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Reassessing the northern limit of maize consumption in North America: stable isotope, plant microfossil, and trace element content of carbonized food residue

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ABSTRACT

In combination, the analysis of carbonized food residue for stable C and N isotopes, elemental composition, and plant microfossils (phytoliths and starch granules) offers a powerful tool for understanding patterns of prehistoric maize (*Zea mays*) consumption in small-scale societies. Using this approach, we conclude that maize was more widely consumed in North America than previously suspected. Between ~AD 700 and 1600, despite little or no archaeological evidence of gardening, corn was a widespread component of diet on the eastern Canadian prairies. This pattern, furthermore, extended into the adjacent boreal forest at about the same time. However, carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) values on food residue samples vary widely, suggesting significant overall dietary differences from one region to the next. Analysis of a subset of residue samples for elemental composition (using ICP-OES [inductively coupled plasma–optical emission spectrometry]) may help identify broad trends in the provenience of foods consumed at these sites.

1. Introduction

The spread of maize (*Zea mays*) horticulture represents a pivotal event in the economic history of the Americas. Although the role of this species in large village economies in North America has generally been established (Ahler et al., 1991; Anfinson, 1997; Cordell, 1997; Lehmer, 1971; Pauketat, 2004), more subtle uses of this plant—of the sort that would occur in small-scale societies where maize was acquired through trade or non-intensive horticulture—are seldom apparent using conventional archaeological methods. Yet, in these subtleties lie clues for understanding the food-producing transition and patterns of food exchange between hunter-gatherer and village societies, among other important issues.

In this paper, we examine maize consumption in small-scale societies living at the northern edge of the Great Plains (specifically, the eastern Canadian prairies) and adjacent boreal forest/Canadian Shield. This region—which lies at the northern limit of maize cultivation today—contains a rich and varied record of Late Woodland occupations, some of which show cultural connections to large, semi-sedentary, horticultural settlements in the Dakotas and Minnesota (Boyd et al., 2006; Nicholson, 1990). However, unlike these large horticultural villages further south, the role of domesticated plants in the diet of prehistoric societies on the Canadian prairies has remained hidden because habitation sites are usually small and ephemeral, archaeological evidence of gardening (such as storage pits and scapula hoes) is rare, and maize macroremains are usually nonexistent. Based on the analysis of carbonized food residue for starch and phytolith content, however, a recent study by Boyd et al. (2006) showed for the first time that maize consumption was widespread in this region well before European contact. In order to obtain a more nuanced understanding of domesticated plant use, we supplement these findings with new multiproxy (stable C and N isotope, trace element, plant microfossil [phytolith and starch]) analyses of food residue samples from a large collection of archaeological sites distributed across the northern prairie-forest border. Among other observations, the present study provides the first evidence of prehistoric maize consumption north of the Great Plains (in the boreal forest/Canadian Shield).

Carbonized food residue is an important archive of information on paleodiet, and provides an ideal opportunity to study subtle, and short-term, subsistence choices. Preserved on the interior portion of ceramic vessels, this inert carbonaceous material represents the

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remains (including lipids, proteins, carbohydrates) of foods actually consumed when the pot was in use; it may potentially be analyzed for a variety of botanical and chemical proxies, directly dated, and linked to specific cultural groups based on stylistic characteristics of the associated ceramic sherd. In other parts of the Americas, maize phytoliths and starch granules have been successfully extracted from food residue and soils, enabling key insight into the history of early agricultural economies (Hart et al., 2003; Pearsall, 2002; Pearsall et al., 2003; Pearsall et al., 2004b; Piperno, 2003; Staller and Thompson, 2002). In contrast, few previous studies have examined stable C and N isotope, and trace element, content of carbonized food residue (Barnard et al., 2007; Craig et al., 2007; Fie et al., 1990; Hart et al., 2007; Morton and Schwarcz, 2004; Sherriff et al., 1995), and no study has combined all of these analyses. We believe, however, that in combination these complementary proxies offer a powerful tool for understanding the relative importance, and possible provenience, of cultigens in small-scale prehistoric societies.

2. Study area

Our sample material was obtained from archaeological sites scattered across the southern portion of Manitoba. Particular emphasis in this study is placed on two locales—the Tiger Hills (TH) and Oak Lake Sandhills (OLS)—where sites with clear cultural affinities to farming populations in the Dakotas and Minnesota (e.g., Nicholson, 1990), and evidence of maize consumption (Boyd et al., 2006), were previously discovered. The modern physical environment, and geological history, of these two prairie locales are described in detail in another publication (Boyd et al., 2006). For purposes of comparison, we also include a suite of contemporaneous sites from the southern boreal forest/Canadian Shield (Winnipeg River) and Lockport region of the northern Red River Valley (Fig. 1). Lockport is significant because earlier excavations (Buchner, 1986, 1988; Deck and Shay, 1992; Roberts, 1991) at one site in this locale revealed evidence of prehistoric maize cultivation and storage.

Modern climate is variable across the study area (Environment Canada, 1993), although some geographical trends are apparent. In general, as might be expected, yearly precipitation values increase (from c. 478 to 565 mm) moving eastwards from the historic prairies (OLS, TH, and Lockport [L] locales) into the boreal forest (Winnipeg River [WR] locale); the maximum July temperature decreases slightly (from c. 26 to 25 °C) over this same distance. Soils also change noticeably across this area, with productive chernozemic types being common in the southwestern corner of the province and thinner, less productive, podzolic soils dominating the boreal forest/Canadian Shield. Vegetation in the prairie portion of the study area was historically dominated by tall grass, mixed-grass, and aspen parkland elements, while the Winnipeg River locale is well within the southern limit of coniferous (boreal) forest (Boyd, 2000).

3. Archaeological background

The archaeological materials (ceramic sherds) analyzed in this study are associated with a broad cross-section of prehistoric cultures that occupied the northern edge of the Great Plains and adjacent boreal forest after ~AD 700. Given the nature of these materials and the vagaries of preservation, not all sherds could be identified to the same taxonomic level. For example, several specimens could only be identified as “Late Woodland” based on the presence of generic stylistic/formal traits characteristic of this tradition, while some others (usually body sherds) could not be identified at all. The remaining sherds, those that possessed traits characteristic of a specific complex, are attributed to a wide variety of archaeological manifestations: Northeastern Plains Village Complex, Vickers Focus, Blackduck Complex, Sandy Lake Complex, and several sub-groups of the Rainy River Composite (Bird Lake, and Winnipeg River Complexes). These are briefly reviewed below.

The Northeastern Plains Village (NEPV) Complex (Toom, 2004), represented in this study by the Duthie site, is associated with a diverse ceramic assemblage (Taylor, 1994). The Duthie site is significant because it is both rather early (ca. AD 1010–1270) and is the only recorded NEPV site in Canada. Furthermore, as reported in a previous study (Boyd et al., 2006), this site yielded the earliest evidence of prehistoric maize on the Canadian prairies. Non-local lithic sources such as Knife River Flint and catlinite dominate, and the ceramic assemblage includes vessels similar to Sandy Lake, Red River, and Lisbon Wares (Taylor, 1994). The large loop-handled vessel examined in this study are similar to NEPV vessels described by Toom (2004) from North Dakota, and no other vessels of this type have been found on the Canadian prairies. In Minnesota and North Dakota, sites containing ceramics similar to those found at the Duthie site have yielded evidence of gardening (Ahler et al., 1991; Anfinson, 1997). However, no artifacts associated with gardening have been recovered from Duthie, the site is relatively small, and storage pits are likewise absent. As with Vickers Focus components (see below), the faunal assemblage at this site is dominated by bison, and consumption of cultivated plants cannot be inferred from artifactual evidence alone.

