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The Moatfield ossuary: isotopic dietary analysis of an Iroquoian community, using dental tissue

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Abstract

The Moatfield ossuary (AkGv-65) was discovered in North York, Ontario, in 1997. Archaeological Services Inc. was contracted to exhume and then re-bury the human remains. Located on the periphery of a Late Woodland Iroquoian village, the ossuary included 87 people, 58 of them adults. First Nations authorities allowed the analysis of one tooth per person. Adult crania provided age and sex information; a posterior maxillary tooth was retained from each of 44 individuals. A single tooth proved ample to provide an AMS radiocarbon date plus stable isotope ratios. Three radiocarbon ages were measured: the site dates to ca. A.D. 1300. Stable carbon isotope ratios were measured for tooth enamel (mean $\delta^{13}C = -4.2 \pm 1.6‰$) and dentin collagen ($-11.3 \pm 1.4‰$); the mean $\delta^{15}N$ value for dentin collagen was $12.6 \pm 0.9‰$. Archaeological bone specimens ($n = 63$) of 19 fish species from Lake Ontario provided $\delta^{13}C$ and $\delta^{15}N$ values. The results show that the Moatfield diet included selected fish species with high $\delta^{15}N$ values (lake trout, salmon, etc.) and a substantial maize component. Peak maize consumption occurred during the growth period of the 20–29-year-old age group.

Keywords: Ontario archaeology; Late Woodland; Iroquois; Bioarchaeology; Paleodiet; Bone chemistry; Tooth enamel; Carbon isotopes; Nitrogen isotopes; Fisheries

Introduction

During the summer of 1997, the renovation of a soccer field in North York (now within the City of Toronto, Ontario, Canada) resulted in the accidental discovery of a Late Woodland Iroquoian village and its associated ossuary (Borden designation AkGv-65; Fig. 1). Situated on the bank of a small stream ca. 10 km north of the north shore of Lake Ontario, the village is 1.2 ha (3 acres) in extent. The human skeletal remains were encountered during construction of a chain link fence around the perimeter of the soccer field. There is no evidence that this secondary burial was previously known or disturbed in historic times. In accordance with the wishes of the Six Nations Council of Oshweken, Ontario, the relevant First Nations authority under Ontario legislation, the City of North York subsequently retained Archaeological Services Inc. to expose and exhume the remains in the ossuary pit so that they could be re-buried in a protected setting.

The only artifact recovered from the ossuary was a small clay turtle effigy pipe, found at the very bottom of the ossuary pit (Williamson et al., 2003). Ceramic seri-

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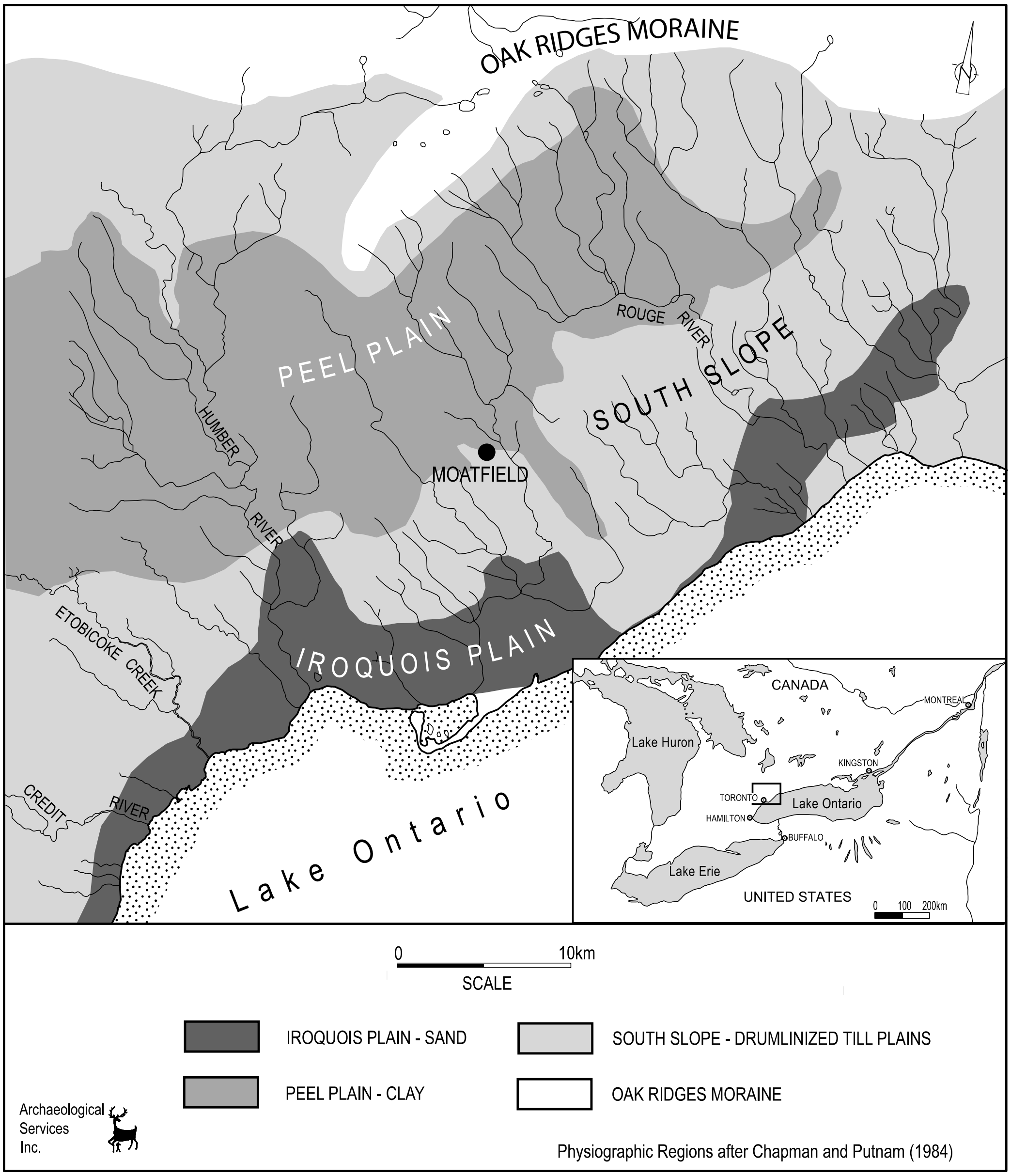

Physiographic Regions after Chapman and Putnam (1984)

Fig. 1. Map of southern Ontario, showing the location of the Moatfield site, and outlining subsistence regions that are relevant to the interpretation of the isotopic results.

ation and radiocarbon assays using bone and dentin from the ossuary, and maize from one of the features of the associated village, indicate a late 13th or early 14th century occupation for the site. With the permission of the Six Nations Council, detailed biological analyses of the skeletal material and isotopic analyses of tooth samples were undertaken before reburial.

Iroquoian society often forms a distinct focus of Late Woodland archaeology. In Ontario, the Late Woodland period is subdivided into Early (A.D. 900–A.D. 1300), Middle (A.D. 1300–A.D. 1400) and Late Iroquoian Periods (A.D. 1400–A.D. 1650).

The Early Iroquoian period is best viewed as a continuation of the important transitional stage between Middle Woodland hunting and gathering societies and later, fully agricultural Iroquoian societies. Villages tended to be small, palisaded compounds with longhouses occupied by either nuclear or, with increasing frequency, extended families. These extended families formed the basis of community socio-politics and, to a lesser extent, the basis of inter-community integration. Around the villages, camps and hamlets were strategically placed to facilitate the traditional exploitation of naturally occurring food resources, while maize horticulture assumed progressively greater importance in subsistence systems (Williamson, 1990).

The Middle Iroquoian period marks a stage in Iroquoian cultural evolution characterized by fully developed corn-bean-squash agriculture, a more fully integrated village political system based on extended matrilineal kinship, and further development of inter-village alliances. Widespread similarities in pottery and smoking pipe styles also point to increasing levels of inter-community communication and integration. Villages and some household groups (and longhouses) become larger at this time (Dodd et al., 1990).

