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The Effects of Processing on Stable Isotope Levels and Mineral Concentration in Foods: Implications for Paleodietary Reconstruction

by

Sylvia Abonyi

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF ARTS

DEPARTMENT OF ARCHAEOLOGY

CALGARY, ALBERTA

April, 1993

ISBN 0-315-83078-6

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "The Effects of Processing on Stable Isotope Levels and Mineral Concentration in Foods: Implications for Paleodietary Reconstruction" submitted by Sylvia Abonyi in partial fulfillment of the requirements for the degree of Master of Arts.

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Abstract

Chemical techniques of paleodietary reconstruction currently utilize raw plant and animal tissue as the source for chemical data on diets. This study addresses the question of whether food processing influences stable isotope levels and mineral concentration in food such that potential for inferential errors may exist.

A population from 19th century Ontario whose diet was independently reconstructed through historical records served as a reference population. The foods chosen and the methods of preparation reproduced as closely as possible those used by the reference population. Results of carbon isotope analysis suggest that food processing does not alter $\delta^{13}C$ by more than $\pm 1.5^{0}/_{00}$. Human bone collagen enrichment with respect to diet was calculated at $+5.5^{0}/_{00}$.

Foods were analyzed for calcium, magnesium, strontium, zinc, and iron. Although preliminary, the results indicate that with the exception of zinc, food processing has a substantial impact on mineral levels. Further research is recommended to fully investigate the significance of food processing for mineral analysis.

Acknowledgements

Having arrived at this moment I find myself reflecting on the events and personalities of the last three years. I want to take this opportunity to express my thanks to those who have helped immeasurably to get me here. First and foremost I thank my supervisor, Dr. M. Anne Katzenberg for her belief in this project, and her support and guidance throughout. To my other committee members Dr. G. Oetelaar, and Dr. H.R. Krouse I also extend my gratitude for their always timely advice.

I would like to thank a number of individuals for their time and assistance during the months I spent in Ontario researching life in 19th Century Belleville. They are; Mr Colin Beckingham of the Bellevue House National Historic Museum in Kingston; Mr. Gerald Boyce, Belleville historian; Mr. Scott Gillies, curator of the Bradley House Historic Museum in Clarkson; Mrs. Lilo Abonyi, formerly of the Bradley House Historic Museum; and Dr. S. Saunders at McMaster University, Hamilton. I especially wish to thank the Bradley Museum for the loan of the iron pot used to prepare the foods for this study.

Isotope analyses were carried out in Dr. H.R. Krouse's laboratory in the Physics Department under the technical supervision of Nenita Lozano. Special thanks go to Dr. Howard Yeager, Head of the Chemistry Department, for allowing me to be the first to break in the CEM Microwave

Digestor and for his enthusiastic support and advice. Elemental analysis was carried out in the Geology Department with the expert guidance of Mr. Patrick Michael.

Financial support and funding for this project was provided by SSHRC grant 410-91-1408 awarded to Dr. M.A. Katzenberg and Dr. S. Saunders. Also thanks to Dr. G. Oetelaar, Dr. J.E. Kelley, and Dr. P. Shinnie for jobs that not only got me through the lean times, but also gave me valuable experience in the field of archaeology.

This section would not be complete without thanking the friends who have been behind me on this since day one in Calgary. I would particularly like to thank Pamela Downe, Donna Duncan, Tina Holitzner, Laurie Beckwith, Ross Jamieson, Loy Neff, Shari Lensen, Jeannette Smith, Warren Hill, Sharon Vieira, Sandra Garvie, and Judy Wheeler.

Finally, I extend my most heartfelt thanks to my family whose uncompromising encouragement and support I have always been able to count on.

To Mom, Dad, Erika, and Peter

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CHAPTER 1
INTRODUCTION

Dietary reconstruction is an important objective in the archaeological quest for understanding the dynamics of prehistoric human populations. Paleodietary information is determined by several means. These include the analysis of; settlement patterns, botanical remains, faunal remains, type and use-wear of tools, protein residues on artifacts, coprolites, skeletal morphology/pathology, and iconography. Over the last two decades analytical biochemical techniques have been incorporated into the discipline. Among them are stable isotope and trace element analysis of floral, faunal, and human remains. Like many new techniques incorporated into the discipline, these have been borrowed from outside and adapted. More recently, uncertainties inherent in these techniques, in the assumptions made, and in the nature of the material analyzed have received attention (Sillen, Sealy, and van der Merwe, 1989). It has become clear that in adapting chemical analysis for paleodiet reconstruction in archaeological research it is necessary to fully consider the effects of variables unique to the discipline.

Statement of Purpose

Thus far researchers have utilized raw food values for paleodietary reconstruction. The assumption is that food processing does not significantly influence stable isotope and trace element levels in food such that they would introduce errors in paleodietary reconstruction. The purpose of this project has been to determine the validity of this assumption.

Some basic research has been done on the effects of heat on stable carbon and nitrogen isotopes in various foods (DeNiro and Hastorf, 1985; DeNiro, Schoeninger and Hastorf, 1985; and Marino and DeNiro, 1987). However, none of the research to date has fully reproduced the actual cooking practices that might be expected in archaeological samples. While the impact of food processing could be adequately assessed by looking at randomly selected raw and cooked versions of food, the approach taken here is ethnohistorical in nature. A unique opportunity to use as a context the diet of a historic population arose with the excavation of a nineteenth century cemetery in Belleville, Ontario. The diet was easily reconstructed independent of chemical analysis. Through historical records, current research, and interviews with historians it was possible to reconstruct both individual recipes and to make an estimate of the proportion of foods comprising the whole diet. The food chosen and the methods of preparation therefore reproduced

as closely as possible those that would have been utilized by the nineteenth century historic human population. This included obtaining organically grown food from southern Ontario and preparing it in an iron pot on loan from a historic museum in Ontario. Chemical analysis of the diet can therefore be directly compared with chemical analysis of the osteological material. Carbon isotope analysis was carried out on a sample of adult individuals from the cemetery excavations and on the food from the reconstructed diet. Individual ingredients, mixed raw ingredients, and the cooked end product were all analyzed. Mineral analysis for calcium, magnesium, zinc, iron, and strontium was carried out on the mixed raw ingredients and the cooked end product. Mineral analysis has not yet been carried out on the osteological material.

The ethnohistorical approach has proven to be a significant contribution to the stable isotope portion of this project. Not only was the main research question addressed but also by comparing whole diet values to bone collagen values, it was possible to speculate on the degree of fractionation of bone isotope values from diet. This is of some importance since the displacement values currently in use are derived from animal research and archaeological populations with unknown diet.

The mineral analysis portion of this project was initially undertaken as a peripheral interest. Though only

preliminary in nature, the results regarding the effect of food processing on mineral levels have significant implications for this method of paleodiet reconstruction. It was not, however, possible at this time to compare these effects directly with the osteological population. Osteological mineral analysis for the reconstruction of paleodiet requires the consideration of a myriad of variables (e.g. diagenesis, metabolism), placing it beyond the scope of this project. Mineral analysis of the historic human remains is planned as a separate project for the near future.

Chapter Summary

A review of the theory behind the use of carbon and nitrogen isotopes and trace elements in paleodietary reconstruction provides the framework for this study and is covered in chapters two and three, respectively. Related research is discussed. Basic food chemistry and physics is reviewed highlighting areas of physical and chemical reactions with potential to alter stable carbon isotope abundances and mineral content of food. Chapter four provides a discussion of the history of Belleville and its inhabitants. It includes a discussion of the foods eaten, and the food processing methods characteristic of nineteenth century Ontario. The chapter concludes with an estimate of the composition of whole diet based on proportions of foods

consumed. In chapter five the details of sample selection and analysis by both mass spectrometry and atomic absorption spectroscopy (AAS) are described. Results of the food and bone analysis by mass spectrometry and food analysis by AAS are presented in chapter six. Chapter seven details the significance of the results with emphasis on the implications for paleodietary reconstruction. The conclusions are presented in chapter eight.