The Vickers Focus (AD 1350–1650) is restricted to southwestern Manitoba, and is characterized by a diverse ceramic assemblage, and abundance of Knife River Flint (sourced to west-central North Dakota) debitage and finished tools. With a few important exceptions (Nicholson, 1990), habitation sites also tend to be small. Predominance of bison bone in all excavated Vickers sites attests to the economic importance of this species at the time of occupation. Artifactual evidence of local gardening is rare to absent, although recoveries from Vickers focus sites in the TH include some grinding stones and a possible bison scapula hoe (Nicholson, 1990). Nicholson (1990) has argued for the practice of small-scale horticulture as support for a foraging subsistence strategy in the TH. In contrast, Vickers sites in the OLS—where no gardening implements have been found—are interpreted as short-term, seasonal, occupations by hunter-gatherers (Hamilton and Nicholson, 1999).

The Blackduck (~AD 700–1200) and Sandy Lake (~AD 1000–protohistoric) Complexes are Late Woodland phenomena defined primarily by their distinctive ceramic wares. Although most sites are found in the mixed forest zone of northern Minnesota and Ontario, and subsistence is thought to emphasize broad-spectrum foraging and the wild rice harvest (Anfinson, 1979), Blackduck and Sandy Lake components have also been identified on the prairies (Lenius and Olinyk, 1990). These prairie sites may represent seasonal, or permanent, shifts in economic orientation towards the exploitation of bison (Hamilton, 1982; Meyer and Hamilton, 1994). In at least one case (Michlovic and Schneider, 1993), the makers of Sandy Lake ceramics adopted a full-fledged Plains Village lifeway, including habitation in a large fortified village and adoption of a mixed horticulture-hunting economy. In general, however, virtually all Sandy Lake and Blackduck habitation sites in both the prairie and mixed forest regions tend to be small and ephemeral, with no archaeological evidence of horticulture or domesticates.

The Rainy River Composite (~AD 1100–1350) consists of a group of temporally and regionally defined complexes that share common ceramic traits, as well as perhaps a shared economy, social structure, and ideology (Lenius and Olinyk, 1990). Samples belonging to two of these complexes (Bird Lake and Winnipeg River) are included in this study. In general, Rainy River ceramics possess traits from both Blackduck and Laurel wares, leading to the suggestion (Lenius and Olinyk, 1990: 82–83) that it was formed from a “coalescence” of these two earlier cultures. Rainy River

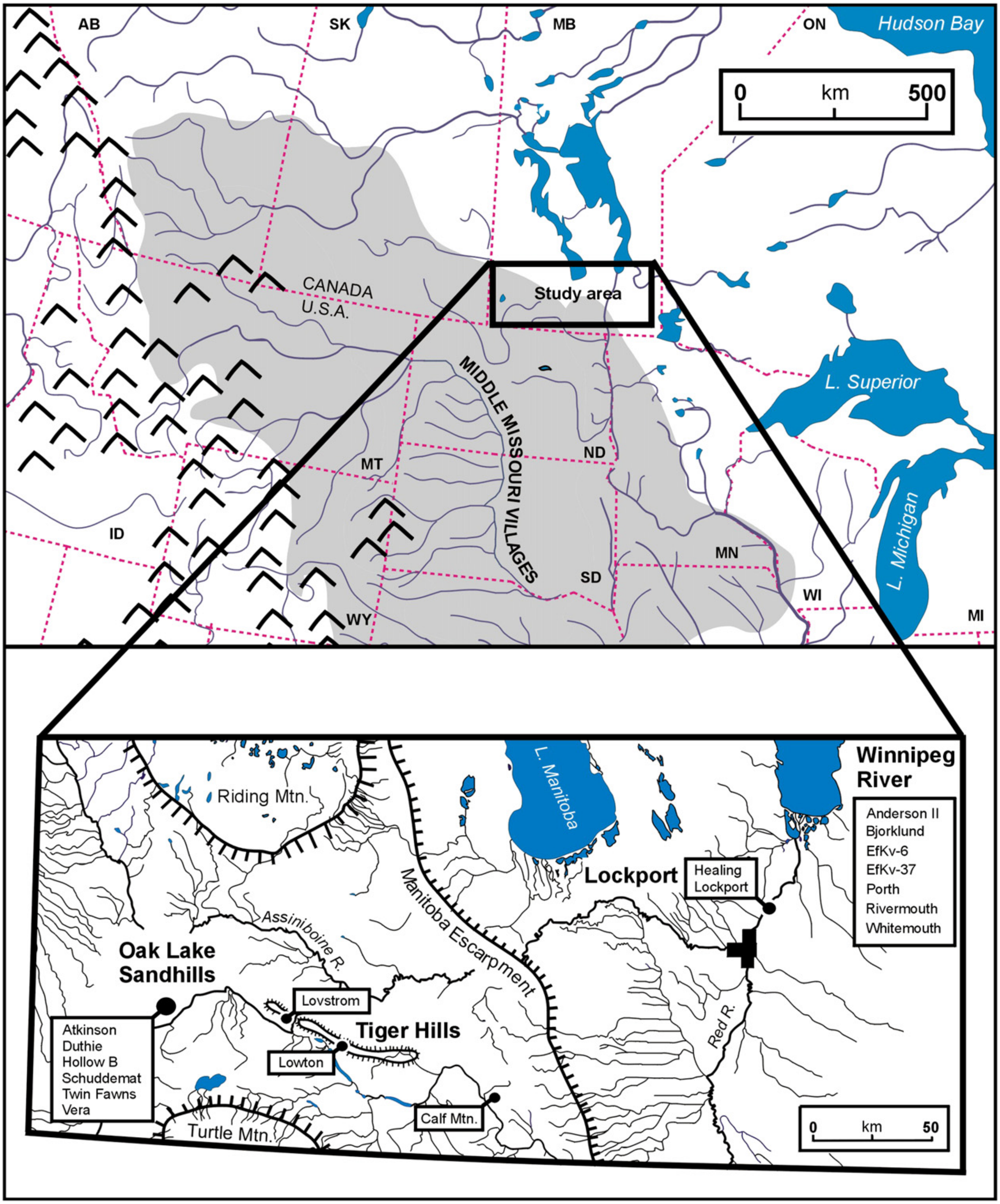

Fig. 1. Location of study locales/sites, and Middle Missouri region within the Great Plains (shaded in gray).

Composite ceramics are distributed from the Mississippi headwaters in central Minnesota to Lake Superior and west of the Rainy River through the Parklands to central Manitoba (Lenius and Olinyk, 1990). In this study, Bird Lake and Winnipeg River vessels are restricted to the Lockport and Winnipeg River locales (these types have not been identified elsewhere in the study area). Few specific details are known about the subsistence base of these cultures; however, no evidence of domesticated plant use has previously been associated with Rainy River Composite sites in any part of its range.

4. Methods

Carbonized food residue was removed from the interior portion of each sherd and subsequently sub-sampled for all three proxies (plant microfossils, stable isotopes, and trace elements). This procedure was done using a clean dental probe and knife under a dissecting microscope. All sherds were washed in water following excavation (in the course of cataloguing), were quite clean upon inspection under a microscope, and so further washing was deemed unnecessary. Special care was taken to ensure that no adhering soil particles were included in the material analyzed, and each residue sample (following removal from the sherd) was examined for possible contaminants before processing. Minimum acceptable sample weights are different for different proxies and not all ceramic sherds provided enough material to perform multiple analyses on each. In these cases, microfossil analysis was usually prioritized unless the sample size was too small to perform this work; we also made sure to leave a sub-sample of residue unanalyzed and unprocessed for future research. These remaining residue samples are stored in the Environmental Archaeology and Paleoecology Laboratory at Lakehead University.

4.1. Phytoliths and starch granules

Because maize produces a variety of phytoliths which are seen in other plant taxa, we take a cautious approach and restrict the positive identification of maize to only those samples that contain ‘wavy-top’ rondels with entire bases (Bozarth, 1993; Pearsall et al., 2003, 2004a; Piperno and Pearsall, 1993). This form, which appears to be restricted to *Zea mays*, is produced in the cob portion of the plant and has been successfully used to identify maize in archaeological sites from South America to the Great Plains and Eastern Woodlands (Bozarth, 1993; Hart et al., 2003; Iriarte et al., 2004; Pearsall et al., 2003, 2004a,b; Staller and Thompson, 2002). Other grass phytoliths were identified following Brown (1984) and Twiss et al. (1969).