Settlement and subsistence patterns appear to have remained relatively stable during the Late Iroquoian period. The most noticeable changes appeared in the socio-political system. Through the 15th century, certain village households were consistently larger and more variable in membership than others within the same community. This trend peaked around the turn of the 16th century: some longhouses reached lengths of over 120 m, with three or more extensions. Some villages attained a size of over four hectares. This trend may reflect changes in the fortunes and solidarity of dominant lineages within villages and/or the movement of families between allied communities. During the 16th century, longhouses became more uniform in size. This modification of residential pattern suggests that changes had occurred in the kin-based political system. It has been suggested that this change reflects increased importance of clans over lineages. Since clan membership cut across related communities, this aspect of kinship was an important source of tribal integration (Lennox and Fitzgerald, 1990; Ramsden, 1990).

When European explorers and missionaries arrived in Ontario at the beginning of the 17th century, Iroquoian villages were under the direction of various chiefs elected from the principal clans. In turn, these villages were allied within powerful tribal confederacies. Intertribal warfare with the Five Nations Iroquois of New York State during the mid-17th century, exacerbated by the intrusion of Europeans, resulted in the dispersal of the Ontario Iroquoian groups—i.e., the Huron, Petun, and Neutral.

The establishment of maize as a dietary staple in northeastern North America has been tracked through stable isotope chemistry. The questions of when and how maize became established impelled the early development of this paleodietary methodology. In the lower Great Lakes it has been established that maize was introduced in the sixth century A.D. (Crawford et al., 1997), and it has been suggested that the contribution of maize to diet peaked at about A.D. 1350 (Schwarcz et al., 1985). The pace with which this dietary shift occurred, however, is not clear. Investigating the nature of the transition to maize horticulture is important not only to answering questions regarding nutrition and health, but also to understanding the evolution of Iroquoian cultural complexity. Living in a relatively cool, cloudy part of the continent, the northern Iroquoians developed or adopted a strain of *Zea mays* that could mature in a growing season with few heat units, and around this and other cultigens (i.e., squash, beans, and tobacco), their distinctive matrilineal-based village life developed.

The practice of secondary ossuary burial among some Iroquoian groups can provide important information about their health and survival at different points in the past. The isotopic analyses for paleodietary reconstruction of the Moatfield community is based almost entirely on teeth (44 individuals), with a smaller group of analyses (11 individuals) of fragments of alveolar bone that adhered to the teeth. Prior isotopic studies of human remains from this area have been based exclusively on bone collagen and bone apatite. Our study demonstrates that the analysis of tooth enamel and tooth dentin provides information comparable to that obtained from bone; it also establishes the isotopic spacing between the two types of sample material. Most importantly, it marks a partnership with descendant groups who gave permission to retain teeth for the analysis.

Materials and methods

Upon discovery of the Moatfield ossuary, the procedures specified by the Ontario Cemeteries Act were followed and direction was sought from the appropriate First Nations Band government. The Six Nations Council directed the municipal government "that *all* of the human remains located in the area must be recovered..." and re-interred at a location that would be less likely to be disturbed. Under the direction of R. Williamson, an archaeological team mapped the ossuary in 14 layers, recording the precise horizontal and vertical location of all major skeletal elements. This has provided important data for understanding the nature and structure of early Middle Iroquoian ossuary burial. In an effort to learn more about their ancestors, permission was also given by Six Nations Council to retain one tooth per person for analysis. Excavation began in late September, 1997, and reburial occurred on December 17, 1997.

Osteobiographic information was recorded about the human remains. Given the short time available, this work was undertaken by a team of selected graduate and undergraduate students from three universities (Guelph, McMaster, and Western Ontario), working under the direction of S. Pfeiffer. The process included the recording of field provenience for all elements, determining the minimum number of individuals, and ascertaining age and sex as available from the commingled elements. The ossuary included the remains of minimally 87 people. Estimated age at death was assigned to each maxilla, using criteria of dental development, dental deterioration, closure of the basilar suture, and obliteration of the incisive suture (Mann et al., 1987). Sex was assigned to each adult cranium, using six observations and a five-point scale (Buikstra and Ubelaker, 1994). Each of 58 crania was designated as male (31), female (18), or undetermined (9). While adult ages were categorized as specifically as possible, they are reported here in broader categories of 12–19, 20–29, 30–50, and over 50 years of age.

After documentation, one tooth from each non-edentulous adult maxilla was removed and retained for analysis. The largest extant tooth was preferred, unless that tooth had extensive caries. About one third of the maxillary molars had been lost antemortem. Hence, the collection of teeth from 44 people includes 13 first, 13 second, 14 third molars, three premolars, and one canine. These teeth represent nine women, 28 men and seven adults of unknown sex. The small proportion of women may at least partially reflect higher antemortem tooth loss among the women.

The assumptions and methodology of isotopic dietary studies on archaeological skeletal remains have been developed over the past 35 years and have been described elsewhere (for review see Katzenberg, 2000; Schoeninger and DeNiro, 1984; van der Merwe and Vogel, 1978; Vogel and van der Merwe, 1977). Isotopic analyses have usually been done on skeletal elements other than teeth; models for the interpretation of such measurements are discussed in the next section. When the sample materials are teeth less than 1000 years old, as in the case of Moatfield, a variety of measurements are possible and they provide different kinds of dietary information. These include stable carbon isotope ratio measurements (δ^{13}C values) on bulk dentin collagen, dentin apatite, and enamel apatite. In a C_3 biome like southern Ontario, δ^{13}C values can provide a measure of the dietary contribution of maize, a C_4 plant. Apatite provides an average of all the carbon in the diet, while collagen emphasizes the protein components from both plant and animal foods. Nitrogen isotope ratios (δ^{15}N values) can be measured in dentin collagen; the results relate entirely to dietary protein. At a finer scale of dietary resolution, δ^{13}C and δ^{15}N can be measured in specific compounds and individual amino acids in dentin collagen. Cholesterol, for example, also averages the carbon in the diet, while essential amino acids may help to identify protein sources.

Teeth form relatively early in life, different teeth form at different ages, and so do the crown and roots of a particular tooth (van Beek, 1983). The dentin may remodel slightly over time, but the enamel does not. Of the 44 teeth analyzed in our study, all but four were maxillary molars. The initial calcification of the first molar starts at birth, the crown is completed by 2.5–3 years of age, and the roots by 9–10 years. For second molars, the initial calcification starts at 2.5–3 years, the crown is complete by 7–8 years, and the roots by 15–16 years. For third molars, the comparable ages are 7–9, 12–16, and 18-25 years, respectively. There is some potential information of life history in the isotopic ratios of different tooth types, indicating different diets before and after weaning (Katzenberg and Pfeiffer, 1995; Wright and Schwarcz, 1998), but these differences are not noticeable beyond the first molar. Likewise, carbon isotope ratios in dentin and enamel apatite refer to diet at different ages, because the crown is completed before the roots. In order to achieve the maximum dietary information from the available dental tissue, we had to make choices. Three measurements were done in the first instance: δ^{13}C in dentin collagen and enamel apatite and δ^{15}N in dentin collagen; these results are reported here. Cholesterol was extracted from dentin collagen by Susan Jim of the University of Bristol for the purpose of δ^{13}C measurements, the results of which are being prepared for publication. Additional measurements may follow as sample materials allow. From a small number of molars ($n = 11$), collagen was prepared from alveolar bone adhering to the roots for δ^{13}C and δ^{15}N measurements. These samples were very small and apatite δ^{13}C values were not measured. Finally, roots from the two biggest teeth and a fragment of human bone (initially identified as deer) were used to extract collagen for radiocarbon dating.

To investigate the role of freshwater fish in the Moatfield diet, collagen was prepared from a series of archaeological fish bone specimens. These include 63 specimens attributable to 19 fish taxa from sites in the Lake Ontario drainage. This material was recovered by Archaeological Services Inc. at the Iroquoian village sites of Moatfield (Williamson and Pfeiffer, 2003), Parsons (Williamson and Robertson, 1998), and Grandview (Williamson et al., 1999). Stephen Cox Thomas of Bioarchaeological Research undertook the zoo-archaeological analysis and taxonomic identification.

For the δ^{13}C and δ^{15}N measurements reported here, all tissue was prepared at Harvard in the context of a Freshman Seminar taught by van der Merwe. Selected freshmen from the seminars of 1998 and 1999 undertook the laboratory work under the supervision of Allegretto. The goals included radiocarbon dating of selected teeth and the stable isotope analysis of tooth enamel, dentin, and alveolar bone. Since this was a training exercise, a variety of laboratory procedures were followed. Collagen and enamel samples were prepared for analysis in a fully automated mass spectrometer on the one hand, while on the other, carbon dioxide samples were prepared for injection into a mass spectrometer with a gas sample manifold. Three collagen samples for radiocarbon dating were likewise prepared at Harvard, after which the students worked at nearby Geochron Laboratories under the supervision of Alex Cherkinsky to produce carbon dioxide samples for AMS radiocarbon measurement at Lawrence Livermore National Laboratory. The results were compared with an AMS radiocarbon date on carbonized maize from the Moatfield village site, which had been measured by Isotrace Laboratory.