CHAPTER 2
THEORETICAL BACKGROUND: STABLE ISOTOPES

Stable Isotopes and Paleodietary Reconstruction

Isotopes and Fractionation

Principles of stable isotope fractionation have been known for many decades and are cited in review articles and texts (e.g. Hoefs, 1973). Isotopes are forms of an element that differ only in their number of neutrons, and therefore, in their nuclear masses. They can be divided into stable and radioactive species. While the term "stable" in reference to isotopes is a relative one, it generally refers to those forms of an element in which the radioactive decay times are beyond the limits of detection. It is because of their resistance to decay that stable isotopes have become useful as tracers of reaction conditions and as a record of origin in biological and geochemical systems. Most significant is that mass differences in isotopes of an element can effect the physico-chemical behaviour of an atom. This isotope effect will be greater in isotopes of an element with a greater mass difference relative to its absolute mass. This effect is therefore more pronounced in the lightest elements (e.g. H, O, C). Isotopes of an element separated mass-dependently are referred to as fractionated. Three basic processes have been described three basic processes in which fractionation may result.

Changes in the distribution of isotopes between different chemical substances, phases, or individual molecules in the absence of other chemical reactions are referred to as isotope exchange reactions:

$$H_2{}^{18}O + 1/3\ CaC^{16}O_3 \rightleftharpoons H_2{}^{16}O + 1/3\ CaC^{18}O_3$$

Fractionations due to physico-chemical effects such as evaporation-condensation, crystallization-melting, adsorption-desorption, and diffusion-thermodiffusion may also occur. These are largely geochemical reactions and will not be further considered here.

Most important from the perspective of biochemical reactions are kinetic isotope effects (KIE). Basic concepts of kinetic isotope effects are discussed in Shiner (1973) and Fry (1964). Primary kinetic isotope effects are the result of differences in the rate of a chemical reaction between isotopes of an element at the reaction site. The term "primary" simply refers to the fact that the isotope is involved in the rate determining step of the reaction. Because light isotopes tend to react more rapidly than their heavier counterparts, it is expected that the product will be depleted in the heavy isotope. Secondary isotope effects can be divided into two types. Kinetics occurring as a result of an atom bound to an isotopic atom undergoing bond rupture and/or formation are referred to as α effects.

Other secondary isotope effects are caused by isotopic substitutions at positions in the molecule more remote from the center of reaction. Secondary isotope effects are usually so small that their observation is difficult in hydrogen isotopes and have only rarely been reported for other elements. The magnitude of the isotopic effect on the reaction rate depends on the mass ratio of the isotopes in question. Hydrogen isotopes of protium and deuterium, for example, have a mass ratio of 2, while the ratio for $^{13}C/^{12}C$ and $^{15}N/^{14}N$ are only 1.08 and 1.07, respectively. As a result, kinetic isotope effects on an order of magnitude less than hydrogen would be expected for carbon and nitrogen (Katz, et al. 1975:185).

Measurement of Isotope Abundance

Because measurement of absolute isotope abundance is difficult, relative abundance by comparison to a known standard is determined by mass spectrometry. Values are expressed in the delta (δ) notation as parts per mil, according to the formula:

$$\delta\ (^{0}/_{00}) = [\ (^{R}\text{sample} - {}^{R}\text{standard}) \ /\ (^{R}\text{standard})\ ]\ \ x1000$$

where R is the abundance ratio of the heavy to light isotope (e.g. $^{13}C/^{12}C$) with the δ value always expressed in terms of the heavy isotope. The isotopic standard for carbon is

PeeDee Belemnite (PDB), which was derived from the fossilized carbonate shell of a Cretaceous mollusc from the PeeDee formation in South Carolina (Craig, 1957). The isotopic standard for nitrogen is atmospheric nitrogen (AIR), which Mariotti (1983) reports is constant within analytic precision.

Principles for Carbon and Nitrogen Isotope Use in Paleodiet

The use of stable isotopes in paleodietary reconstruction is based on studies that have linked diet with variations in stable isotopic composition of consumers (DeNiro and Epstein, 1978 and 1981). Carbon and nitrogen are most commonly used. Ambrose (1993) has written the most recent and comprehensive background review of the basic principles of isotope analysis, methods, and applications. For other reviews see Chisholm, 1989; DeNiro, 1987; Price et al, 1985; Klepinger, 1984; and van der Merwe, 1989 and 1982.

Carbon

Stable carbon exists as a ratio of $^{13}C/^{12}C$ in the atmosphere of approximately 1.11: 98.89. It has a $\delta^{13}C$ value of approximately $-7.7^{0}/_{00}$ relative to PDB (Keeling, 1961; Craig, 1953). Atmospheric carbon is the primary source of carbon for terrestrial plants. When CO_2 is metabolized by plants during photosynthesis carbon isotopes are strongly

fractionated (see O'Leary, 1981 for a review). Discrimination against the heavier isotope of carbon results in plants having a lower $\delta^{13}C$ content than the atmosphere (Bender, 1971). Three photosynthetic pathways have been identified in the plant world. Each one fractionates carbon distinctively. C_3 plants, consisting of most trees, shrubs and temperate zone grasses, discriminate strongly against $^{13}CO_2$. Leaf values for these plants range from $-35^0/_{00}$ to $-20^0/_{00}$ relative to PDB (Troughton, 1972). CAM (Crussalacean Acid Metabolism) plants, which include succulents such as cacti, discriminate less against $^{13}CO_2$. Delta values for CAM plants range from $-28^0/_{00}$ to $-10^0/_{00}$ (Bender, 1971). Plants metabolizing carbon by the C_4 pathway discriminate the least against $^{13}CO_2$. They include maize, sorghum, sugarcane, and other grasses of tropical and subtropical regions, with δ values ranging from $-15^0/_{00}$ to $-7^0/_{00}$ (Troughton, 1972). The inorganic carbon reservoir for marine plants consists of dissolved CO_2 and carbonate ions as well as atmospheric carbon and has a $\delta^{13}C$ value near $0^0/_{00}$ (Emrich et al, 1970). Thus values for marine plants vary from -35 to $-4^0/_{00}$ (Fry and Sherr, 1984).

DeNiro and Epstein (1978) found that $\delta^{13}C$ values of an animal reflect the relative contributions of $\delta^{13}C$ to the diet when the $\delta^{13}C$ values of diet sources are sufficiently different. The separation of approximately $14^0/_{00}$ between the C_3 and C_4 group averages allows them to be discriminated

from each other. One area of research where this is important archaeologically is in detecting the arrival of a domesticate such as maize (a C_4 plant) in a C_3 environment (van der Merwe, 1982). Although DeNiro and Epstein (1978) found that additional fractionation takes place during the incorporation of dietary carbon by animals (with significant differences between various tissues, minerals, and fluids) the most significant fractionation takes place in plants and is preserved in higher organisms (van der Merwe, 1982). Fractionation factors for different tissues have been calculated, based on laboratory experiments, by DeNiro and Epstein (1978). They initially reported the "collagen enrichment factor" between diet and bone to be on the order of a conservative $+3^0/_{00}$. This was subsequently amended to $+3.9^0/_{00}$ (DeNiro and Epstein, 1981). Other researchers (Chisholm et al., 1982; van der Merwe, 1982; and van der Merwe and Vogel, 1978) cite enrichment factors of as much as $+5.1^0/_{00}$. A further trophic level fractionation of $+1^0/_{00}$ from herbivore to carnivore or omnivore has also been suggested (DeNiro and Epstein, 1978). As a result, corrections applied to data derived from only one tissue can indicate the value of the diet. This is significant for paleodietary reconstruction since bone is generally the only material available. The use of carbon isotopes is generally restricted to applications in which the dietary sources have relatively large differences in their $\delta^{13}C$ values, such as in

C_3 versus C_4 plants or marine versus terrestrial organisms.

Nitrogen

Stable nitrogen atoms occur in the natural environment in two forms, ^{14}N and ^{15}N. The latter represents 0.3663 % of available nitrogen, with the rest made up of the former (Parwell et al, 1957). Plants derive their nitrogen from one of two sources. Microbes fixing atmospheric nitrogen ($\delta^{15}N$ = approximately $0^0/_{00}$) may exist in soil in a symbiotic relationship with plants. These plants (predominantly legumes) may then derive their nitrogen from the microbial source rather than directly from soil as non-nitrogen fixing plants do. Soil nitrogen values can vary from -7 to $+18^0/_{00}$, with a mean of approximately $+5^0/_{00}$. These values are passed on to plants that are not nitrogen-fixers. Because nitrogen-fixing plants rely on both soil and atmospheric nitrogen, their values may reflect either source (Peterson and Fry, 1987). Marine plants rely on dissolved nitrates with $\delta^{15}N$ values ranging from $+6^0/_{00}$ to $+19^0/_{00}$. Although not as significantly as with carbon, plants discriminate against ^{15}N during nitrogen metabolism. Legumes have a $\delta^{15}N$ which ranges between $-6.5^0/_{00}$ and $+6.5^0/_{00}$ with an average of around $+1^0/_{00}$. Non-legumes range from $-7.8^0/_{00}$ to $+17^0/_{00}$ with an average of around $+3^0/_{00}$ (Schoeninger and DeNiro, 1984). Animals are usually enriched in ^{15}N compared to vegetal matter as a result of catabolic pathways which

preferentially eliminate small molecules depleted in ^{15}N (Hoering, 1955; Gaebler et al, 1963). As with carbon, the isotopic composition of nitrogen in an animal therefore theoretically reflects the nitrogen isotope composition of its diet (DeNiro and Epstein, 1981). There is, however, a great deal more overlap in the distributions of nitrogen isotopes between legumes, non-legumes and marine plants, making it more difficult to resolve the differences between them. Another confounding factor is the pervasive use of fertilizers in recent times which alter soil nitrogen values.