Starch granules may also be recovered from food residues and soil samples, providing additional insight into the plant component of paleodiet (e.g., Haslam, 2004; Pearsall et al., 2004b; Perry, 2004; Zarrillo and Kooyman, 2006). As with phytoliths, identification of starch is based on size and morphological characteristics (in particular: grain shape and thickness, position and shape of hilum, polarization cross type, and presence and appearance of lamellae). Although variable, starch from *Zea mays* tends to be larger (4–24 μm) than granules from wild grasses, has a rounded to polygonal shape, a prominent, linear, X- or Y-shaped fissure in the centre of the granule, and a 90° extinction cross when viewed under cross-polarized light (XPL) (Babot and Apella, 2003; Pearsall et al., 2004b). However, because very few wild prairie species have been analyzed for their starch content, we suggest that starch granules by themselves do not constitute strong proof of prehistoric maize in northern Plains archaeological sites. The need for multiple lines of evidence in reconstructing crop histories has been noted by others and should be considered standard procedure in archaeobotany (Hart et al., 2007; Smalley and Blake, 2003). In this study, we consider maize to be positively identified in a given sample only when phytoliths diagnostic of this plant (with or without maize-type starch) are recovered. This cautious approach is warranted given the poor understanding of the diversity of starch assemblages produced by native plants in this region.

Approximately 5–40 mg of carbonized food residue was processed for plant microfossils from each sherd. These samples were digested in heated 50% HNO_3 for 12–24 h, and the acid was subsequently removed by repeated dilution with water followed by centrifugation for 15 min at 3000 rpm (Boyd et al., 2006; Hart et al., 2003; Staller and Thompson, 2002). The remaining residue was mounted and examined using a compound light microscope (with differential interference contrast), petrographic microscope, and scanning electron microscope (SEM). Minimum phytolith and starch counts were generally 250–300 specimens each (for a minimum total of 500–600 plant microfossils per residue sample). Only starch granules identified to genus or species are presented, and discussed, in this paper. Although acid treatment may have caused some loss of starch during processing, our average starch count was high (315 grains per sample). Furthermore, starch preservation in processed samples was generally good (i.e., usually presenting features required for identification such as the hilum or lamellae). For these reasons, it is unlikely that the treatment method significantly affected our results. Other possible sources of starch attrition include physical damage due to prehistoric flour milling, cooking method and temperature, and postdepositional processes.

4.2. Stable C and N isotopes

Stable carbon and nitrogen isotope analyses of food resources are well established in archaeology for paleodietary reconstruction (Ambrose, 1993). Native vegetation in the three prairie locales is predominately composed of C3 species with variable amounts of C4 plants (Boyd, 2000; Terri and Stowe, 1976; Tieszen, 1994). In general, the proportion of C4 grass decreases with latitude over the prairie regions of North America with some local and regional variations (Clark et al., 2001; Terri and Stowe, 1976; Tieszen, 1994). That sufficient C4 forage existed at least in the more southern part of the study area to produce less depleted $\delta^{13}C$ values than would be expected of C3 grazers or browser is demonstrated by two studies that included bison bone from prehistoric archaeological sites. Ens (1998) reports $\delta^{13}C$ values of -16.3 and $-17.7‰$ and Garvie (1993) reports $\delta^{13}C$ values that range from -15.8 to $-18.7‰$ for a sample of seven bison (mean $= 17.3‰$, standard deviation $= 0.9$). These two studies also present data for animals consuming C3 vegetation including moose and beaver which have bone values in the range of -19.9 to $-20.7‰$. The flesh values for meat is usually estimated to be 1.5‰ lighter (Tieszen et al., 1983; Tieszen and Fagre, 1993) than the bone, but we are unable to determine if bison flesh was cooked in a given pot or if, instead, bison bone was boiled for grease extraction in that same vessel (e.g., Quigg, 1997). In any case, based on Ens (1998) and Garvie (1993), we expect that residues containing substantial amounts of bison that had consumed C4 forage over much of their adult life would have less depleted $\delta^{13}C$ values. The primary objective of this study was to explore maize consumption on the northeastern plains and adjacent boreal forest; however, there are inherent limitations with stable isotopes that preclude an easy interpretation of our $\delta^{13}C$ and $\delta^{15}N$ data. In general, C and N stable isotope values provide only a broad picture of past diet rather than identifying specific foodstuffs. Dietary regimes that included different sources with similar isotopic values cannot be differentiated. This is precisely the issue that has frustrated attempts to use $\delta^{13}C$ values of bone collagen to reconstruct the past diet where both animals consuming C4 vegetation and maize are consumed, because the former isotopically masks the latter (Katzenberg, 1989; Tuross and Fogel, 1994). As such, the adoption of maize consumption by bison hunters is impossible to detect in isotopic studies of archaeological bone. The issue is similar for ceramic residues, and thus, the less negative $\delta^{13}C$ values of residues from the OLS and TH cannot easily be attributed to either consumption of bison (grazing on a mix of C4 and C3 forage), maize or both. Hart et al. (2007) have recently cautioned against any estimations of the relative of amount of maize in ceramic residues from $\delta^{13}C$ values based on their experimental work. Their results strongly suggest that isotopic values on food residue may not always reflect the original proportions of C3 and C4 items cooked in the vessel (see discussion in Hart et al., 2007). Due to the constraints discussed above, the application of stable carbon isotopes to the identification of the presence of maize or any attempt to quantify proportions of C3 and C4 food stuffs in ceramic residues may not be realistic.

Given that bison and maize are at different levels of the trophic scale, $\delta^{15}N$ might be expected to provide a straightforward means of identifying the relative importance of these two foods in a given sample. In general, $\delta^{15}N$ values of different animal tissues are very similar (DeNiro and Schoeninger, 1983; Hare et al., 1991) and are more heavily influenced by foods with higher proportions of protein (Phillips and Koch, 2002; Schwarcz et al., 1985). Since maize has 11% protein and meat (bison in this case) has approximately 90% protein (van Klinken et al., 2000), one might expect that in cases where both resources are being consumed, the δ^{15}N value from bison would be more strongly expressed in the δ^{15}N values of ceramic residues (Craig et al., 2007), effectively masking the nitrogen isotope signature of maize. Furthermore, bison bone and maize have been reported to have overlapping δ^{15}N values (DeNiro and Hastorf, 1985; Ens, 1998; Habicht-Mauche et al., 1994; Morton and Schwarcz, 2004; Schoeninger et al., 1984; Varney et al., 2001). Due to this overlap in the δ^{15}N values of bison and maize, and the expected underrepresentation of maize due to its lower protein content, variability in δ^{15}N is unlikely to provide much help in understanding the relative importance of maize in prehistoric bison-hunting cultures.

Despite the limitations of both carbon and nitrogen isotopic analysis in identifying the presence or relative importance of maize when applied to ceramic residues, it is still an analytical tool with good potential for assessing other dietary information. Stable carbon isotope values can be expected to provide a general indicator of the δ^{13}C values of predominate foodstuffs within the residues (Barnard et al., 2007; Craig et al., 2007; Hart et al., 2007). Stable nitrogen isotope values will also provide a measure of residue composition with respect to terrestrial versus aquatic protein resources (Craig et al., 2007; Morton and Schwarcz, 2004). As such, the overall variation in both stable carbon and nitrogen isotopes should provide a rough gauge of general resource use and diet breadth.

Residue sub-samples designated for isotope analysis were not pretreated because previous work has detected no diagenetic alteration in carbonized plant matter or ceramic residues (DeNiro and Hastorf, 1985; Morton and Schwarcz, 2004). In order to confirm this, two residue sub-samples were taken from 14 ceramic sherds that were randomly selected from the study collection. One sub-sample from each sherd was subject to pretreatment with a 0.1 M NaOH solution and the second sub-sample was left untreated. Isotopic analysis revealed that the δ^{13}C values of the two sets of samples were indistinguishable.