The laboratory procedures for the extraction of collagen were essentially those of Longin (1971), adapted and improved over time by the stable isotope laboratories at the Universities of Cape Town and Harvard. These are described in some detail here. The procedure for the extraction of enamel apatite is that used by the Cape Town group (Lee-Thorp et al., 2000).

Each tooth was cleaned ultrasonically to remove adhering soil and alveolar bone was salvaged where possible. A sample of 100 mg enamel powder was removed from each tooth, using a diamond burr bit on a variable speed electric drill. A sample of 100–200 mg of dentin/cementum fragments was obtained from the root. For apatite separation, tooth enamel was ground in a Spex mill, the organic phase was dissolved in a 2% solution of sodium hypochlorite (Clorox) for 1 h, and possible calcite contaminants were dissolved in 0.1 M acetic acid for 15 min. To extract collagen, bone and dentin fragments were treated with 2% NaOH (1–2 h) to remove humic acids and defatted in a 2:1:0.8 mixture of methanol:chloroform:water for several days. After neutralization with distilled/de-ionized water, the mineral phase was dissolved with 0.1 M HCl over the course of several days, with the acid solution changed every day. The resulting collagen pseudomorphs were washed and freeze dried. All $\delta^{13}C$ measurements on tooth enamel apatite were done in a VG Optima mass spectrometer in the laboratory of Daniel Schrag of the Department of Earth and Planetary Sciences at Harvard. Carbon dioxide was produced from the enamel by reacting it with 100% phosphoric acid at 90 °C. The gas was cleaned in a vacuum line, sealed in a Pyrex tube, and injected into the mass spectrometer through the sample manifold. Collagen was also extracted from the dentin of a small group of teeth ($n = 9$), and their carbon isotope ratios were measured in the VG Optima. In this case, carbon dioxide was generated by combusting the extracted collagen in closed quartz tubes with copper oxide, copper and silver; clean carbon dioxide was isolated in a vacuum line and sealed in a Pyrex tube for injection through the manifold.

Ian Newton and John Lanham measured the carbon and nitrogen isotope ratios for all 44 teeth using the Finnegan MAT 252 mass spectrometer of the Archaeometry Research Unit, University of Cape Town. This instrument is equipped with an automatic Carlo Erba HCN analyzer that combusts 1–2 mg of collagen, wrapped in tinfoil, and then injects the resulting carbon dioxide and nitrogen into the mass spectrometer for isotope ratio measurements. This procedure was followed for the isotopic analysis of 44 dentin collagen and 11 alveolar bone collagen samples.

For carbon isotope ratio measurements in both the VG Optima and Finnegan MAT 252, two laboratory standards (Lincoln Limestone and Carrara Z Marble) and five NBS standards were used; the $\delta^{13}C$ values are reported in per mil (‰) relative to the PDB standard. The $\delta^{15}N$ values are reported relative to the AIR standard.

The replication of $\delta^{13}C$ measurements of dentin and bone collagen by both laboratories was done for the purpose of intercalibration; the difference proved to be negligible. Machine precision was 0.1‰ for both laboratories. C:N ratios were generally 3.2–3.3. Values for $\delta^{15}N$ are not reported unless the C:N ratio was in acceptable range.

Metabolic models

Models for the dietary interpretation of stable isotope ratios have been developed and refined over the past 35 years. These have involved primarily carbon isotopes, but both $\delta^{13}C$ and $\delta^{15}N$ values are of interest here. Initially, a simple linear relationship was used to calculate the contribution of different dietary components to the carbon isotopes of consumer tissues; this has become know as the 'scrambled egg model' (van der Merwe, 1982). Based on carbon isotope measurements on archaeological remains of animals (mostly herbivores) and foraging humans in the C_3 woodlands of eastern North America, bone collagen was observed to be enriched in ^{13}C by about 5‰ relative to the diet, with bone apatite enriched by a further 7‰ (i.e., 12‰ more positive than the $\delta^{13}C$ value of the diet). Since the $\delta^{13}C$ values of C_4 plants are 14‰ more positive than those of C_3 plants, on average, a linear relationship was used to calculate the contribution of maize to the diets of farmers in the Woodlands. Krueger and Sullivan (1984) proposed a "routing model" to explain the collagen-apatite spacing, which holds that the carbon in consumer protein (e.g., bone collagen) is provided entirely by dietary protein, while the carbonate in bone apatite is derived from the energy substrate of the diet (carbohydrates and lipids). The diet-collagen spacing of 5‰ and diet-apatite spacing of 12‰ should, therefore, hold only for herbivores. For carnivores, the $\delta^{13}C$ spacing between collagen and dietary protein was assumed to be 0‰ and the apatite-diet spacing was assumed to be 3‰. Omnivores like humans should be somewhere in between, with the apatite-collagen spacing varying in relation to the amount of protein in the diet. Field studies of

African wildlife (Lee-Thorp et al., 1989) confirmed the $\delta^{13}C$ spacings for herbivores; for carnivores, however, the $\delta^{13}C$ spacing between collagen and the meat diet was found to be 4–5‰, while the apatite-diet spacing was 9‰.

These relationships were explored through dietary experiments with mice (Tieszen and Fagre, 1993) and rats (Ambrose and Norr, 1993). The results showed that the carbon isotope signature of apatite represents that of the whole diet, not just the energy substrate. Using cholesterol from rat collagen provided by Ambrose and Norr, Jim (2000; Jim et al., 2001) also showed that the whole diet is represented in the $\delta^{13}C$ signature of this compound. The isotope signature in bulk collagen (Ambrose and Norr, 1993) depends on the extent to which dietary protein, carbohydrates and lipids are metabolized to synthesize consumer collagen. In general, collagen $\delta^{13}C$ values over-estimate the protein component of the diet.

Rats and mice can provide a first approximation of human metabolism, but they do not provide good models for human growth and nutrition. Human collagen is composed of 20 amino acids, of which 10 are essential (i.e., they cannot be synthesized by humans and must be acquired directly from dietary protein). An 11th amino acid (tyrosine) can be synthesized, but only from an essential precursor. In all, 21.5% of the carbon in collagen is derived directly from dietary protein, while the rest can be synthesized from protein, carbohydrates, and lipids. The extent to which each dietary component is metabolized depends on a variety of factors, the most obvious being digestibility: maize porridge is easier to digest than whole kernels, for example. Experimental diets are usually compounded from refined foods, which may explain why the diet-collagen spacing of laboratory animals is usually less than the 5‰ observed in field studies.

The development of compound-specific isotopic analysis (GC-IRMS) has stimulated new directions in dietary studies, including dietary experiments with pigs. These animals are better analogues for human metabolism, since they have the same amino acid requirements. Hare et al. (1991) raised pigs on controlled diets with C_3 and C_4 isotopic signatures and showed that the isotopic enrichment in carbon between the whole diet and collagen can be explained by the enrichment in some of the constituent amino acids. Of particular importance is their demonstration that nitrogen from dietary protein (the only nitrogen source) is pooled in the body and then used to synthesize amino acids. The $\delta^{15}N$ signature of the whole diet is therefore averaged in consumer collagen and other proteins in all cases.

There is no established model for the distribution of nitrogen isotopes in plants. In the well-watered environment of southern Ontario, however, the distribution of $\delta^{15}N$ values in the terrestrial food chain can be predicted with reasonable confidence. Since the standard for $\delta^{15}N$ measurements is air nitrogen, those plants that can fix nitrogen directly will have values near 0‰. These are leguminous plants, with beans being an obvious example in the Moatfield case. Most plants fix nitrogen from soil nitrates and have $\delta^{15}N$ values of about 3–5‰. Herbivores have $\delta^{15}N$ values that are 3–4‰ more positive than their diets and this "trophic effect" occurs at each level of the food chain (DeNiro and Epstein, 1981; Schoeninger and DeNiro, 1984; Schoeninger et al., 1983a,b; Sealy et al., 1987). Marine food-webs may have many trophic levels and many marine fish have $\delta^{15}N$ values above 10‰. Freshwater habitats may also have long food chains; for this reason, archaeological fish remains from southern Ontario have been included in our isotopic analyses.