DeNiro and Epstein (1981) further determined that nitrogen ratios are influenced by a trophic level effect. They become enriched by approximately $+3^0/_{00}$ as they are passed through increasing trophic levels with a further collagen enrichment factor calculated at $+2.4^0/_{00}$. Although more restricted in its applications, the nitrogen isotope method has been used most successfully in conjunction with $\delta^{13}C$ to differentiate terrestrial from marine feeders (Norr, 1982; Schoeninger et al, 1983; Schoeninger and DeNiro, 1984; and Walker and DeNiro, 1986), or on its own as an indication of trophic level within a specific food web (Schoeninger, 1985).

Literature review: Previous studies of the effects of heat on stable isotope levels

As indicated in the introduction, there are many assumptions underlying the application of stable carbon and nitrogen isotopes to paleodietary reconstruction. Research on the effects of food processing, specifically heat, on stable isotope levels has only been conducted within the last decade, and because there are only a small number of publications on this topic, it is worthwhile to review them in some detail. They provide the groundwork from which the major component of this project is a natural extension.

DeNiro and Hastorf (1985)

The stable carbon and nitrogen isotope ratios of plant materials excavated in Peru, dating from 400 to 4000 B.P., were analyzed. The archaeological material consisted of identifiable carbonized and uncarbonized botanical remains. In many archaeological contexts only morphologically unidentifiable carbonized plant material is recovered. Stable isotopes offer the potential to characterize plant remains by their photosynthetic or nitrogen-fixing pathways. The question of the usefulness of carbonized botanical remains from sites for stable isotope research was therefore addressed in this study. The effects of heat on uncarbonized plant remains also had to be considered since there is no way to determine which of the prehistoric

botanical remains recovered from the site may have been heated (but not to the point of carbonization) at one time. DeNiro and Hastorf (1985) set up a controlled laboratory experiment to determine the effects of heat on the isotope ratios of fresh plant materials. Parts of modern plants were either boiled in distilled water for an hour, or roasted over charcoal for periods of time ranging from thirty to ninety minutes. Carbonized samples were heated in an oven for three to five hours under both aerobic and anaerobic conditions. Results indicate that boiling or roasting do not shift the $\delta^{13}C$ or $\delta^{15}N$ values by more than $+2^{0}/_{00}$. Anaerobic and aerobic carbonization produced shifts of up to $\pm 3^{0}/_{00}$. A generalized conservative shift of $\pm 3^{0}/_{00}$ in stable isotope values of $\delta^{13}C$ and $\delta^{15}N$ is estimated to occur as a result of heating. Hastorf and DeNiro (1985) successfully characterized morphologically unidentifiable plant remains based on results from this study.

DeNiro, Schoeninger and Hastorf (1985)

Instead of botanical remains, this paper looked at the effects of heat on the collagen component of bone tissue. $\delta^{13}C$ and $\delta^{15}N$ were both examined. They also looked at C/N ratios and collagen concentration since these have proven to be useful techniques for identifying collagen compromised diagenetically (DeNiro, 1985). Three experiments were conducted in which the carbon and nitrogen isotope ratios of

collagen from heated and unheated freshly killed animal bone were compared. Bones were boiled in distilled water for one hour, roasted either in cow meat or bare over charcoal for two hours, or subjected to varying temperatures simulating cremation in a muffle furnace for up to three hours. Their results indicate that $\delta^{13}C$ and $\delta^{15}N$ can be altered when the bones are heated. The extent of the shift relates to the type and duration of heating. Boiling and roasting were found not to alter collagen concentration or atomic C/N ratios. These treatments also produced $\delta^{13}C$ and $\delta^{15}N$ isotope ratios within approximately $\pm 1^{0}/_{00}$ of controls. The bones heated in the muffle furnace produced shifts of up to $+5^{0}/_{00}$ and $+4^{0}/_{00}$ in $\delta^{13}C$ and $\delta^{15}N$, respectively. Exposure of bone at either lower temperatures or for a shorter duration produced smaller shifts. The collagen concentrations and the C/N ratios were also increasingly affected with the length of exposure time to intense heat. The C/N ratio, in particular, was outside what is considered to be the acceptable range of 2.9-3.4. The investigators conclude that the current practice of eliminating bone collagen data with C/N ratios outside the acceptable range from paleodiet reconstruction also effectively eliminates bone with heat-induced isotopic shifts of greater than $\pm 1^{0}/_{00}$.

Marino and DeNiro (1987)

Although this paper was aimed at discussing the potential for isotopes to aid in the reconstruction of paleoclimate, its results are worth considering from a paleodietary perspective. The cellulose fraction of botanical remains recovered from archaeological sites is potentially useful for isotope studies of paleoclimate; but because botanicals recovered from archaeological sites may have been subjected to processing by humans, it is important to determine the magnitude of change that manipulation related to food processing might have had. The plant cellulose fractions of *Zea mays* cobs, *Helianthus annus* seeds, *Agave americana* leaves, and *Pachrrhizus erosus* tubers were subjected to a variety of treatments that included boiling, roasting, fermentation, liming, molding, and carbonization. (It is interesting to note, however, that the food items were (p.539) "dried for 24h at 50°C, comminated to 40 mesh with a Wiley mill, thoroughly homogenized and desiccated by freeze drying", prior to experimental processing treatment; a procedure that hardly emulates possible prehistoric food preparation practices.) Stable isotope ratios of carbon, hydrogen, and oxygen were determined for control and treated groups. Their results indicate that cooking and other food preparation techniques do not significantly alter the isotopic composition of the cellulose fraction of botanical remains recovered from archaeological sites. The range of

variation reported for $\delta^{13}C$ (less than $1^0/_{00}$) is within the level of precision inherent in the technique.

Literature Review Summary

Extreme conditions of heat such as are produced under conditions of carbonization for botanicals, or cremation for human remains alters $\delta^{13}C$ and $\delta^{15}N$ values by $\pm 3^0/_{00}$, and ± 4-$5^0/_{00}$, respectively. More conservative treatment, such as roasting of botanicals, produces shifts of $+2^0/_{00}$. These values and the suggestions offered by researchers for dealing with them are useful, but only in a limited capacity. The research is focused towards being able to analyze human or botanical materials recovered from archaeological sites that are suspected to have been subjected to heat stress. The impact of processing on stable carbon and nitrogen levels in food, *prior* to ingestion by humans has not been fully considered. Current baseline dietary data are based on plant and animal samples not subjected to any form of food processing. Research conducted by DeNiro, Schoeninger and Hastorf (1985) implies that low levels of heat used in processing are not likely to affect $\delta^{13}C$ values by more than $+2^0/_{00}$. However, none of the research to date has fully reproduced the conditions of food processing that might be expected to alter stable isotope ratios. DeNiro and others chose to look at foods in isolation. However, the processing of food for human

consumption commonly involves the *combination* of materials under conditions of heat. The isotope effects that may be produced by the resulting chemical reactions that occur have not yet been determined and form the focus for this study.

Chemistry of Food Processing

Part of the purpose for food processing from a cultural perspective is to extend the storage life of food and make it more palatable. The chemical reactions that occur as a result not only have nutritive implications (e.g. Lund, 1982), but also provide potential for the occurrence of isotope fractionation through kinetic isotope effects. In order to gain a better understanding of how food processing might influence stable isotope levels, it is necessary to consider the resulting chemical reactions. A huge and complex body of literature exists on this topic. Unfortunately, the majority of it is incomprehensible to the non-specialist with results not oriented towards archaeological interests. It is, however, helpful to consider basic effects of heat on the chemical structure of carbohydrate, lipid and protein components of food as a means of alluding to the complexity of chemical reactions that are a potential source of primary and secondary kinetic isotope effects.