Stable isotope analysis was performed at the Isotope Science Laboratory, Department of Physics and Astronomy, University of Calgary. Approximately 0.09 mg and 0.13 mg were analyzed separately for δ^{13}C and δ^{15}N respectively using continuous flow-elemental analysis–isotope ratio mass spectrometry (CF-EA-IRMS) technology on a Finnigan Mat TracerMat mass spectrometer interfaced with a Carlo Erba NA 1500 elemental analyzer. Analytical precision of the stable isotopic analysis was $\pm 0.2‰$ for both C and N. Carbon and nitrogen ratios are expressed as δ^{13}C and δ^{15}N values as parts per thousand (per mil, ‰) relative to the PDB and atmospheric N2 international standards, respectively.

4.3. Trace element analysis

A subset of our samples (TH and OLS locales) was also analyzed for their elemental composition. Following Fie et al. (1990), this was undertaken in order to identify the possible source area of foods cooked in the ceramic vessels—in particular, we wished to identify if these foods (especially the domesticated plants) were primarily from local or non-local areas. In the case of local foods, residue samples from the same geographic region would be expected to cluster together; samples composed of foods grown elsewhere, on the other hand, should fail to cluster with other samples from the same site or locale (Fie et al., 1990). In this way, trace element data should help identify if maize or other cultivated plants consumed at a site were grown locally or acquired through trade. Although the validity of this technique still needs to be established for food residue through experimentation, trace element analysis (TEA) is an established means of determining provenience for many other types of archaeological materials. Indeed, it is well established that the trace element composition of soils reflects the elemental composition of parent material, and that this elemental signature is inherited by both plants and soil (Fie et al., 1990; Grunes and Alloway, 1985; Kubota, 1983). Furthermore, in the Fie et al. (1990) study, trace elemental analysis of carbonized food residue samples resulted in the detection of food resource areas which were supported by other lines of archaeological evidence.

Residue sub-samples and blanks were first ashed in a programmable muffle furnace for 3 h at 300 °C. Next, 5 ml of concentrated HCl (trace element grade) was added to each (covered) sample and placed on a hotplate for 15 min; 1 ml of concentrated HNO_3 (trace element grade) was then added and the samples allowed to evaporate (Allen et al., 1974; Fie et al., 1990). After cooling to room temperature, the remaining material was placed in a solution of 10% trace element grade HNO_3 for ICP-OES (inductively coupled plasma–optical emission spectrometry).

Elemental analysis was performed at the Lakehead University Instrumentation Lab using a Varian Vista Pro radial ICP-OES equipped with an inert v-groove nebulizer, Sturman–Masters spray chamber and demountable torch with alumina injector. Measurements were obtained for a suite of 28 elements, calibrated with a series of six multi-element standards, with detection limits ranging from 0.004 to 0.5 parts per million (ppm). Prior to statistical processing, elements with values below the detection limit were removed from the dataset, and the values obtained on "blanks" (i.e., empty crucibles processed in the same manner) were subtracted from the remainder.

Statistical analysis of elemental data was performed using the software package "R" (R Development Core Team, 2006). Patterns in this dataset were sought using principal components analysis (PCA) and cluster analysis (partitioning around medoids [PAM] method) (Kaufman and Rousseeuw, 1990; Pison et al., 1999). For PAM, the value of k (number of clusters) was determined by comparison of silhouette plots for $k = 2$, 3, 4, and 5 (Kaufman and Rousseeuw, 1990).

5. Results

5.1. Plant microfossils

Phytoliths and starch granules were generally abundant in the residue samples. The phytolith assemblages were dominated by various types of elongate plates, trapezoids, and rondels (Fig. 2). Trace quantities of bilobate, polylobate, and cross-shaped phytoliths (produced within the Panicoideae subfamily) were also observed, in addition to saddles (subfam. Chloridoideae) and diatom valves.

Multiproxy (phytolith/starch) evidence of maize was recovered from most (76%) of the residue samples in the three prairie locales (OLS, TH, and Lockport) (Figs. 2 and 3, Table 1). In fact, only one sherd (Healing site [AN-04-08]) produced no phytolith or starch evidence of this plant, and the remaining 20% of the prairie samples yielded only maize-type starch granules. Absolute numbers of maize phytoliths were generally low, a fact that is not surprising given the production of wavy-top (*Zea mays*) rondels in only the inedible (cob) portions of the plant. Possible evidence of bean (*Phaseolus*) was also observed in 40% of the samples from these three locales, as reported earlier (Boyd et al., 2006).

The samples from the Winnipeg River locale generally yielded fewer maize phytoliths (relative to the total assemblage) and only one sample (Bjorklund [W3830]) provided multiproxy evidence of corn. No *Phaseolus*-type starch was observed in the boreal forest (WR) sites.

5.2. Isotopes

Summary statistics for δ^{13}C and δ^{15}N values on samples from all four locales are presented in Table 2.

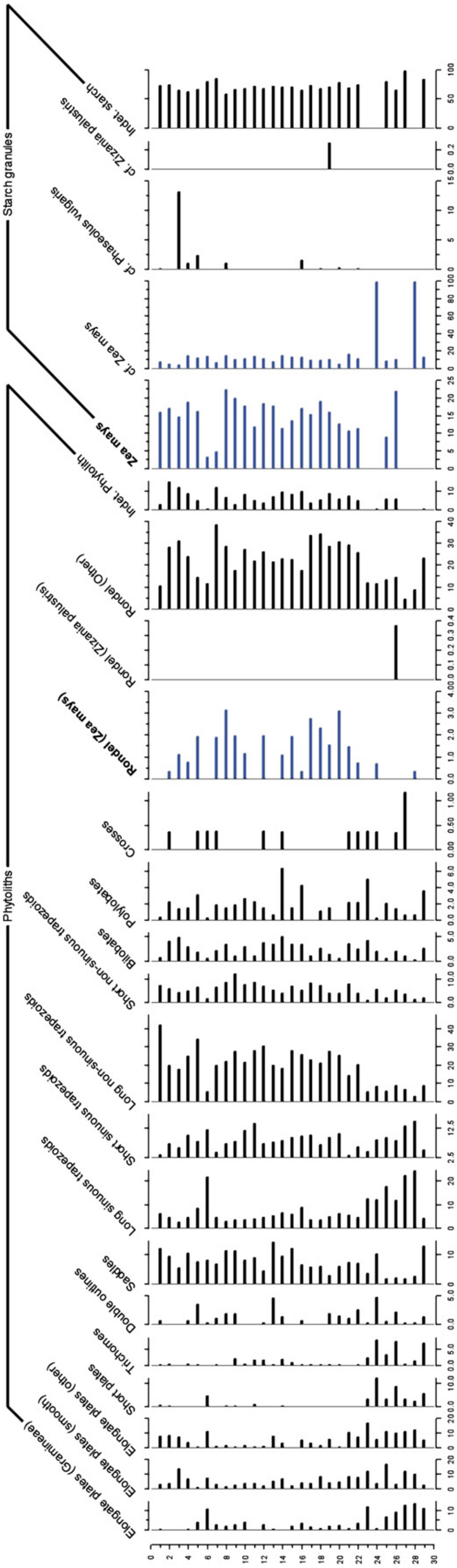

Fig. 2. Starch and phytolith data from food residue samples. Sample identification provided in Table 1 ("ID" column).

As illustrated in Fig. 4, the isotope values for sites in the OLS and TH locales generally cluster close together and away from those situated within or beside the boreal forest margin (i.e., the WR and Lockport locales). Values for sites in the latter locales tend to be very similar in terms of their distribution. Sites in the former two locales also have less negative δ^{13}C and lower δ^{15}N values.