It is clear from the archaeological evidence that maize and freshwater fish were major components of the Moatfield diet. Recent data from a controlled dietary experiment with pigs provide a model by means of which the interpretation of $\delta^{13}C$ and $\delta^{15}N$ values for the human dental tissues can be approached (Howland et al., 2003; Young, 2002). The experiment is still incomplete, but the results obtained with one diet are relevant here (Table 8). The diet was compounded from 74% ground maize, 23% fishmeal, 2% soybean oil, 1% vitamins, and minerals. This diet produced a pig with ^{13}C enrichment relative to the whole diet of 1.7‰ in muscle, 4.0‰ in bone collagen, and 11.2‰ in apatite. For nitrogen, the ^{15}N enrichment relative to the whole diet was 3.0‰ in muscle and 3.6‰ in collagen. The $\delta^{15}N$ values for the pig muscle and collagen were, in fact, closely similar to that of the fishmeal, showing that this dietary component contributed most of the nitrogen to the pig proteins. The small difference in $\delta^{15}N$ values between muscle and bone collagen is probably due to the fact that muscle has more essential amino acids than bone.

While the diet used in this experiment is obviously not a replica of the presumed human diet at Moatfield, it provides the closest analogue available at this time to interpret the isotopic results for the people in the ossuary.

Results

Radiocarbon dates

The results of the accelerator mass spectrometric ^{14}C dating are summarized in Table 1. There is good agreement among the samples suggesting that the ossuary and the occupational feature from the village both date to ca. A.D. 1300. Seriation of the ceramic vessel rims recovered from the various village contexts are also consistent with this date.

The date for the fragment of human bone is earlier than those for the two teeth and may reflect measurement error, or may indicate that this bone was from

Table 1
AMS ^{14}C dates from the Moatfield occupational feature and ossuary, with confidence intervals and calibrated ages according to Stuiver and Reimer (1993; Stuiver et al., 1998)

Lab ID	Sample	Context	$\delta^{13}C$	Age (BP)	68% confidence	95% confidence
TO-6945	Carbonized maize	Occupational feature	N/A	620 ± 60	1295–1400	1280–1430
GX-26240 AMS	Tooth root 492b	Ossuary	−14.7‰	810 ± 40	1210–1270	1160–1290
GX-26251 AMS	Tooth root 1000e	Ossuary	−11.6‰	730 ± 40	1260–1300	1215–1310
GX-26148 AMS	Human bone	Ossuary	−10.5‰	910 ± 40	1040–1205	1020–1220

someone who had died considerably earlier and was incorporated into the ossuary.

Carbon isotope ratios

Mean collagen yields were 13% by weight from tooth dentin and 10.8% by weight from alveolar bone. The two laboratories produced very similar results from duplicate samples. For example, nine duplicate samples of dentin collagen were analyzed for carbon isotope ratios. Among these, the Harvard values were more negative in four cases, the UCT values in five. The mean difference between the pairs is 0.1‰, the same value as the machine precision. There is negligible bias, and the variability may be linked at least in part to the inherent variability in small samples associated with the anisotropy of collagen. Where duplicate values exist, the UCT value is presented in the tables below for the purpose of consistency.

Values for $\delta^{13}C$ are summarized in Table 2. There are no significant differences between sexes, or between different teeth in the tooth row. Research on Mayan enamel apatite values (Wright and Schwarcz, 1998) has demonstrated a patterned dietary shift within the tooth row, explained by the fact that the first permanent molar crown develops during a time when a child is normally breast-fed, prior to the introduction of C_4 foods (maize gruel). The other teeth, with crowns that develop after weaning, are not predicted to differ from one another in a patterned way. In the Moatfield sample, this patterned shift within the tooth row is not apparent. While the mean value for enamel apatite $\delta^{13}C$ is slightly more negative for the first permanent molars, this difference is not statistically significant.

There are, however, significant differences among age groups (Fig. 2). Based on *t* test comparisons of independent samples, the oldest age group, over 50 years, has enamel apatite $\delta^{13}C$ that is significantly more negative than the 20–29-year-olds ($p < 0.005$) and more negative than the 30–50-year-olds ($p < 0.05$). The youngest group, <20 years, has significantly more negative enamel apatite $\delta^{13}C$ than the 20–29-year-olds ($p < 0.05$). Because there is a slight difference in means among tooth types, the age effect might be influenced by certain ages being represented by certain types of teeth. While tooth types appear to be rather equally distributed in each age group, the possibility of bias was explored statistically. An ANOVA shows that age class explains a significant amount of the variance in enamel apatite $\delta^{13}C$ ($F = 3.22$, $p = 0.023$), but tooth type does not, and there is no significant interaction between age and tooth type.

The dentin collagen $\delta^{13}C$ values show the same pattern of age group differences, but the differences are less marked. In *t* test comparisons of independent samples, the oldest age group, over 50 years, is significantly more negative than the 20–29-year-olds ($p < 0.05$). The relationship between enamel apatite $\delta^{13}C$ and dentin collagen $\delta^{13}C$ in individual teeth is not particularly strong (35 pairs, $r = 0.57$). This probably reflects the different ages at which the enamel and dentin were formed, as well as the slight capacity of dentin and cementum to remodel after formation (cf. Hillson, 1996), versus the lack of remodeling in enamel.

The spacing between dentin collagen and bone collagen is close, with bone collagen isotopically lighter by 1.0‰ on average. Every sub-set of the collection shows dentin collagen values being isotopically heavier than those of bone collagen. Among the 11 individuals for whom we have both bone and tooth values, the mean value of dentin collagen $\delta^{13}C$ is −11.3‰, identical to the tooth collection as a whole. The spacing between enamel apatite and dentin collagen is about 7‰, when the mean for all teeth is used. Again, the mean value of enamel apatite $\delta^{13}C$ for the 11 individuals from whom we have both bone and tooth values, −4.0‰, is very close to the value for the whole collection (−4.2‰), so this spacing holds. For this sub-sample of 11, the correlation between enamel and dentin isotope values is $r = 0.685$. However, the correlation between dentin collagen and bone collagen values is $r = 0.307$. The small amount of variance in the collagen isotope values shows no dependence between tissues within individual bodies.

A spacing of 7‰ in $\delta^{13}C$ between enamel apatite and dentin collagen is similar to that observed between bone apatite and collagen in the dietary experiment with pigs (Table 8). This is a C_3 biome, in which all the plants and terrestrial animals have C_3 carbon isotope signatures, so hunter-gatherers in this environment would have $\delta^{13}C$ values of about −13‰ in their tooth enamel and −21‰ in bone collagen (Table 7). A comparable value for dentin collagen would be −20‰.

Table 2
Stable isotope ratio measurements from individuals from the Moatfield ossuary, organized by estimated age; includes δ^{13}C values for tooth enamel, as well as δ^{13}C and δ^{15}N values for dentin collagen and, in 11 cases, for alveolar bone