Protein

Proteins are comprised of one or more complex polypeptide chains made up of individual amino acids. Amino acids all have the same basic chemical structure consisting of an amino end (containing nitrogen and hydrogen) and a carboxyl end (containing carbon and oxygen), linked in the center by a carbon (Figure 2.1). Side chains characteristic of each type of amino acid are bonded to the center carbon (R in Figure 2.1). Polypeptide chains are formed by bonds between the amino terminus of one amino acid and the carboxyl terminus of another. Protein structure is made up of polypeptide chains folded onto themselves and into other chains by bonds between side chains (Coultate, 1989:88-90). Complete proteins are referred to as being secondary, tertiary, or quaternary, depending upon the number of folded polypeptide chains in their structure. This structure is compromised when bonds between the chains are broken. This may then be followed by separation of individual amino acid units (primary structure). Low heat levels result in the unfolding, or denaturation, of polypeptide chains. This is largely a morphological change. More intense heat may result in the chemical modification of the primary structure of amino acids, particularly amino acid side chains. This chemical modification is referred to as deterioration (Mauron 1982:443). While denaturation can actually enhance amino acid availability in the diet,

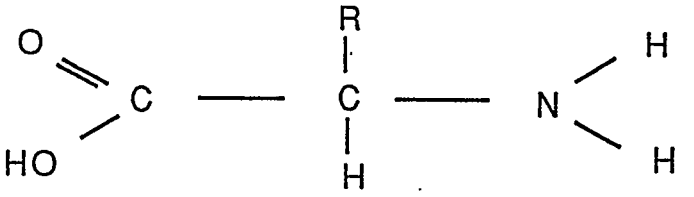


Figure 2.1 Generalized structure of an amino acid

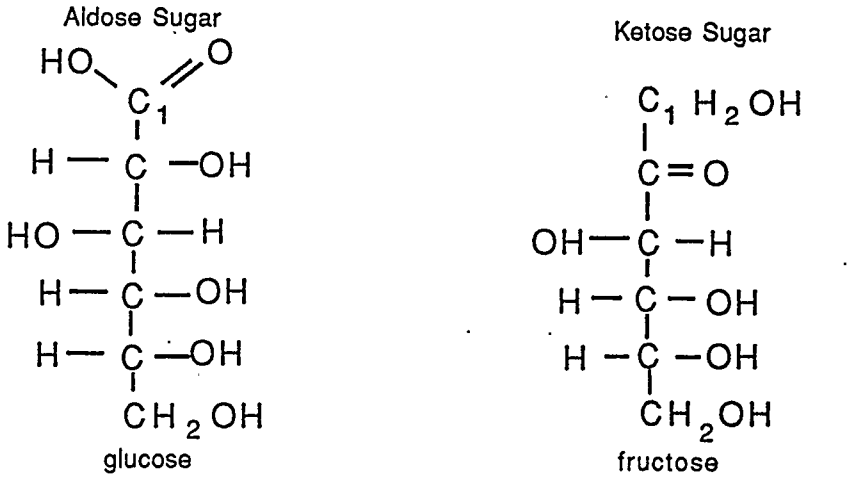


Figure 2.2 Monosaccharide sugars glucose and fructose showing aldose and ketose functional groups at the carbon 1 position.

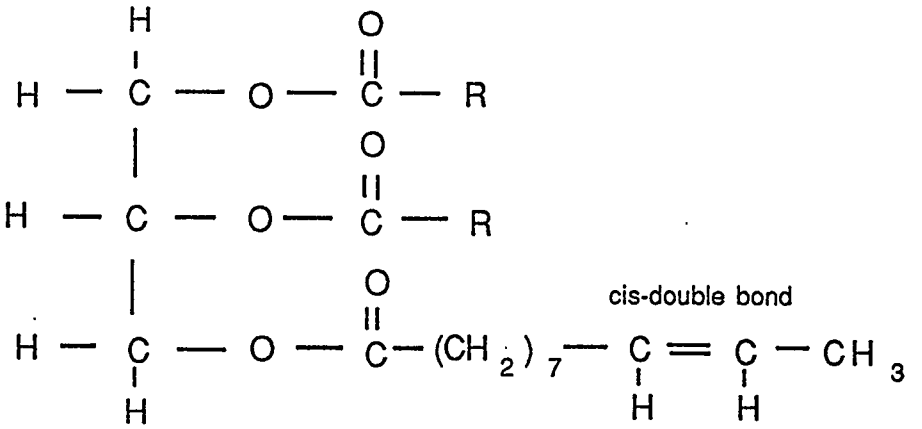


Figure 2.3 Generalized example of an unsaturated fatty acid

deterioration can result either in the complete destruction of an amino acid or result in it and its constituent protein becoming biologically unavailable. (Coultate, 1989:95). A study conducted by Purcell and Walter (1982), for example, found that changes in the amino acid content of the jewel sweet potato were related to heat processing treatment. They particularly noted the destruction of the amino acid lysine. Another study found that as well as lysine, a decrease in arginine, tryptophan, and sulfur-containing amino acids (methionine and cystine) occurred in cooked biscuits (Björck et al., 1983). When the forgoing results are considered together with research that has shown that amino acids vary in their carbon isotope values (e.g. Abelson and Hoering, 1961), potential for fractionation as a result of amino acid destruction can be clearly seen to exist. Although only in the preliminary stages, some researchers have shown that isotopic fractionation does occur during peptide bond hydrolysis (Bada et al, 1989).

Carbohydrates

Carbohydrates consist of simple sugars such as sucrose and glucose as well as complex polysaccharides such as starch and cellulose (Coultate, 1989). Monosaccharides commonly used in food processing are described as either aldoses or ketoses, depending upon whether an aldose or ketose group is located at the carbon 1 position on the

molecule (Shahied, 1977)(Figure 2.2). Monosaccharides are bonded together to form polysaccharides by glycosidic bonds that may be broken by heat-catalyzed hydrolysis. In the presence of an acid environment, heat catalysis simply results in the separation of carbohydrate molecules from each other at the glycosidic bond. Base hydrolysis may further result in fragmentation, rearrangement, and side chain reactions (Shahied, 1977). When sugars are heated to temperatures above 100°C, a complex series of reactions results (Coultate, 1989:21). Most significant among these is the Maillard reaction. This occurs in foods in which sugar is heated in the presence of a protein. The reaction generally occurs between free aldose sugars and the free amino groups of amino acids, peptides, and proteins (Mauron, 1982). Ketose sugars also sometimes participate in the reaction (Adrian, 1982). The result is either the destruction of both amino acids and sugars or the formation of compounds that are nutritionally unavailable due to their enzyme-resistant character. The essential amino acid most sensitive to destruction by the Maillard reaction is lysine (Adrian, 1982). A Ziderman and Friedman (1985) study looking at the chemistry of crust baking found that even in the presence of non-reducing polysaccharides such as cellulose, protein decomposition may result. The products of the Maillard reaction are responsible for the browning of breads, crusts, and biscuits and produce the aromas

associated with the roasting of meat and baking (Adrian, 1982).

Lipids

Up to 95% of dietary fat is ingested in the form of triglycerides (Witting and Dimick, 1982:403). These are generally straight-chain molecules with an even number of carbon atoms and may contain from zero to six methylene-interrupted cis-double bonds (Figure 2.3). They range from very short molecules, consisting of four to eight carbons in the chain, to very long molecules, with greater than 20 carbons in the chain. Saturated fatty acids contain no double bonds, while unsaturated fatty acids contain one or more double bonds. The most chemically reactive sites are the sites of double bonds. Most reactions, involving heat, oxidation, or thermal-oxidation, result in modifications of the double bond by the insertion or formulation of new functional structures (Witting and Dimick, 1982:407). Because the oxidation products of lipids may bear -CHO or -CO functional groups characteristic of aldose and ketose sugars, it is also possible for these substances to participate in the Maillard reaction with proteins.

Chemical Implications: A Closer Look at the Chemistry and Physics of Baking

The forgoing discussion on the basic effects of heat on the chemical structure of carbohydrates, lipids, and proteins suggests the potential for kinetic isotope effects. While the significance of mixing ingredients has been alluded to, it is worthwhile to further consider this aspect of food processing.

Baking is an enormous industry for which an understanding of molecular dynamics can translate into better products and commercial success. As a result, a significant body of literature on the physical and chemical interactions that are important in the baking process has accumulated. The mixing of ingredients and the resulting kinetics has naturally been an integral focus of this research.