The overall range of isotopic values for residues from the Lockport and WR locales is notably wider than the total range of isotopic values for residues from both the OLS and TH (see Tables 2 and 3, Fig. 4). The overlap in the range of isotopic values between the two sets of locales is due to the isotopic values of four samples from either the L or WR locales, particularly the δ^{15}N values. In only one of these four samples (Rivermouth site, WR locale) are both δ^{13}C and δ^{15}N values overlapping with those of the OLS and TH locales and in fact fall well within the mid-range of values for those prairie locales. Another sherd (Bjorklund) from the same locale had a δ^{13}C value that overlapped slightly (1.1‰) with the minimum end of the range of variation of the OLS locale. Two other residues, one from the WR river locale (Rivermouth site) and one from the Lockport locale (Lockport site) had δ^{15}N values that were low in comparison to the majority of residues from other sites in the WR and L locales; instead, they fell within or below the range of δ^{15}N values observed for the OLS and TH locales. One other WR sample was notable in that it did not contain enough nitrogen for a stable isotope value (Table 3), a fact confirmed by repeated analysis.

5.3. Trace element analysis

When plotted against the first two principal components of the elemental data (Table 4), no significant separation is observed between the bulk of the TH and OLS samples (Fig. 5). Cluster analysis (see ellipses in Fig. 5) supports this observation by grouping virtually all of the TH and OLS samples in one cluster. In fact, only one sample failed to cluster with the others (the Duthie loop-handled [NEPV] pot, sample #2 in Fig. 5). This sample was assigned to a separate group based on its elemental composition.

6. Interpretations and discussion

In a previous study (Boyd et al., 2006), we demonstrated that maize was consumed at multiple sites on the Canadian prairies well before European contact. However, the components selected for the Boyd et al. (2006) paper were ones that showed clear cultural connections to farming populations in the Dakotas or Minnesota, based on the presence of particular exotic lithic materials and ceramic types. In the present study, we also examine food residue from Late Woodland cultures that do not show these affiliations, and from sites located outside of the prairies (within the boreal forest/Canadian Shield). Given the cultural and environmental diversity inherent in this material, it is remarkable that botanical evidence of maize was recovered from virtually all of the residue samples. These results suggest that corn was a widespread component of diet after ~AD 700 in the study area—regardless, it seems, of either cultural identity or geographic setting. Why?

Although maize may have been consumed earlier in the study area, its widespread recovery in Late Woodland ceramic residue is significant given the apparent intensification and expansion of maize production in the Lower Great Lakes, Middle Missouri, and Oneota regions after ~AD 900. It was during this period that maize horticulture in the US Northeastern Plains reached its maximum geographic extent (Ahler et al., 1991), evidenced in part by the expansion of the Plains Village tradition into neighboring Minnesota (Anfinson, 1997) and perhaps the Canadian prairies (Forbis, 1982; Nicholson, 1990; Walde, 1994). Indeed, maize has been regarded as universally available by at least AD 900 across

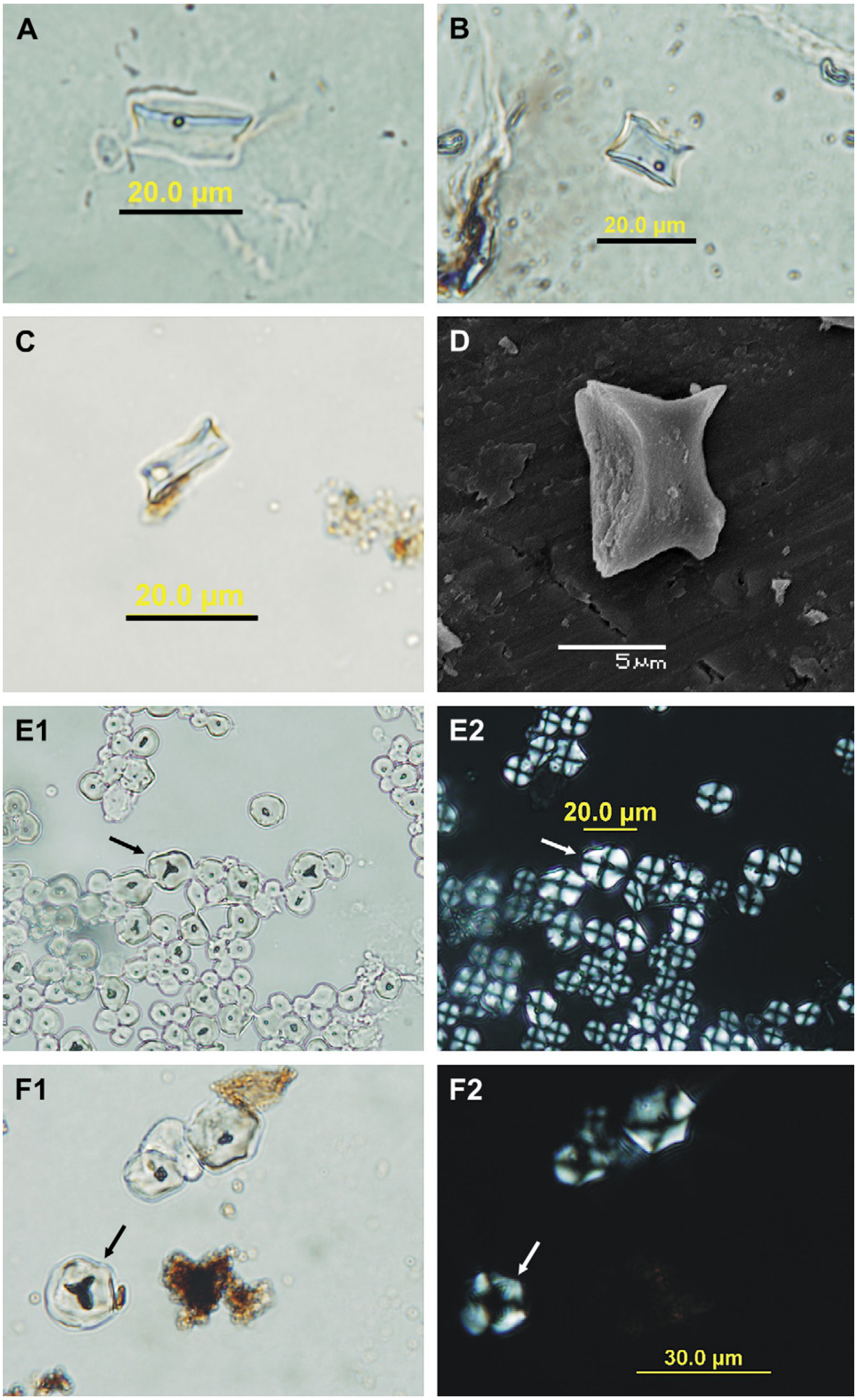

Fig. 3. Microscopic images of *Zea mays* (maize) rondel phytoliths and starch granules from comparative and archaeological samples. A + B: comparative samples (Mandan corn); C: wavy-top rondel phytolith from Twin Fawns site; D: wavy-top rondel from Lowton site (scanning electron micrograph); E1 + E2: comparative maize starch granules under plane polarized light (PPL) and cross-polarized light (XPL), respectively; F1: maize granule from Lowton site under PPL; F2: same specimen under XPL. Arrows point to same granule in paired images.

the US Midwest (Asch and Asch, 1985; Conard et al., 1984). Parallel developments are seen in several other regions of the Eastern Woodlands, where stable isotope values on human bone trace the increased dietary importance of maize around this time (e.g., Ambrose, 1987; Katzenberg et al., 1995; Schurr, 1992). The widespread evidence of maize in our study area may therefore reflect, in part, this larger economic transition occurring across eastern North America. In particular, if corn was supplied through trade, then the period after ~AD 700 may represent a threshold when the supply of this commodity was regular enough to provide a reliable dietary supplement for populations living across the prairie-boreal margin. Alternatively, if maize was grown locally then varieties capable of

Table 1
Residue samples analyzed for plant microfossils (starch and phytoliths), with isotope results