Specimen	Age	Sex	Tooth	δ^{13}C enamel	δ^{13}C dentin collagen	δ^{15}N dentin collagen
6	12		LM1	−4.6	−10.3	11.5
6	12		BONE		−11.6	11.6
L8D9	12		LM2	−5.6	−11.4	12.6
1485	15		RM1	−3.3	−10.4	11.0
754	15		RM2	−4.6	−12.5	13.7
1571	15		RM2	−6.5	−11.5	12.8
546	15–19	F	LM3	−3.2	−10.4	11.7
2014	18	F	RM1	−4.7	−11.8	13.0
5	20–29	M	RM3	−3.0	−10.0	12.0
8	20–29	F	LM2	−5.1	−11.3	12.9
12	20–29	M	LM3	−2.3	−10.6	13.5
15	20–29	M	RM1	−3.4	−9.5	11.4
20	20–29	M	RM3	−4.3	−10.3	12.7
24	20–29	F	RM3	−2.9	−9.6	12.3
561	20–29	M	RM3	−2.0	−9.4	12.0
561	20–29	M	BONE		−12.0	11.7
629	20–29	M	RM2	−3.1	−10.6	12.7
740a	20–29	F	RM2	−2.7	−9.3	11.8
740a	20–29	F	BONE		−10.2	11.7
1000d	20–29	M	RM2	−2.3	−10.4	13.0
1150	20–29	M	RM2	−3.6	−13.0	13.8
1198	20–29	M	RM2	−3.9	−13.0	13.4
1198	20–29	M	BONE		−11.6	12.5
1895	20–29	?	RM2	−2.1	−11.3	11.1
1442	>30	F	RM2	−2.0	−11.3	11.7
1652a	>30	M	LM1	−5.1	−10.0	11.8
1700a	>30	M	LM1	−4.6	−11.3	13.1
1700a	>30	M	BONE		−10.8	11.9
2044a	>30	M	LP2	−5.1	−13.8	13.3
683	30–50	M?	RM3	−2.4	−9.8	11.9
683	30–50	M?	BONE		−14.4	11.9
756	30–50	F	RM3	−1.7	−10.8	12.4
756	30–50	F	BONE		−13.2	12.7
2	30–50	M	LPM1	−4.0	−10.9	13.1
3	30–50	M	LPM1	−1.8	−13.2	13.4
7	30–50	M	RM2	−5.5	−10.7	11.9
7	30–50	M	BONE		−12.9	12.5
18	30–50	M	RM1	−8.0	−15.4	14.3
595	30–50	M	RM3	−3.8	−11.3	12.1
9	>50	M	LM1	−6.3	−14.3	12.9
9	>50	M	BONE		−13.9	12.1
21	>50	M	LC	−3.9		
492a	>50	M	RM3	−4.2	−9.1	12.4
492b	>50	M	RM3	−5.2		
493	>50	F	LM2	−7.5	−11.9	12.8
828	>50	M	LM3	−4.9	−11.3	13.3
828	>50	M	BONE		−11.0	13.2
1430	>50	M	LM3	−4.7	−12.8	13.0
1000e	>50	F	RM1	−4.7	−12.0	13.3
1652b	>50	?	LM1	−6.5	−11.6	12.5
1666	>50	M	RM1	−4.1	−10.4	15.5
1790a	>50	M	RM1	−4.7	−12.3	12.6
1866	>50	M	LM3	−5.2	−13.7	13.0
1866	>50	M	BONE		−13.2	14.0
2079	>50	M	RM1	−6.5	−10.2	11.9

All values are in per mil (‰) relative to PDB and AIR nitrogen.

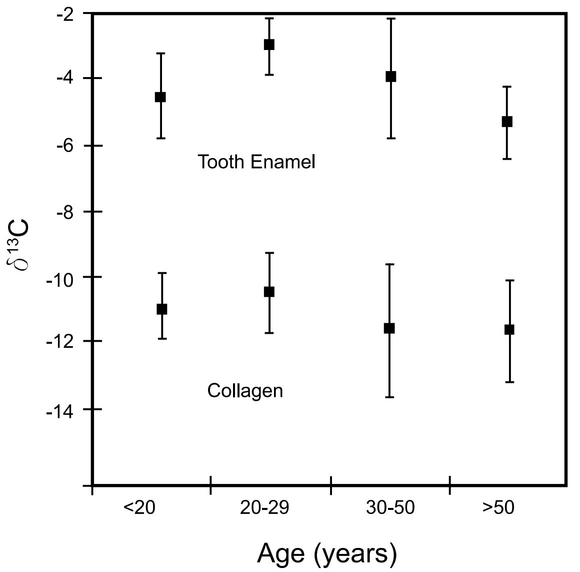

Fig. 2. Comparison of $\delta^{13}C$ values from tooth enamel and collagen samples from Moatfield people of different ages. The tooth enamel differences among age groups are statistically significant.

We know that the Moatfield diet included freshwater fish, since most of the faunal remains from the occupational feature were fish bones. The $\delta^{13}C$ values for archaeological fish bones from sites in southern Ontario (Table 6) closely resemble those of C_3 plant consumers and will not alter the C_3 signature of local hunter-gatherers (as Table 7 demonstrates).

Stable carbon isotope ratios vary among fish species depending on their sources of carbon. Unlike the terrestrial environment, where carbon comes from atmospheric CO_2, carbon in freshwater lakes and streams comes from many different sources (Hecky and Hesslein, 1995; Katzenberg and Weber, 1999). In general, fish inhabiting the littoral (shallow water, near shore) zone where water temperatures tend to be warmer are enriched in $\delta^{13}C$, relative to pelagic (open water) species and benthic (deep water) species where the water temperature is lower (France, 1995). In this series, drum and eel have the most enriched $\delta^{13}C$ values. Much lighter $\delta^{13}C$ values are found in sunfish, pike, whitefish and bowfin. With the exception of bowfin and pike, these fish prefer cooler waters (open and deep waters). In the case of pike, while they generally seek deep, cool water in the heat of summer, their usual habitat is clear, warm, slow meandering heavily vegetated rivers or warm, weedy bays in lakes (Scott and Crossman, 1973, p. 360).

Of particular interest here are species with high $\delta^{15}N$ values (> 10‰; Fig. 4), because they are prey candidates that may explain the elevated $\delta^{15}N$ values of the Moatfield people (Fig. 3). All of these, with the exception of eel, have $\delta^{13}C$ values at the C_3 endpoint and would, therefore, not contribute to ^{13}C enrichment in consumers. The meat diet presumably also included terrestrial animals as well as birds; among the latter, several species are fish consumers. It is not possible to calculate the composition of the meat diet from the available data.

To interpret the isotopic contribution of maize in the Moatfield diet, we can set the C_3 and C_4 endpoints (i.e., 100% C_3 foods versus 100% C_4 foods) at −13‰ and +1‰ for tooth enamel and −20‰ and −6‰ for dentin collagen. Using this scale, the percentage of carbon derived from maize in the Moatfield teeth is summarized in Table 5.

The enamel $\delta^{13}C$ signatures are better proxies for the amount of C_4 carbon from maize calories in the diet, since fish protein with C_3 isotope signatures are preferentially recorded in the dentin collagen. The data indicate that maize consumption reached a peak during the growth period of the 20–29-year-old age group.

A chronological comparison of $\delta^{13}C$ values for human bone collagen in southern Ontario shows that maize consumption reached a peak during the lifetime of the Moatfield population (Table 7). If we calculate that the 20–29-year-old age group had bone collagen $\delta^{13}C$ values of about −11.6‰ (1.0‰ lighter than their dentin collagen), then the only site with a higher maize component is that of Fairty (−11.3‰, $n = 4$), which is roughly contemporary, or slightly later.

Nitrogen isotope ratios

Values for $\delta^{15}N$, based on both dentin collagen and bone collagen, are summarized in Table 3. All values are similar. There are no significant differences between sexes, among ages or among tooth types. The small standard deviations of the $\delta^{15}N$ values reflect a coefficient of variation that is lower than that of the $\delta^{13}C$ values. This suggests an unchanging source of animal protein that contributed much of the nitrogen in Moatfield human protein tissues (see Table 4).

The $\delta^{15}N$ values for Moatfield human collagen are higher than expected for a terrestrial diet in this well-watered environment. A predator such as a bobcat can be expected to have a $\delta^{15}N$ value of ca. 10‰ in this area, while the Moatfield $\delta^{15}N$ values for human collagen have a mean of 12.6‰. This is not the highest $\delta^{15}N$ value that has been recorded for southern Ontario: Donaldson Cemetery 1 (13.7‰, $n = 1$) and Levesconte Mound (13.4‰, $n = 4$) have slightly higher values (Fig. 3). On average, however, the $\delta^{15}N$ collagen values for this area were remarkably stable over more than 3000 years. The protein source that produced these elevated $\delta^{15}N$ values in the people of southern Ontario was clearly the fish from the lake (Table 6), with the possible addition of birds with fish diets. The stable nitrogen isotope ratios of the fish species reflect their trophic position (Katzenberg, 1989; Vander Zanden and Rasmussen, 1995)