Recent articles by MacRitchie (1986), Davies (1986), and van Dam (1986) review the basic stages of manufacture and most importantly, the chemical reactions that occur in each stage, that are characteristic of the baking process. The stages of manufacture are; hydration of ingredients, development (by mixing) of the raw batter/dough, introduction of the gas phase, and heat setting into a rigid structure which maintains its integrity when the product is cooled. The most significant stages for chemical reactions that may result in kinetic isotope effects are mixing and

the introduction of the gas phase. During dough hydration soluble components are dissolved. This liquid phase provides the medium for reactions to take place in the dough and for the CO_2 produced to dissolve and diffuse to gas cells. When components are being moved with respect to each other during mixing, continuous contact between reactants and removal of products from the reaction site occurs. This creates optimal conditions for physical processes and chemical reactions to proceed at a rate no longer possible during the rest of the baking process. The gas phase is introduced partly through the mixing process, and more significantly, from the release of CO_2 from baking powders or yeast fermentation. Baking powders release CO_2 gas during various stages of manufacture; during mixing, resting, and baking. Yeast metabolizes carbon sources such as glucose, fructose, and sucrose during mixing and resting, but during baking the yeast is rapidly killed off after temperatures of 55°C or higher are achieved. During heating, starch (flour) gelatinizes and proteins polymerize to transform the fluid dough into a predominantly solid product. Expansion, or oven rise, is caused by an expansion of the gas produced by yeast fermentation or baking powder/soda and by the evaporation of water and CO_2 that is dissolved in the dough. The combination of the structural changes in starch and protein and gas production and evaporation results in a transformation of the original

structure with separate gas cells into a sponge-like structure with interconnected gas cells (Bloksma, 1986).

Chemistry and Physics of Food Processing: Summary

Chemical reactions that occur in food processing are clearly not only significantly affected by heat alone, but also by the act of combining different types of food. The forgoing overview has shown that both carbon and nitrogen are at the center of some of these reactions. Since these are the locations at which primary kinetic isotope effects occur, it is conceivable that some of these reactions are mediated by isotope mass differences. It is therefore important to understand the magnitude of kinetic isotope effects produced to determine whether or not it is significant in terms of paleodietary reconstruction.

CHAPTER 3
THEORETICAL BACKGROUND: THE ELEMENTS IN BONE AND DIET

Elements in Paleodietary Reconstruction

Basic concepts of bone structure and physiology have been known for some time and are referred to in review articles and texts (e.g. McLean and Urist, 1961). The two major components of bone are the organic matrix (collagen) and the inorganic matrix (mineral). The mineral phase of bone consists of crystals of calcium and phosphate in a hydroxyapatite structure deposited in a crystal lattice formation within and between long collagen fibrils. Bones therefore serve as a reservoir for calcium and phosphorous. Other elements are, however, also deposited in bone mineral. They may substitute for calcium, phosphorous, or hydroxide ions because behavioral and structural similarities make it possible for them to compete for bonding sites. Elements such as strontium, zinc and lead, for example, are able to substitute for calcium in the hydroxyapatite structure. Other elements which are deposited in bone include magnesium, iron, potassium, sodium, copper, manganese, cadmium, aluminum, and lead. Some of these elements are required by the human body for its proper functioning and are therefore referred to as essential minerals (e.g. Mg, Fe, Cu, Mn). Becker et al (1968) and Spadaro et al (1970a, 1970b) conducted research to establish baseline data on specific elements and their varying levels in bone. Elements

may fix in bone up to a certain level at which point the surplus of the intake may be excreted. They are mobilized from bone for physiologic use by homeostatic mechanisms. A range of presence may therefore be found in bone indicative of trace element consumption (Gilbert, 1975:6). Non-essential trace minerals, those with no known physiological function, are also deposited in bone (e.g. Pb, Cd, Sr). These are often cumulative and will fix in bone as long as the element forms a portion of an individual's intake. The major source for these inorganic nutrients and contaminants is the diet.

The ultimate source of elements to the diet is the geochemical environment. They reach the human body via a series of complex pathways through plant and animal interactions with the environment. These pathways and networks of interaction result in significant differences in element concentration both at different trophic levels and in diverse environments. The use of this technique in reconstructing paleodiet is based on the assumption that variation in elemental levels in human bone reflects dietary intake. As a result the selection of elements for this technique has two basic requirements. A predictable association of specific elements with certain types of food must exist. Those same elements must also be detectable in the inorganic matrix of bone. A range of elements are believed to satisfy the basic requirements and have been

applied by researchers in the reconstruction of paleodiet. Five of these form the focus for this study.

Calcium

Calcium is the most abundant mineral in the human body. It makes up about 40% of the total mineral present in the body, with 99% of this stored in the bones and teeth (Ensminger et al., 1983b:1511). The richest dietary sources for calcium include milk products, blackstrap molasses, green, leafy vegetables, almonds, brazil nuts, hazelnuts, and fish with soft, edible bones. Fair sources are beans, bread, broccoli, cabbage, eggs, legumes, lettuce, lobster, rhubarb, and turnips. Sources with negligible amounts of calcium range from vegetables such as asparagus, beets, brussel sprouts, cauliflower and cucumbers, to beef, corn, pork, and poultry (Ensminger et al., 1983b:1511). A dietary excess of calcium or phosphorous can interfere with the absorption of both minerals, and an increase in the excretion of the lesser one. Excess calcium can also significantly depress iron absorption. Calcium concentration in bone tissue provides a constant measure against which strontium and phosphorous concentrations are compared in paleodietary reconstruction. Ca/P ratios are used as a means of assessing the impact of diagenesis. The role of strontium is outlined below.

Strontium

Strontium is one of the non-essential trace elements. Because of its chemical similarity to calcium, it is able to compete with calcium for bonding sites in the hydroxyapatite structure of bone. Detailed knowledge about the geochemical and biological behaviour of strontium is available since radioactive strontium from nuclear fallout became a concern in the mid-1950's (e.g. Comar et al., 1957; and Kulp et al., 1957). The uptake of strontium and calcium from the soil is proportional to soil content although it is affected by factors such as clay, organic content, and soil pH (Isermann, 1981). Most important in terms of paleodiet is that plant uptake does not result in the discrimination of strontium in favour of calcium (Isermann, 1981). Strontium is, however, discriminated against (in favour of calcium) in mammalian digestive tracts and is excreted more rapidly by the kidney (Spencer et al., 1960, 1973; and Walser and Robinson, 1963). As a result, meat foods are expected to have a lower concentration of Sr and therefore a lower Sr/Ca ratio than plant foods. It follows that individuals with a high meat content in their diet will have a lower Sr/Ca ratio than individuals subsisting largely on plants. Both strontium concentration and Sr/Ca ratios have been extensively used in dietary studies of human skeletal remains (see for example: Brown, 1973; Gilbert, 1975; Szpunar, 1977; Stedt, 1979; Elias, 1980; Price and Kavanagh,

1982; Katzenberg, 1984; and Sealy and Sillen 1988) . It is important to note, however, that strontium content in the same types of plants and animals varies regionally a great deal. Geochemical studies of strontium have found this to be a result of significant differences in strontium content of rock (Turkenian and Kulp, 1956). The North American Rockies, for example, display very high levels of strontium, while eastern North American values are much lower (Katzenberg, 1984). These geologic differences are carried through the food chain, so that dietary analysis of the same plant or animal from different regions are not comparable.

Multi-Elements In Paleodietary Reconstruction

While strontium has been the most popular element in paleodiet studies, Gilbert (1975) and then Szpunar (1977) began to look at multi-element approaches. Since these pioneering studies several other researchers have employed multi-element analyses (see for example Katzenberg, 1984; and Beck, 1985). Some of these studies looked not only at the reconstruction of paleodiet but also applied their data to the determination of status based on assumptions of status-related access to food (e.g Geidel, 1981, 1982; Hatch and Geidel, 1983, 1985; Blakely and Beck, 1981; and Brown and Blakely, 1985). Benfer (1984) noted gender- and age-based differences in diet from zinc and strontium analysis. Others (e.g. Bisel, 1980) have incorporated multi-element

data in studies of health and disease. For an excellent review of these and other multi-element studies conducted to date see Buikstra et al (1989). Strontium, magnesium, and zinc are often used for paleodietary reconstruction since they are believed to be the least susceptible to the influences of diagenesis (Lambert et al, 1979, 1982, 1984; Szpunar, 1977; Vlasak, 1983). It is clearly of some value to look at the impact of food processing on these elements as well.