ID	Site (sherd)	Locale	Type	Maize?	d13C	d15N
1	Atkinson (AT-S04-08)	OLS	Late Woodland	S		
2	Duthie (large reconstructed rim)	OLS	Northeastern Plains Village	S/P	−23.7	7.6
3	Duthie (small reconstructed rim)	OLS	Northeastern Plains Village	S/P	−24.3	7.9
4	Duthie (17-4-154)	OLS	Indet	S/P	−23.4	7.6
5	Hollow B (1-4-16)	OLS	Late Woodland	S/P	−23.4	7.3
6	Schuddemat (12-3-60)	OLS	Late Woodland	S	−22.9	7.9
7	Schuddemat (12-4-10)	OLS	Late Woodland	S/P	−23.3	7.5
8	Schuddemat (12-4-18)	OLS	Late Woodland	S/P	−23.7	7.2
9	Schuddemat (12-4-19)	OLS	Late Woodland	S/P	−23.1	6.9
10	Twin Fawns (41-4-5)	OLS	Late Woodland	S/P		
11	Twin Fawns (43-3-92)	OLS	Late Woodland	S	−22.6	7.6
12	Twin Fawns (44-3-128)	OLS	Late Woodland	S/P	−22.7	7.9
13	Twin Fawns (45-2-8)	OLS	Late Woodland	S	−22.0	8.0
14	Vera (23-6-30)	OLS	Indet	S/P		
15	Vera (35-6-127)	OLS	Late Woodland	S/P	−21.6	7.7
16	Vera (53-6-25)	OLS	Late Woodland	S/P		
17	Lovstrom (173-3-15)	TH	Late Woodland	S/P		
18	Lovstrom (XU 114)	TH	Late Woodland	S/P		
19	Lowton (30-4-16)	TH	Late Woodland	S/P		
20	Lowton (60-1-13)	TH	Late Woodland	S/P	−23.4	6.1
21	Lowton (2153)	TH	Vickers Focus	S/P	−23.7	6.6
22	Lowton (120-874)	TH	Vickers Focus	S/P		
23	Healing Site (AN-04-8)	L	Indet		−29.6	9.6
24	Healing Site (AN-04-6)	L	Indet	S/P	−27.2	11.3
25	Lockport (W49)	L	Winnipeg River complex	S	−27.8	11.9
26	Whitemouth Falls (W-8)	WR	Late Woodland	S	−27.1	11.5
27	Bjorklund (W243)	WR	Blackduck		−27.4	Too small
28	Bjorklund (W3830)	WR	Late Woodland	S/P	−25.3	10.2
29	EfKv-6 (W210)	WR	Winnipeg River complex		−30.9	10.8

Identification of maize based on microfossil content (S = maize starch; P = maize phytolith) as shown in Fig. 2. As explained in the text, a positive identification occurs when either maize phytoliths or both maize phytoliths and starch granules are present in a given sample.

Table 2
Summary statistics (C and N isotope data)

	d13C	d15N
Oak Lake Sandhills (OLS)		
Mean	−23.1	7.7
Max	−21.6	8.1
Min	−24.5	6.9
Std dev	0.84	0.30
n = 21		
Tiger Hills (TH)		
Mean	−22.6	6.7
Max	−21	7.5
Min	−23.7	6.1
Std dev	1.22	0.58
n = 4		
Lockport (L)		
Mean	−27.2	10.3
Max	−25	11.9
Min	−29.6	7.1
Std dev	1.68	1.97
n = 3		
Winnipeg River (WR)		
Mean	−27.2	9.6
Max	−22.2	11.8
Min	−32.7	5.2
Std dev	2.63	1.90
n = 11		

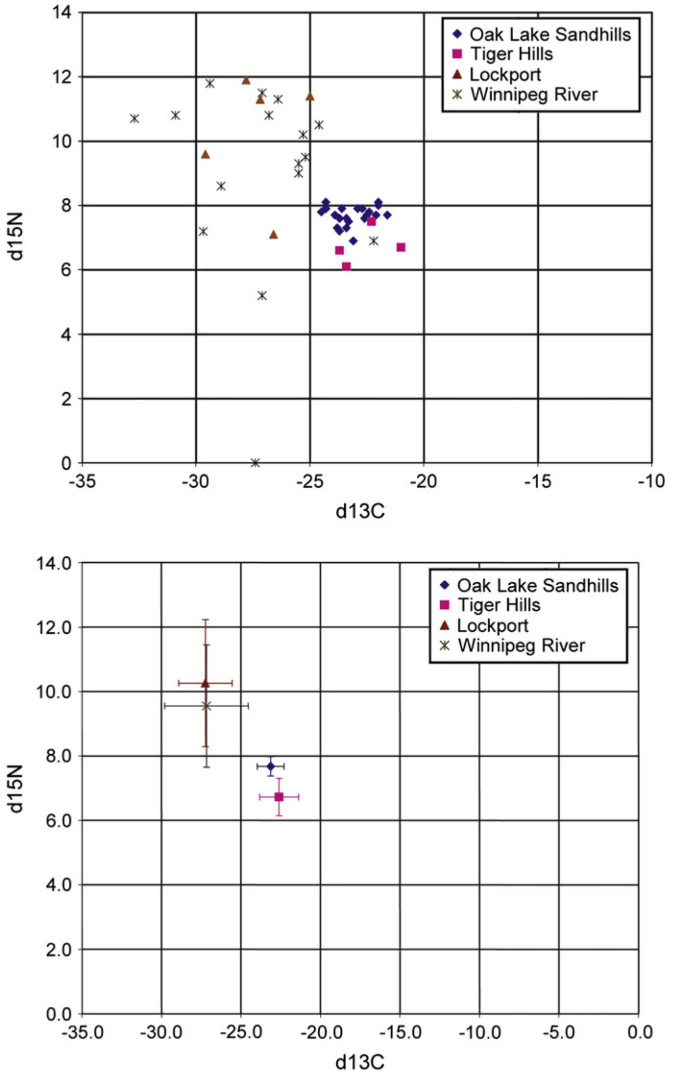

Fig. 4. δ^{15}N vs. δ^{13}C for all residue samples, identified by locale. Top graph: scatterplot; bottom graph: same data but showing only mean and standard deviation values.

reaching maturity in this northern setting may have only emerged after this time. The possibility of an earlier (Middle Woodland, <1000 AD) presence of maize in the region should not be ruled out, however.

Although maize microfossils are found in food residue throughout our study area, we observe that the strength of this evidence generally declines in the boreal forest sites (WR locale). Only one sample in this region, for example, was associated with multiproxy (starch and phytolith) evidence of corn. This may suggest that maize was a less frequent, or otherwise less important, component of paleodiet outside of the prairies during the Late Woodland period. This could occur if corn was either grown locally or acquired through trade—poorer quality soils and a shorter growing season in the boreal forest, for example, could have resulted in lower maize productivity; under a trading scenario, furthermore, the cost of obtaining maize would likely be higher, and the supply less secure, with increased distance from the source. The presence of analogous wild plant foods in the boreal forest—in particular, wild rice (*Zizania palustris*)—may have also reduced the incentive for either local maize gardening or its acquisition through trade. However, microfossil evidence of wild rice was recovered from only one of the sherds (Whitemouth Falls [WR]) included in this study.