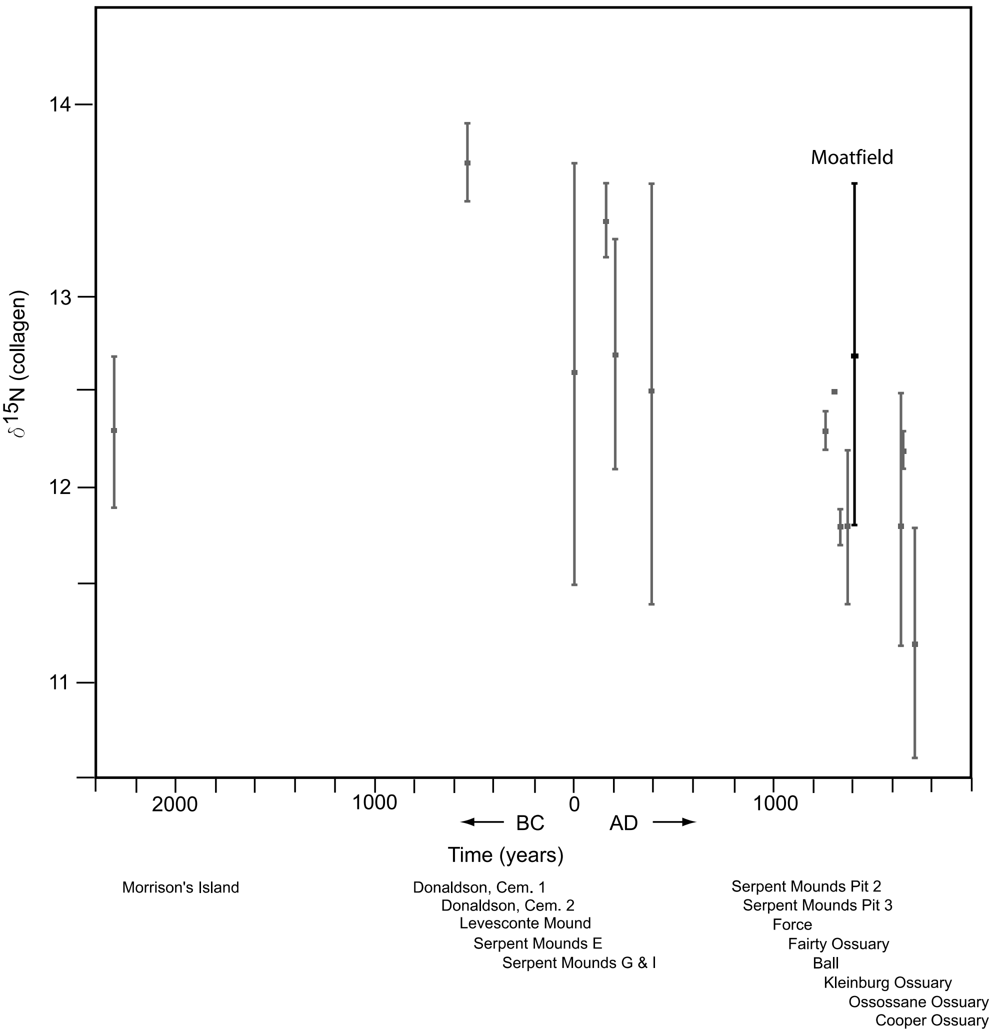

Fig. 3. Plot of dietary nitrogen values for southern Ontario archaeological sites, plotted in the same order as in Table 7. Note that sample sizes vary, contributing to the differences in ranges among sites.

although predatory fish undergo a trophic ontogeny as they progress from juvenile to mature stages (Johnson et al., 2002). Generally, those fish that feed on plant material and detritus have the lowest δ^{15}N values, followed by consumers of insects and crustaceans. The fish furthest up the food chain, those with the highest δ^{15}N values, are generally large members of species that feed primarily on other large fish (e.g., lake trout, burbot, and walleye). In Table 6, the lowest δ^{15}N values are found among the suckers and the drum. Both freshwater drum and white sucker are bottom feeding species. Drum eat insects, particularly mayflies and aquatic insect species, amphipods, snails, and clams. Larger drum also eat small fish and crayfish (Scott and Crossman, 1973, p. 815). White suckers consume chironomid (midge) larvae and pupae, mollusks, and cladocerans (water fleas) (Scott and Crossman, 1973, p. 542).

The fish species that are the most obvious candidates for the elevated δ^{15}N values of the Moatfield people are burbot, prized for its oily liver (Fox, 2000), and three large predatory game fish species—lake trout, Atlantic salmon, and yellow walleye (Fig. 4). Perch, northern pike, and American eel may also have contributed to the high values. Northern pike are omnivorous carnivores and have been known to consume fish, frogs, mice, ducklings, and even muskrats (Scott and Crossman, 1973, pp. 360-361). Its relatively low nitrogen isotope ratio at Moatfield may have been due to trophic ontogeny whereby the pike remains that were selected for analysis were from a specific feature at Moatfield containing the remains of particularly small individuals, perhaps taken from the Don River rather than from Lake Ontario. American eel, while characterized as a "voracious carnivore" (Scott and Crossman, 1973,

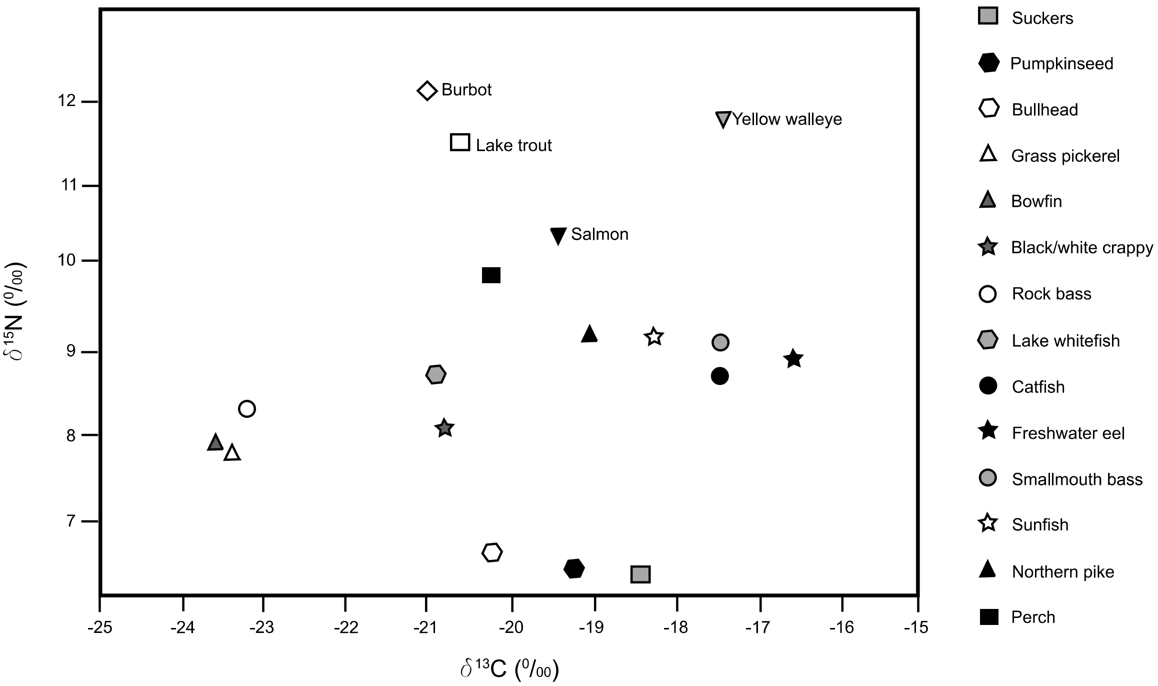

Fig. 4. Plot of isotopic values for Ontario fish from archaeological sites. The four highlighted species may have made major contributions to the diet of the Moatfield people.

Table 3
Values of $\delta^{13}C$ and $\delta^{15}N$ obtained from dentin collagen and alveolar bone collagen of 11 individuals from Moatfield, as well as the $\delta^{13}C$ values of the apatite in their tooth enamel

Specimen	$\delta^{13}C$ dentin	$\delta^{13}C$ bone	$\delta^{13}C$ enamel	$\delta^{15}N$ dentin	$\delta^{15}N$ bone
6	−10.3	−11.6	−4.6	11.5	11.6
7	−10.7	−12.9	−5.5	11.9	12.5
9	−14.3	−13.9	−6.3	12.8	12.1
561	−9.4	−12.0	−2.0	12.0	11.7
683	−9.8	−14.4	−2.4	11.9	11.9
740a	−9.3	−10.2	−2.7	11.8	11.7
756	−10.8	−13.2	−1.7	12.4	12.7
828	−11.3	−11.0	−4.9	13.3	13.2
1198	−13.0	−11.6	−3.9	13.4	12.5
1700a	−11.3	−10.8	−4.5	13.1	12.5
1866	−13.7	−13.2	−5.2	11.9	11.9
Means	−11.3 (1.5)	−12.3 (1.3)	−4.0 (1.4)	12.4 (0.7)	12.3 (0.5)

All values are in per mil (‰) relative to PDB and AIR nitrogen.

p. 627) and having a relatively high $\delta^{15}N$ value range of 8.1‰ to 10.1‰, has small jaws compared to those of lake trout and pike thereby limiting its consumption of prey to those animals lower on the trophic ladder.