Magnesium

Magnesium is an essential component of cellular metabolism. Like strontium, it also is chemically similar to calcium and is therefore a bone-seeking element. It has critical functions in the activation of enzymes involved in energy transfer and the digestion of proteins. An excess of magnesium may upset calcium metabolism. Rich sources of magnesium include nuts, cocoa powder, sesame seeds, spices, wheat bran, molasses, and whole wheat flour. Magnesium is found in all photosynthetic plants with the highest concentrations by weight in the herb and spice groups (Schroeder et al., 1969). Avocados, bananas, bread, fish and sea foods, pork, beef, and veal are considered fair sources. Cabbage, eggplant, lettuce, milk, most fruits, mushrooms, rhubarb, and tomatoes contain very little magnesium (Ensminger et al., 1983b:1514). Magnesium is

thought to be potentially useful for paleodietary reconstruction because of its concentration in plants.

Zinc

While zinc is required for normal skin, bones, and hair, it is also a significant component of several enzyme systems which are involved in respiration and protein and alcohol metabolism (Underwood, 1975:119). It is, for example, required for the transfer of carbon dioxide in red blood cells, for the synthesis and metabolism of proteins and nucleic acids, for wound and burn healing, and for the proper calcification of bones (Ensminger et al., 1983b:1521). Meats and seafoods are good sources of dietary zinc, while vegetables are not remarkably so. Thus, high zinc levels in bone are inferred to result from the consumption of meat and seafoods which contain considerable amounts of bioavailable zinc (Runia, 1987:107). Zinc bioavailabilty is, however, reduced by high calcium levels, phytates, oxaloates, and high fibre. An excess of Zn interferes with the metabolism of copper, which in turn is required for the proper utilization of iron.

Iron

Iron is an important constituent of haemoglobin and also acts as a component of enzymes involved in energy metabolism (Underwood, 1975:229). Milk products, vegetables

and sugars are very poor sources of iron, while pork, beef, and chicken giblets are a very good source. An excess of dietary iron can tie up phosphorous in an insoluble iron-phosphate compound. Iron is not traditionally used in the reconstruction of paleodiet. Its presence in bone, particularly when the surrounding soil matrix has relatively high amounts of iron, is considered to be a sign of diagenesis (Runia, 1987:58). It is incorporated into this study since the preparation of foods by the reference population involved the use of iron cookware. The potentially high iron levels in the cooked product may translate into high enough iron intake to merit consideration as a source of high levels in bone. It may also require consideration as a potential source of influence on elements that it interacts with (e.g. phosphorous) that are more commonly used in dietary reconstruction.

Trace Element Interaction

Trace element bioavailability is mediated by many factors other than its availability in the diet. As the preceding discussion of just a few elements has shown, an intricate network of interactions occurs between the elements themselves (Figure 3.1) and components of food. Many naturally occurring substances in foods, such as amino or organic acids may chelate with mineral elements in the

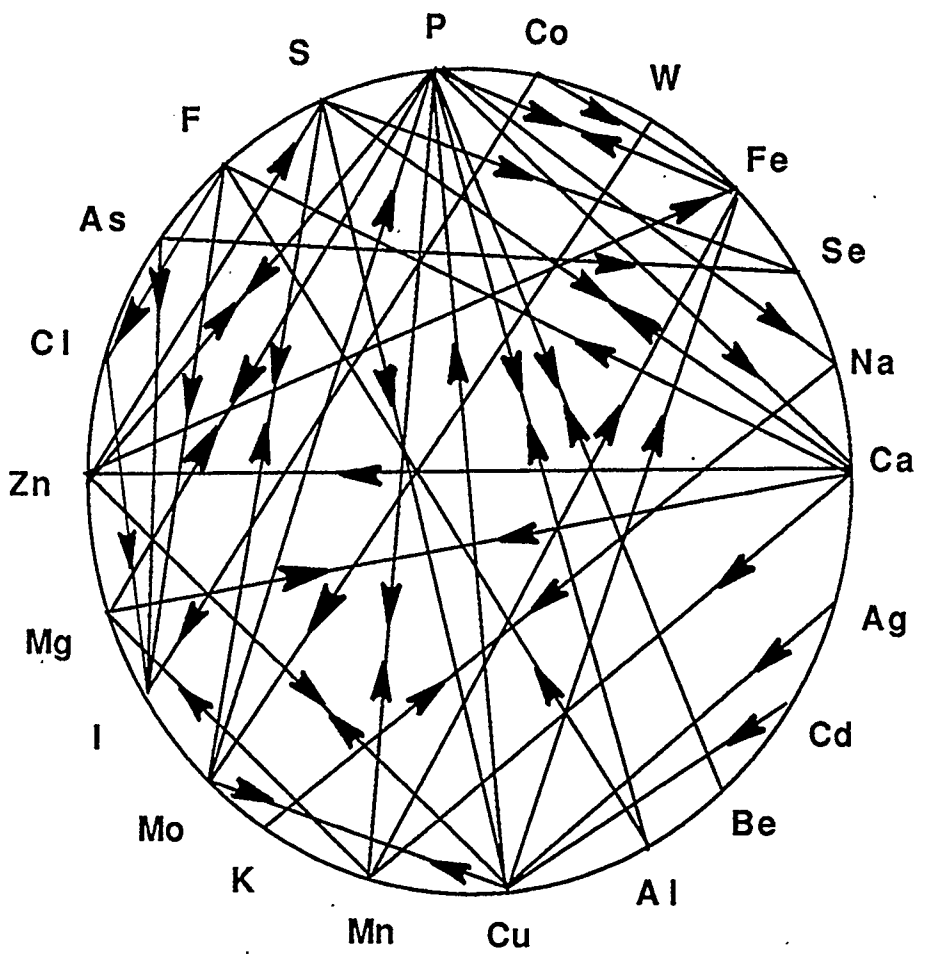


Figure 3.1 Mineral Interaction Chart Showing the Interrelationship of Minerals (from Ensminger et al 1983:1508)

digestive tract, resulting in either enhancement or reduction of mineral absorption (Ensminger et al., 1983b:1533). Phytates, which are poorly utilized phosphorous compounds present in the outer layer of grains, bind with such minerals as calcium, iron, and zinc and therefore interfere with their absorption. Oxalates, present in rhubarb, spinach, cashews, cocoa, tea, and almonds, also bind to calcium and/or iron, rendering them biologically unavailable. Conversely, similarities between metals may act to inactivate chelating agents because they may compete for binding to the chelator (Ensminger et al, 1983b:1533-1354).

As is only too clearly illustrated in figure 3.1, many elements interact with each other in complex pathways. This may be only further compounded by the effects of food processing.

Food Processing and the Elements

Preparation of meals involves procedures which influence element availability (Ensminger et al, 1983b:1534-1538). Large amounts of peelings and trimmings may be richer in certain minerals than the portion which is retained. The outer green leaves of cabbage, for example, contain from 1.5 to 3 times as much iron as the inner, bleached leaves. Vegetables soaked in water prior to cooking also tend to lose mineral content through leaching.

Cooking results in the most significant mineral losses. Boiled cabbage results in up to a 72% loss of calcium, a 76% loss of magnesium, a 60% loss of phosphorous, and a 67% loss of iron (Ensminger, et al, 1983b). Baking, frying, steaming, and roasting do not have as significant an impact as boiling. Food processing also may result in an increase in mineral values. The homogenization of vegetables results in greater iron availability since the procedure breaks down fibrous cell walls. Yeast fermentation results in the breakdown of phytates in whole grain bread, decreasing their role as competitive chelating agents. The same results were also noted for the effects of fermentation, drying, frying, and cooking on phytates in cassava, cocoyam, maize, sorghum, rice, cowpea, and soybean (Marfo et al.,1990). Similarly, soaking spinach and rhubarb removes oxalates. Bressani and Scrimshaw (1958) demonstrated that the lime treatment used in the manufacture of tortillas in Central America increases the bio-availablility of several of the essential amino acids. Katz et al (1975) applied this data in a pioneering study that demonstrated the significance of considering food preparation procedures for various anthropological data, concepts, and theories.

