a common response to these disruptions (Tooker, 1964:31). There is also no reason that an individual found in the Maurice Ossuary may not have started their life on a Georgian Bay site, prior to their family moving to historic Wendake.

The strontium ratio values from enamel of small mammals and humans from archaeological sites across a wide swath of south-central Ontario support previous analyses of mobility of past Huron-Wendat peoples. Communities are shown to have moved across the landscape, and subsets have formed new communities. Occasionally, someone from a non-agriculturally focused community was integrated into the Huron-Wendat community. Values from teeth of white-tailed deer show that there was movement of these important resources across the landscape. It is our hope that this research will form a framework, and that future studies of dietary isotopes will include measurement of strontium isotope ratios so that dietary and mobility information can be integrated. The insights generated here about the lives of Huron-Wendat ancestors may encourage others to develop collaborations between researchers and descendants, so that human teeth from other regions will be tested. Information about the ways that past individuals and groups moved and affiliated with one another is fundamental to their stories.

CRediT authorship contribution statement

Susan Pfeiffer: Conceptualization, Methodology, Supervision, Formal analysis, Writing - original draft. **Ronald F. Williamson:** Conceptualization, Supervision, Formal analysis, Writing - original draft. **Jennifer Newton:** Methodology, Formal analysis, Data curation, Visualization. **Petrus le Roux:** Methodology, Investigation. **Crystal Forrest:** Methodology, Resources, Investigation. **Louis Lesage:** Conceptualization, Resources.

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Data Availability Statement

The isotope values used in these analyses are all presented as tabulated data within the document and in the supplementary table. Some aspects of archaeological interpretation may be based in part on input from archaeological site reports that may not be readily available to the public. Such data that support the findings of this study are available from the corresponding author upon reasonable request, as are the values in the supplementary information, if colleagues experience any difficulty accessing it.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2020.102466.

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