Discussion

Other research on populations of the Great Lakes region has been undertaken with bone collagen, hence comparisons with Moatfield focused on the carbon isotope values derived from the 11 bone collagen samples. The enamel and dentin values from this subsample confirmed that it is an unbiased representation of the larger Moatfield sample. While we are interested in chronological questions relating to the establishment of dependence on maize, temporal questions cannot be answered precisely until all the samples in the regional comparison are dated and calibrated with the same methods. With this disclaimer, our exploration will use and interpret the published literature verbatim.

Table 4
Values of δ^{13}C and δ^{15}N from dentin and bone collagen and δ^{13}C from enamel apatite, summarized by the total sample and subsets; mean, standard deviation, and sample size provided

		δ^{13}C enamel apatite	δ^{13}C dentin collagen	δ^{13}C bone collagen	δ^{15}N dentin collagen	δ^{15}N bone collagen
Sexes	Male	−4.2 (1.4) $n = 28$	−11.4 (1.7) $n = 26$	−12.7 (1.4) $n = 9$	12.8(0.9) $n = 26$	12.5 (0.8) $n = 8$
	Female	−3.8 (1.8) $n = 9$	−10.9 (1.0) $n = 9$	−11.7 (2.1) $n = 2$	12.4 (0.6) $n = 9$	12.2 (0.8) $n = 2$
	Unknown	−4.7 (1.6) $n = 7$	−11.3 (0.8) $n = 7$	−11.6 $n = 1$	12.2 (1.0) $n = 7$	11.6 $n = 1$
Ages	<20	−4.6 (1.2) $n = 7$	−11.2 (0.8) $n = 7$	−11.6 $n = 1$	12.3 (0.9) $n = 7$	11.6 $n = 1$
	20–29	−3.1 (0.9) $n = 13$	−10.6 (1.2) $n = 13$	−11.3 (0.9) $n = 3$	12.5 (0.8) $n = 13$	11.9 (0.5) $n = 3$
	30–50	−4.0 (2.0) $n = 11$	−11.7 (1.7) $n = 11$	−12.8 (1.5) $n = 4$	12.6 (0.8) $n = 11$	12.3 (0.4) $n = 4$
	>50	−5.3 (1.1) $n = 13$	−11.7 (1.5) $n = 12$	−12.7 (1.5) $n = 3$	13.0 (0.9) $n = 11$	13.1 (0.9) $n = 4$
Tooth types	M1	−5.1 (1.4) $n = 13$	−11.5 (1.7) $n = 13$		12.7 (1.2) $n = 13$	
	M2	−4.2 (1.8) $n = 13$	−11.4 (1.0) $n = 13$		12.6 (0.8) $n = 13$	
	M3	−3.6 (1.2) $n = 14$	−10.7 (1.3) $n = 13$		12.5 (0.6) $n = 13$	
	PM	−3.6 (1.7) $n = 3$	−12.6 (1.5) $n = 3$		13.3 (0.2) $n = 3$	
	C	−3.9 $n = 1$				
Total		−4.2 (1.6) $n = 44$	−11.3 (1.4) $n = 42$	−12.2 (1.3) $n = 11$	12.6 (0.9) $n = 42$	12.3 (0.7) $n = 11$

All values are in per mil (‰) relative to PDB and AIR nitrogen.

Table 5
Comparison of the C_4 carbon components (attributed to dietary maize) in enamel apatite and dentin collagen of different age groups at Moatfield

Age group	Enamel	Dentin
<20 years	60% maize	59% maize
20–29 years	70%	66%
30–50 years	64%	59%
>50 years	54%	59%

Carbon isotope data and the adoption of agriculture by Ontario Iroquoians

While relatively few sites have been documented that date to between A.D. 500 and A.D. 900, most Ontario archaeologists believe that this was the period during which regional Middle Woodland populations were introduced to new cultigen-based subsistence technologies (Crawford and Smith, 1996). This introduction, however, did not immediately effect a fully developed Iroquoian cultural pattern as suggested by Snow (1995). That does not appear to have occurred until the turn of the 14th century (Kapches, 1995; Williamson, 1990; Williamson and Robertson, 1994). From what is known in the record, there was relatively little change in the settlement subsistence strategies of populations from the first appearance of horticultural base settlements in the late 10th century until the late thirteenth and early fourteenth centuries (during which Moatfield was occupied), when it appears that there was sudden and radical change among Iroquoian societies.

The transformations in settlement patterns at this time are represented foremost by the coalescence of neighbouring communities into larger villages, which appears to have effected dramatic alterations at the household, community, and regional levels. Prior to this time in the archaeological record of Iroquoia, the self-governing multi-lineage village represents the maximal political unit (Williamson and Robertson, 1994; Niemczycki, 1984; Timmins, 1997). Many such units formed a pattern of discrete regional clusters across the northeastern landscape, defined by factors of distance or physiography. Timmins (1997) has argued that there

Table 6
Values of δ^{13}C and δ^{15}N for bone collagen from fish remains, excavated at Moatfield and other Iroquoian sites in southern Ontario; summarized by the total sample and subsets; mean, standard deviation, and sample size provided

Site	Taxon	Common name	*N*	δ^{13}C (SD)	δ^{15}N (SD)
Moatfield	*Amia calva*	Bowfin	2	−23.6 (0.2)	7.8 (0.2)
	Salmo salar	Atlantic salmon	3	−19.5 (0.5)	10.5 (0.2)
	Salvelinus namaycush	Lake trout	3	−20.2 (0.5)	11.0 (1.0)
	Coregonus clupeaformis	Lake whitefish	4	−21.2 (0.3)	8.3 (0.5)
	Catostomus commersoni	White sucker	4	−18.9 (2.1)	5.1 (0.3)
	Ameiurus nebulosus	Brown bullhead	6	−20.2 (1.7)	6.5 (0.7)
	Esox lucius	Northern pike	4	−19.0 (1.1)	9.1 (0.3)
	Anguilla rostrata	American eel	3	−17.0 (0.1)	10.1 (0.6)
	Perca flavescens	Yellow perch	5	−19.6 (2.3)	9.0 (0.3)
	Stizosteidon sp.	Walleye or sauger	1	−17.4	11.7
	Micropterus dolomeiu	Smallmouth bass	2	−17.4 (0.2)	9.0 (0.1)
	Lepomis gibbosus	Pumpkinseed	4	−19.2 (2.8)	6.3 (1.2)
	Amblopites rupestris	Rock bass	4	−21.5 (0.5)	8.4 (0.3)
	Pomoxis cf. *nigromaculatus*	Crappy (probably black)	2	−20.8 (0.7)	8.0 (0.04)
Parsons	*Catsostomus catostomus*	Longnose sucker	1	−17.5	5.8
	Ictalurus punctatus	Channel catfish	2	−17.4 (0.1)	8.6 (0.5)
	Esox americanus	Grass pickerel	2	−23.4 (0.3)	7.7 (0.1)
	Lota lota	Burbot	1	−21.0	12.0
	Amblopites rupestris	Rock bass	1	−24.9	8.0
	Aplodinotus grunniens	Freshwater drum	1	−11.5	6.1
Grandview	*Salmo salar*	Atlantic salmon	4	−19.3 (0.2)	10.1 (0.4)
	Salvelinus namaycush	Lake trout	1	−21.0	11.8
	Coregonus clupeaformis	Lake whitefish	1	−20.7	8.8
	Anguilla rostrata	American eel	1	−16.2 (2.0)	8.1 (0.6)

All values are in per mil (‰) relative to PDB and AIR nitrogen. Taxonomic terminology follows Mandrak and Crossman (1992). Salmonid species listed below include Atlantic salmon, lake trout, and lake whitefish.