Clearly, interpretation of paleodiet from trace and major element analysis of human archaeological bone is currently much more problematic than interpretations based on stable isotopes. Buikstra et al (1989:156), echoing the

conclusions of the Katz study, conclude that among other problems, studies employing multi-element approaches to the reconstruction of paleodiet "have produced mixed results as a result of ... imprecise estimations of expected trace element patterns in ancient menus". This is in part based on a lack of research, oriented specifically to an archaeological context. Despite the findings of the Katz et al study in 1975, the paleodietary literature continues to assume that trace and major element levels in food are not significantly affected by processing (Buikstra, 1989: 155). The Katz study suggests that this clearly not the case. Thus the question remains: Does food processing alter the predicted relationship between element concentration and different food sources enough to make it difficult to distinguish diet? In this context it is especially important to consider the effects of procedures (such as baking or boiling) that are commonly employed over a long enough period of time to be reflected in human bone.

CHAPTER 4
BACKGROUND TO THE REFERENCE POPULATION

Selection of Sample Population

A historic population whose diet is relatively simple, based on food availability, and can also be easily reconstructed through historic records, is ideal as a reference population for this study. The human remains chosen as a reference for the food data in this study are from the excavations of St. Thomas Anglican Church in Belleville, Ontario. The St. Thomas' project arose out of a decision by the church to build a new parish hall on the site of the abandoned 19th century burial ground (Herring et al., 1991). Burials took place at the church cemetery for a period of 54 years between when the original structure was first erected in 1820, until 1874. (Bellstedt, 1969:19). In the summer of 1989, 579 graves were excavated. Osteological and historical research was conducted before the remains were reinterred in 1990. Bone samples were collected at this time with the view to conducting ultrastructural and chemical analyses (Katzenberg and Saunders, n.d.).

In order to better understand the burial population a short history of Belleville covering the time period in question is necessary.

History of the City of Belleville

The modern city of Belleville is located on the shores of Lake Ontario at the mouth of the Moira river, between Toronto and Kingston (Figure 4.1). While the vicinity of Belleville has a long history of occupation by indigenous people, the first European settlement dates as recently as 1668 and lasted only until 1682. Mika and Mika (1975:13) describe it as an Indian mission to the Cayugas known as the Quinte mission. The settlement's short duration was due to the excessive costs of the venture and its apparent lack of success as a mission. The next infusion of settlers did not occur until during and after the American revolution and consisted largely of United Empire Loyalists. With the arrival of the Loyalists the region was introduced to English laws, religion, and culture, where previously it had been governed by French Quebec (Boyce, 1967:27). Beginning in 1784, lands along the Bay of Quinte were settled (Mika and Mika, 1973:32). Among the first settlers was a Loyalist by the name of Captain George Singleton. From 1785 until his death in 1789 he conducted a profitable trading business resulting in the settlement at the mouth of the river being named Singleton's (Boyce, 1967:32). After Singleton's death Captain John W. Meyers became the leading merchant of the community. Because he established the area's first industries (a sawmill and a gristmill), the community became known as Meyer's Creek in his honour (Boyce, 1967:33-34).

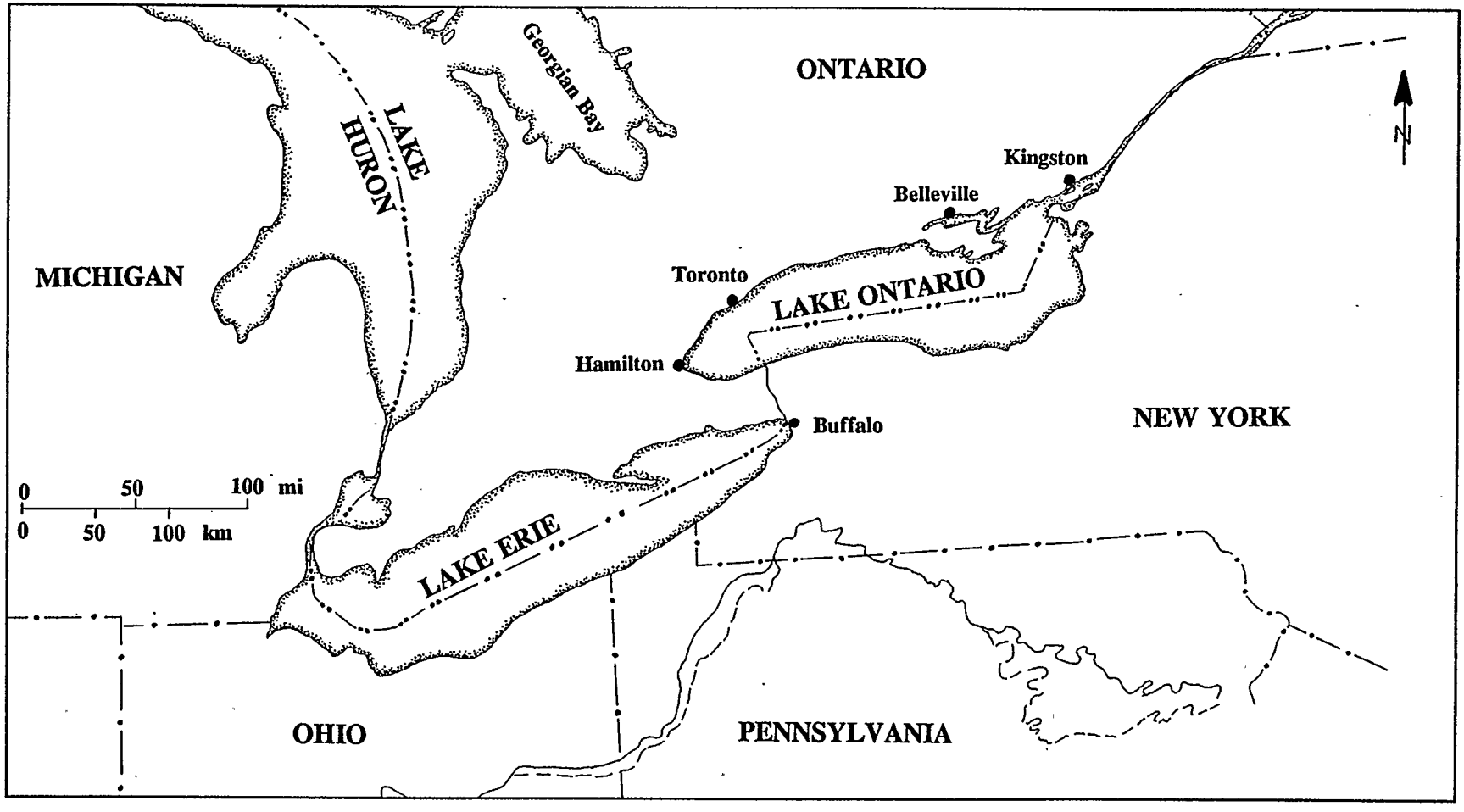


Figure 4.1 Map of the eastern Great Lakes region showing the location of the town of Belleville.
(from Herring et al, 1991)

Following the war of 1812-1814 Captain Meyer's loyalties during the war were rumoured to be suspect. It may be that this prompted the final name change of the community to Bellville (some original documents show it spelled without the "e") in 1816. At this time Bellville had reached a population of approximately 150 people and boasted over 50 homes, stables, taverns, and other buildings (Mika and Mika, 1973:45). Although contentious, the naming of the community is believed by some to have been in honour of Lady Arabella Gore, wife of the provincial Lieutenant Governor at that time, Sir Francis Gore (Boyce, 1967:44).

The community continued to grow and prosper. By 1836, when Belleville was incorporated as a police village, the population had reached 1700 inhabitants. There were at this time 380 private dwellings, 26 merchant shops, 12 huxters and grocery shops, 3 breweries, 2 flour mills, 7 blacksmith shops, 2 wheelwrights, 2 tanneries, 2 apothecaries and druggists, 9 taverns, 2 butchers, 4 sawmills, 1 pail factory, 3 cabinet makers, and 2 harness makers (Mika and Mika, 1978:9).

Belleville's leading industry from the 1840's until well into 1870's was lumber. The arrival of the Grand Trunk Railway in 1856 provided further impetus for continued growth (Mika and Mika,1978:11). With both a port and a railway station a steady flow of lumber, grain, and flour were exported while more fineries and fancy goods were

imported. By 1870 the town of Belleville reached a population of 7300. The 1877 census recorded a population of 11,200 and city status was granted by the provincial government (Mika and Mika, 1978:16).