Table 3
Stable carbon and nitrogen isotope results, carbonized food residue samples

Site (sherd)	Locale	Type	d13C	d15N
Duthie (17-3-112)	OLS	Indet	−24.3	8.1
Duthie (17-4-160)	OLS	Indet	−23.6	7.9
Duthie (17-4-155)	OLS	Indet	−23.9	7.7
Duthie (17-4-15)	OLS	Indet	−22.4	7.8
Duthie (17-4-154)	OLS	Indet	−23.4	7.6
Duthie (small reconstructed portion)	OLS	Northeastern Plains Village	−24.3	7.9
Duthie (large reconstructed portion)	OLS	Northeastern Plains Village	−24.5	7.8
Duthie (large reconstructed portion)	OLS	Northeastern Plains Village	−23.7	7.6
Hollow B (1-4-16)	OLS	Indet	−23.4	7.3
Schuddemat (12-4-18)	OLS	Late Woodland	−23.7	7.2
Schuddemat (12-4-19)	OLS	Late Woodland	−23.1	6.9
Schuddemat (6-4-50)	OLS	Indet	−22.5	7.7
Schuddemat (12-3-60)	OLS	Late Woodland	−22.9	7.9
Schuddemat (12-3-19)	OLS	Late Woodland	−23.8	7.3
Schuddemat (12-4-2010)	OLS	Late Woodland	−23.3	7.5
Twin Fawns (44-3-128)	OLS	Late Woodland	−22.7	7.9
Twin Fawns (44-3-92)	OLS	Late Woodland	−22.6	7.6
Twin Fawns (45-5-14)	OLS	Late Woodland	−22.0	8.1
Twin Fawns (45-2-8)	OLS	Late Woodland	−22.0	8.0
Twin Fawns (37-3-122)	OLS	Late Woodland	−22.1	7.7
Vera (35-6-127)	OLS	Late Woodland	−21.6	7.7
Lowton (60-1-13)	TH	Late Woodland	−23.4	6.1
Lowton (2153)	TH	Vickers Focus	−23.7	6.6
Lowton (60-1-5)	TH	Late Woodland	−21.0	6.7
Calf Mountain (W190)	TH	Plains Woodland	−22.3	7.5
Lockport (W120)	L	Late Woodland	−25.0	11.4
Lockport (W49)	L	Winnipeg River complex	−27.8	11.9
Lockport (W27)	L	Bird Lake complex	−26.6	7.1
Healing Site (AN-04-8)	L	Indet	−29.6	9.6
Healing Site (AN-04-6)	L	Indet	−27.2	11.3
Anderson II (W428)	WR	Late Woodland	−25.5	9.0
Anderson II (W873)	WR	Late Woodland	−28.9	8.6
Anderson II (W1877)	WR	Bird Lake complex	−25.5	9.3
Bjorklund (W3830)	WR	Late Woodland	−25.3	10.2
Bjorklund (W1035)	WR	Late Woodland	−25.2	9.5
Bjorklund (W243)	WR	Blackduck	−27.4	Too small
Bjorklund (W41)	WR	Laurel	−24.6	10.5
EfKv-6 (W210)	WR	Winnipeg River complex	−30.9	10.8
EfKv-37 (W294)	WR	Winnipeg River complex	−32.7	10.7
Porth (W837)	WR	Late Woodland	−26.4	11.3
Porth (W333)	WR	Sandy Lake	−26.8	10.8
Rivermouth (W818)	WR	Blackduck	−22.2	6.9
Rivermouth (W1666)	WR	Laurel	−27.1	5.2
Whitemouth Falls (W8)	WR	Late Woodland	−27.1	11.5

As already discussed, there are some important caveats to be considered when assessing stable isotope data from heterogeneous materials such as ceramic residues. Despite these limitations, stable isotope analysis still has the potential to contribute insights into the overall diet. As such, in order to supplement information provided by plant microfossils, stable isotope analyses were performed on the food residue samples as discussed above.

The extent to which C and N isotope values vary within and among the four locales included in this study is remarkable (Fig. 4). In particular, we observe the following key regional trends in the isotope data.

(1) C isotope values for OLS and TH are shifted towards the less depleted end of the δ^{13}C spectrum relative to the other samples, suggesting that either C4 plants or tissue from animals that grazed upon C4 forage are present in the residues. This, in combination with the botanical (starch/phytolith) and archaeofaunal evidence (see above), supports the notion of a bison-based economy *minimally* supplemented with maize in these prairie locales during the Late Woodland period. Furthermore, the possibility that this economic pattern was not necessarily restricted to the prairies is indicated by the isotopic data for the Rivermouth site (WR): as noted

Table 4
Elemental composition of food residue samples (ICP-OES data) in parts per million (ppm), Oak Lake Sandhills (OLS) and Tiger Hills (TH) locales

	Al	Ba	Ca	Fe	K	Mg	Mn	Na	Ni	P	S	Si	Sr	Ti	Zn
Atkinson (surface)	1.9833	0.1799	4.512	6.791	0.5231	0.6768	1.23	0.3034	0.0226	1.409	0.1364	3.153	0.0246	0.0348	0.0419
Duthie (Lisbon ware)	4.9243	1.046	83.27	28.01	2.834	4.526	2.753	2.005	0.0524	12.62	2.676	2.582	0.1855	0.0963	0.1644
Duthie (17-3-162)	0.8924	0.2243	27.12	2.505	0.2105	1.522	0.417	0.4363	0.0175	10.39	0.5337	1.96	0.0815	0.0238	0.0949
Duthie 17-4-15	1.028	0.2599	28.75	4.057	0.284	1.754	1.031	0.4055	0.013	10.7	1.039	0.6447	0.0855	0.0227	0.0456
Duthie 17-4-154	0.7576	0.3279	40.85	3.235	0.2511	2.346	1.431	0.4187	0.0084	15.51	1.022	0.5982	0.1114	0.0132	0.0918
Lowton (2153)	3.0293	0.2121	20.41	4.086	1.623	2.157	0.2811	0.3638	0.0178	3.094	0.6782	4.075	0.0492	0.0496	0.0941
Lowton (36-2-3)	4.7153	0.0978	17.23	6.627	1.191	4.269	0.2918	0.2937	0.0207	0.9849	0.353	3.136	0.025	0.0659	0.076
Lowton (60-1-13)	0.8924	0.2501	31.88	5.625	1.066	2.527	0.2522	0.458	0.0106	4.343	0.6266	2.174	0.0822	0.0496	0.1273
Lowton (70-0-3)	2.744	0.0891	10.97	3.586	0.8164	2.225	0.1751	0.2375	0.0124	0.8521	0.3246	1.454	0.0192	0.0532	0.0675
Schuddemat (12-3-64)	2.0643	0.3348	16.96	2.695	0.5736	1.427	0.4182	0.8368	0.0147	4.102	0.4734	0.8021	0.0555	0.0885	0.2497
Schuddemat (12-4-14)a	1.6913	0.2515	19.57	2.617	0.596	1.313	0.3475	0.4771	0.0123	4.293	0.4803	1.719	0.0583	0.0298	0.2147
Schuddemat (12-4-14)b	1.131	0.2487	21.75	1.796	0.3791	1.307	0.2516	0.3381	0.0054	7.101	0.5737	0.6024	0.0655	0.0449	0.1608
Schuddemat (12-4-22)	1.5723	0.317	28.9	2.961	0.4919	1.385	0.6751	0.3372	0.0189	6.002	0.4729	1.232	0.083	0.0324	0.3072
Twin Fawns (37-3-102)	0.9913	0.0725	3.741	1.726	0.3941	0.2443	0.2443	0.187	0.0058	0.3396	0.0905	2.51	0.0172	0.0179	0.0251
Twin Fawns (43-3-92)	1.8363	0.651	33.37	14.78	0.9253	3.293	1.199	0.2729	0.0156	9.164	1.044	0.5938	0.1794	0.0561	0.1913
Twin Fawns (45-2-8)	0.9263	0.5348	26.84	6.261	0.6116	1.96	1.952	0.2823	0.0208	4.244	0.5644	0.8337	0.1122	0.0418	0.154
Vera (57-6-9)	0.9473	0.482	12.99	7.894	0.3505	1.762	0.4313	0.3427	0.0171	4.116	0.3076	0.9462	0.0845	0.0223	0.0761

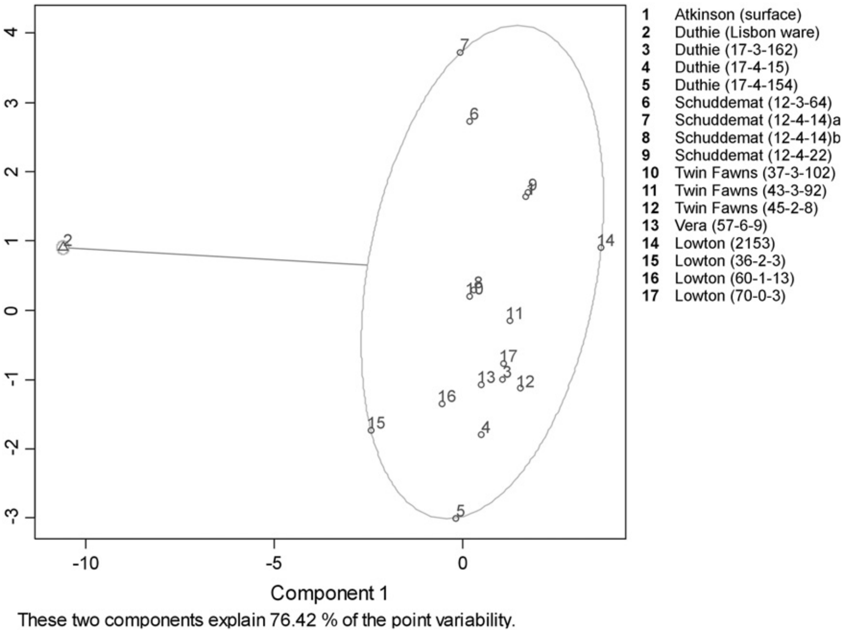

Fig. 5. PCA (Principle Components Analysis) and cluster analysis of elemental data, Oak Lake Sandhills (OLS) and Tiger Hills (TH) carbonized food residue samples.

above, both the δ^{13}C and δ^{15}N values at this site overlap with those from the OLS and TH.