Table 7
Isotopic values for human bone collagen from Ontario archaeological sites, in context of their temporal association

Site/component	Approx. date	*N*	δ^{13}C (SD)	δ^{15}N (SD)
Morrison's Is.	2300 ± 400 B.C.	3	−20.8 (1.4)	12.3 (0.4)
Donaldson site/Cemetery 1	530 B.C. 555 ± 25 B.C.	1	−19.2 (0.3)	13.7 (0.2)
Donaldson site/Cemetery 2	A.D. 5 ± 75	3	−19.0 (0.9)	12.6 (1.1)
Levesconte mound	A.D. 174 ± 55	4	−21.9 (0.4)	13.4 (0.2)
Serpent mounds/Mound E	A.D. 205 ± 90	3	−21.1 (0.7)	12.7 (0.6)
Serpent mounds/Mounds G and I	A.D. 400 ± 100	4	−21.1 (0.4)	12.5 (1.1)
Serpent mounds/Pit 2	A.D. 1170 ± 120	3	−15.3 (0.8)	12.3 (0.8)
Serpent mounds/Pit 3	A.D. 1290	2	−15.8 (2.9)	12.5 (0.0)
Force site	A.D. 1240 ± ?	2	−12.6 (0.7)	11.8 (0.1)
Moatfield ossuary	A.D. 1300	11	−12.2 (1.3)	12.4 (0.7)
Fairty ossuary	A.D. 1350 ± 50	4	−11.3 (1.1)	11.8 (0.4)
Ball site	A.D. 1600	5	−12.6 (0.9)	11.8 (0.7)
Kleinberg ossuary	A.D. 1600	4	−12.2 (0.4)	12.2 (0.1)
Ossossane ossuary	A.D. 1636	4	−12.2 (1.0)	13.2 (0.6)
Cooper ossuary	A.D. 1645	3	−13.6 (1.4)	11.2 (0.6)

See also Fig. 1. All values are in per mil (‰) relative to PDB and AIR nitrogen. Source for all values except Moatfield is Schwarcz et al. (1985). Moatfield is represented by 11 specimens of alveolar bone.

simply does not appear to have been a social network integrated by cross-cutting pan-residential institutions until even the 15th century or later. The mid-to-late 15th century sites of Parsons (Williamson and Robertson, 1998) and Draper (Finlayson, 1985) and similar communities in the London and Trent Valley areas suggest that these sites were formed by amalgamations of one or more already large settlements, were heavily defended,

Table 8
Preliminary results obtained by feeding pigs on a diet of 74% maize, 23% fish meal, 2% soybean oil, plus vitamins and minerals (Howland et al., 2003; Young, 2002)

	%C	%N	δ^{13}C‰	δ^{15}N‰
Diet				
Bulk diet			−15.5	9.8
Maize	39.3	1.3	−12.2	3.0[a]
Fish meal	41.5	9.9	−18.7	12.7[a]
Soybean oil	78.3	0.1	−33.5	—
Pig tissues				
Bone collagen			−11.5	13.4
Meat			−13.8	12.8
Bone apatite			−4.3	—
Isotopic spacings				
Collagen-diet			4.0	3.6
Meat-diet			1.7	3.0
Apatite-diet			11.2	—
Apatite-collagen			7.2	—

All values are in per mil (‰) relative to PDB and AIR nitrogen.

[a] A δ^{15}N value of 3‰ was assumed for maize and the δ^{15}N value for fish meal was calculated from the other measured data.

and were feuding with neighbouring communities of a similar size and nature. Fully formed tribal social systems that were involved in large-scale politics, warfare, and exchange are not evident in the archaeological record of southern Ontario until the 15th century. That is not to say, however, that the consolidation of autonomous Early Iroquoian communities during the late 13th and early 14th centuries did not represent significant socio-political events.

There is clear evidence of change in economic strategies during the late 13th century, although the degree and nature of such change varied with individual communities. The hamlets and camps of the previous period were used to exploit naturally occurring resources and were frequently occupied throughout the year, perhaps by nuclear rather than extended families (Williamson, 1986, 1990). These were replaced by agricultural cabin sites, which were situated within the vast agricultural fields that surrounded the major villages (Lennox, 1995; Pearce, 1983; Williamson, 1983). While slight increases in house lengths and community size in the preceding centuries may have resulted from internal population growth, these changes in subsistence patterns probably related to the need to produce more maize for more people in one place.

The carbon isotope data from Moatfield suggest that this need, in some communities, may have evolved within one generation. While maize appears to have already played a central role in the diet of the Moatfield inhabitants and their ancestors, the isotope data suggest a considerable intensification of horticultural practice over a 25–50 year period. These are new and significant data to contribute to the discussion of shifting economic strategies at the turn of the 14th century.

Nitrogen isotope data and changes in Iroquoian diet on the north shore of Lake Ontario

Early and Middle Iroquoian settlements were situated frequently along the Iroquois Sand Plain (Fig. 1), often associated with prominent estuaries and significant wetlands. Such coastal wetlands were of manifest importance: they supported habitats and spawning grounds for fish; migratory staging, breeding and overwintering areas for waterfowl and other birds; habitats for numerous mammals, reptiles, amphibians and plants; and played a general role as transition zones and regulators of nutrient transport from the land to lake waters (MacDonald, 2003).

Although they were evolving horticulturalists, these communities followed many of the subsistence strategies of their Middle Woodland predecessors, including certain hunting, fishing, and gathering activities. Three distinct fisheries are often noted on sites of the Middle Iroquoian period (e.g., Thomas, 1996a, 1999). One group consisted of brown bullhead, lepomid sunfish (primarily pumpkinseed), yellow perch, sucker spp. (primarily white sucker), bowfin, smallmouth bass, and rock bass. It was likely the object of a warm season, opportunistic fishery that focused on the low-gradient, lower reaches and estuaries of the streams and shallow inlets along the north Lake Ontario shoreline. The second fishery involved the exploitation of species such as pickerel (walleye) and sucker that spawn in the spring up the rivers and streams along the shoreline. The third involves a fall fishery focused on lacustrine salmonids—including lake whitefish, lake trout, and lake herring, all of which spawn on inshore shoals, and, to a lesser extent, a riverine fishery focused on Atlantic salmon, which ascend rivers to spawn, and American eel, which descend rivers on their way to spawn in the Atlantic ocean.

It is likely that these fisheries, especially the latter, gave rise to the relatively high δ^{15}N values reflected in the Middle Woodland (Donaldson and Serpent Mounds) and the later Middle Iroquoian Moatfield populations.

In the mid-to-late 14th century, Iroquoians moved north off the Iroquois plain to colonize the South Slope Till Plain; the Moatfield community appears to have already moved in that direction by the early 14th century. They were probably in search of more fertile soils for maize horticulture, as well as habitat capable of supporting large numbers of white-tailed deer, necessary to clothe ever-increasing populations. Their sites appear to have been situated so as to take advantage of nested, linear series of microenvironments, centred on the riparian wetlands of the various river valleys. Nevertheless, the fall lacustrine-based fishery appears to be absent from many of these sites (e.g., Thomas, 1998), perhaps as a result of a scheduling conflict with the fall deer hunt (MacDonald, 2003; Thomas, 1996b). With the intensification of agricultural production, other hunting and fishing activities became largely opportunistic. While sites such as Force and Cooper belong to entirely different cultural traditions in entirely different environments, this general pattern is perhaps responsible for the somewhat reduced δ^{15}N values at the late 16th century Kleinberg site, which is situated on the northern reaches of the Humber River on the South Slope Till Plain.

On the other hand, by the late 15th century, most of these populations had abandoned the South Slopes region for the perimeter of the Simcoe Lowlands, perhaps attracted to the very rich Minesing Swamp and Holland Marsh (MacDonald, 2003). The very high ^{15}N content in the 17th century Ossosane population is entirely consistent with what is known of historic Huron subsistence practice. In the almost total absence of deer from the Simcoe County environment (Robertson et al., 1995), the Huron engaged in seasonal, co-operative long-distance deer hunts along the north shore of Lake Ontario, and also relied on traded moose and bear skins for clothing (Trigger, 1976, pp. 41–43, 63, 317), while small mammal hunting was opportunistic. Fishing had resumed its central importance in the economic strategies of all Huron tribal systems, as it had been for many north shore communities 300 years previously. The lower δ^{15}N content of the late 16th century Huron population at the Ball Site, on the other hand, may reflect that community's recent arrival in Huronia from the South Slopes region.

Conclusion

While this paper has demonstrated methodological advances in the extraction of stable carbon and nitrogen isotope ratios from human tooth enamel and dentin collagen, it is clear that the implications of the trends generated by the data need much further testing. Further isotopic data for cholesterol are being prepared for publication and further analyses (dentin apatite and amino acids) may be done as sample materials allow. This study, nevertheless, provides for the first time reliable data regarding the nature and extent of agricultural intensification around the turn of the 14th century and some understanding of the shifting economic trends that are apparent in the distribution of Iroquoian sites in the north shore region.

Perhaps even more significantly, this study represents a tentative step toward co-operative research ventures between researchers and First Nations interested in their distant past.

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