(2) C and N isotopic values for the OLS and TH are less variable than those obtained from sites in the Lockport and WR locales. This suggests that overall diet may have been less varied in the TH and OLS prairie locales, in contrast to sites in the boreal forest. Although this trend may be due, in part, to natural variation in the amount of available C4 vegetation for grazers such as bison in the more northern region of the Lockport and WR locales, the suggestion of differing dietary breadth is supported by archaeofaunal assemblages in these two environmental zones. In a detailed comparison of a Blackduck site on the prairies and adjacent boreal forest, for example, Hamilton (1982) shows that although both sites indicate hunting of multiple wild resources, the prairie Blackduck site was overwhelmingly dominated by one food (bison); all other taxa were apparently minor supplements in a bison-dominated diet. In general, a narrowing of diet breadth may occur if new or existing items included in the diet increase in abundance, energetic return, or require less time and energy to obtain and process (Bettinger, 1991). On the prairies, one or more of these conditions may have been met through focal exploitation, and communal killing, of large plains bison herds. This effect may have been enhanced through the use of anthropogenic burning to increase herd predictability—a phenomenon that was observed during the historic period on the Canadian prairies and reconstructed for the Woodland period in the OLS (Boyd, 2002). Additionally, greater investment in maize production or trade may have provided a mechanism for further decreasing total diet breadth. Although no unequivocal archaeological evidence exists for maize production in any of the sites included in this study, components in the OLS and TH show the strongest evidence of cultural affiliation or trade with horticultural villages in the Middle Missouri and Oneota areas. Plant microfossil evidence of maize is also more abundant in the residue samples from the OLS and TH sites (see above), suggesting that corn was more regularly consumed or consumed in larger quantities in a given meal. This, in turn, may explain the subtle trend towards increased settlement sizes and decreased residential mobility reconstructed for at least one of the prairie locales (TH) (Nicholson, 1990).

(3) The greater variability in δ^{15}N in the L and WR locales supports the idea that a broader range of resources may have been exploited in the boreal forest. Furthermore, the high δ^{15}N values of many of the Lockport and WR samples suggests greater overall importance of freshwater fish in the diet (Katzenberg and Weber, 1999; Katzenberg, 1989). In other cases, the isotopic values of residues from sites in the same locales predominately, if not entirely, reflect consumption of terrestrial resources. In general, and with some important exceptions (e.g., Landals, 1995), fish bone remains tend to be rare in archaeological sites on the Northern Plains—a fact that Malainey et al. (2001) attribute to deliberate, health-related, fish avoidance among plains-adapted foragers. Our isotope results do suggest sharp differences in the importance placed on fish in the diet of boreal- and plains-adapted people within the study area. This pattern, furthermore, is probably not due to season of occupation or site setting: both warm- and cold-season occupations are represented in the study collection, and the OLS and TH locales contain numerous lakes and rivers where fish populations would have been available throughout the year.

A key question that remains to be answered is whether the evidence of maize from sites on the Canadian prairies and boreal forest reflects local production, trade, or both (Boyd et al., 2006). We explored this issue through trace element analysis (TEA) of carbonized food residue for a subset of our samples. As summarized above, elemental data from virtually all OLS and TH residue samples are statistically indistinguishable and are therefore assigned to the same cluster. However, this is not the case with one of the samples from the OLS (#2 in Fig. 5). This sample was obtained from a large loop-handled pot recovered in several sections from the Duthie site. Significantly, unlike all other ceramics examined in this study, this vessel is unique in Canada—only one example has been recovered from one site. This same vessel, however, is similar to several Northeastern Plains Village tradition (NEPV) pots from North Dakota (Toom, 2004); for this reason, we suspect that it was either acquired through trade or manufactured elsewhere and transported to the Duthie site by its maker(s). In any case, the unique trace element signature associated with this exotic vessel may indicate that foods cooked in this vessel (including maize and beans, Fig. 2) were not grown locally. During the early historic period, maize and other domesticated plants were obtained by foragers living on the fringe of the Northern Plains through trade with distant village populations (see Boyd, 1998 and references therein). In the case of the Cree-Assiniboin/Mandan–Hidatsa network, this relationship was based in part on the exchange of bison meat for maize, which provided both a means of dietary optimization and expansion of social and military alliances (Boyd, 1998). The results of our elemental analysis, while only suggestive, offer the possibility that maize was acquired occasionally through trade during prehistoric times as well.

7. Conclusions

By ~AD 1000, profound changes were taking place in many Aboriginal societies across the Eastern Woodlands and Great Plains. Perhaps most conspicuous of which was the intensification of maize horticulture and the conversion of this plant to a dietary staple. At the northern edge of the Plains and adjacent boreal forest, like many other regions on the fringe of these developments, little is known about the role that domesticated foods may have had in the diet of local populations. With few exceptions, these societies have been characterized as mobile foragers who depended exclusively on wild food resources for their survival. Conventional archaeological sources of information provide a reasonable basis for this interpretation, because habitation sites are almost always small with no evidence of permanent settlement, food storage, or gardening. At the same time, the remains of wild foods (in particular, large mammals) tend to be highly conspicuous at these sites, overwhelming the more subtle indications of plant use.

Based on archaeobotanical and chemical analysis of carbonized food residue from multiple components and sites, we observe that consumption of domesticated plants (especially maize) was a widespread practice on the eastern Canadian prairies after AD 700. Furthermore, although the microbotanical (starch/phytolith) evidence of maize generally diminishes northward, this practice also extended into the adjacent boreal forest/Canadian Shield. Stable C and N isotope analysis of food residue, while unable to identify the presence, or relative importance, of maize from one site to the next does suggest that a wide variety of foods were consumed, varying according to region, culture, and perhaps season of occupation (among other potential factors). Furthermore, based on the clustering and variation in the isotope data, we suggest that diet breadth may have been wider in the boreal forest sites (when considered as a whole) in contrast to those on the Canadian prairies. Much of the increased variability in the boreal sites may be attributed to the exploitation of fish during certain times of the year—a practice that is not recorded in the isotopic data from two of the prairie locales. Instead, lower standard deviations for both $\delta^{13}C$ and $\delta^{15}N$, in combination with archaeological and microbotanical evidence, suggest that a bison-based economy, supplemented *minimally* by maize, was the characteristic and dominant subsistence mode on the eastern Canadian prairies shortly before European contact. It is possible that increased dependence on maize in the OLS and TH locales, for which there is some plant microfossil evidence, may have contributed to a narrowing of diet breadth and somewhat larger, perhaps more permanent, settlements in a few cases. However, communal killing of large bison herds and the use of anthropogenic burning to increase herd predictability could have produced the same effect.

Despite considerable environmental, cultural, and economic, differences across the prairie-boreal margin, maize was a common thread that linked Late Woodland subsistence economies throughout this region. These surprising results indicate that the conventional understanding of small-scale economies, and the history of maize in northern North America requires revision.

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