Bellstedt (1969:5-20) provides the most comprehensive account available of the history of St. Thomas Anglican Church and the following description is adapted from her publication. The St. Thomas Anglican Church congregation of Belleville was formed on December 26, 1818. The building of the first church was completed by June 1821 when the first service is recorded to have been held. The first burial service took place in the church on August 30, 1821. The original structure is described by Susanna Moodie (1853:23) as "...a homely structure; and has always been to me a great eyesore". However, the churchyard enjoys "the finest view of the surrounding country". When the original structure became too small to handle the size of the congregation, it was replaced by a stone structure in 1858. Unfortunately, in 1876 it was destroyed by fire. The church was once again rebuilt and opened for services on December 28, 1879. Almost 100 years later the church was once again destroyed by fire. The outer walls and tower remained standing so that when the current structure was erected it was possible to maintain these remnants of the historic building (Mika and Mika, 1978:80).

Dietary Reconstruction from Journals, Historical Records, and Interviews

A great deal has been written about the dietary habits of 19th century inhabitants of Ontario. It is important for the purposes of this study to gain as localized an image as possible of the types of food that were available to the inhabitants of Belleville, and also as to the methods of preparation. The most useful primary sources of information include journals, emigrant guides, and local newspapers. Contemporary research papers were another very valuable source of information. Interviews were also conducted with the following individuals; the curator of the Bradley House Museum in Mississauga, Ontario; the gardener/historian at the Bellevue house national historic museum in Kingston Ontario; and historian Gerald Boyce of Belleville, Ontario.

Types of Food Available in Belleville

European visitors were impressed with the abundance of food on Canadian tables but often remarked on the sameness of the meals (Talbot, 1824; and Proudfoot, 1915). Although most households observed a daily meal schedule of three meals, consisting of breakfast, dinner, and supper, there was not a great deal of difference in the food served at each (Kenyon and Kenyon, 1992:10). Unlike the English meal pattern, items like meat, bread and tea appeared at every

meal. Kenyon and Kenyon (1992) examined over 120 sources and found that meat was mentioned more than 60% of the time as being present at all three meals. Their survey of food consumption in Upper Canada in the early 19th century concluded that pork, potatoes, and wheat flour formed the basic dietary staples. The pork and potato diet was, however, generally considered the backwoods diet of the emigrant until settled and established; "The emigrant must not expect to live very comfortably at first. Pork, bread, and what vegetables he may raise, will form the chief part of his diet for at least two years" (Howison, 1821:256). Belleville between 1820 and 1870, however, was no longer a backwoods community and its inhabitants therefore enjoyed access to a more diverse diet.

> "...we enjoyed...many of the comforts of a cleared farm; poultry of every kind, beef of their own killing, excellent mutton and pork: we had a variety of preserves...with honey in the comb, delicious butter, and good cheese, with divers sorts of cakes; a kind of little pancake, made from the flour of buckwheat...also a preparation made of Indian corn flour...eaten with maple syrup..." (Traill, 1836:100).

and

> " [we]...were gathered round the table, which groaned, metaphorically speaking, under the load it bore. There were turkey, beef and ham, bread and favorite short cake, sweet cakes in endless variety, pies, preserves, sauces, tea, coffee, cider...The visitors were amazed...at the lavish display of cooking" (Haight, 1885:14).

Belleville's inhabitants enjoyed access from an early date

not only to the produce and livestock from local farms, but also to goods imported from the larger markets of Kingston and Toronto. These were the markets to which goods from Europe were sent and Belleville's strategic location between them ensured that the more exotic goods would also be readily available there.

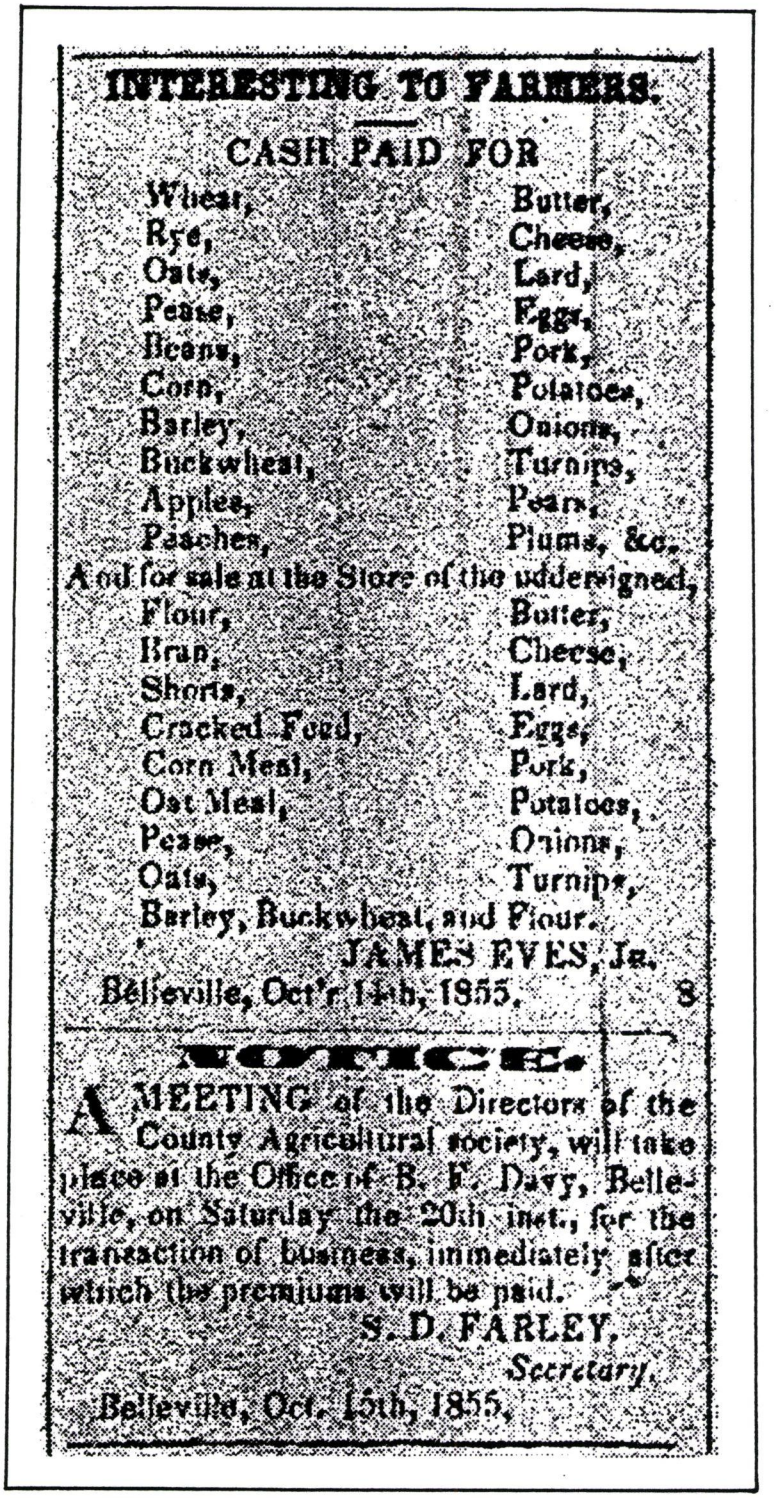
The letters of William Hutton, an Irishman who settled with his family on a farm just outside of Belleville in 1834, provide a valuable first-hand account of the setting up and maintenance of a farm in the area (Boyce, 1972). Other accounts such as *The Canadian Settler's Guide* (Traill, 1855), *The Backwoods of Canada* (Traill, 1836), the letters of Anna Leveridge (Tivy, 1972), and Canniff's *The Settlement of Upper Canada* (1869) provide the same basic vignette. However, Hutton's account is particularly useful not only because he had direct ties to Belleville during the period of investigation but also because he describes in some detail the types of crops planted, his livestock, and family lifestyle.

In his first year Hutton planted a few acres of potatoes and purchased two cows and a pig (the basic "backwoods" staples). He also makes mention of the usefulness of turnips, dutch cabbage and carrots as they can be preserved in a cellar. At the same time the Traill (1836:70) family had planted oats, corn, pumpkin, potato and turnip; with plans for the following year for wheat, rye,

oats, potato and corn. Bread for the Hutton household was being baked at home with yeast being procured from a nearby brewery. Hutton described maple sugar as being good for culinary purposes but not pleasant in tea, while Traill (1836:65) actually preferred it to muscovado sugar. By 1837 the Hutton livestock included sheep as well as pigs and cows. Hutton's wife Fanny was making butter to be sold in town. Their crops included primarily wheat and potatoes, but also onions, carrots, cabbages, turnips, and apples. In 1840 they added beets, cucumbers, melons, and Indian corn to this assortment. Surplus crops and livestock were sold at the markets of Kingston, Belleville, and Toronto. Livestock were largely left to forage in the summer with their diets being supplemented by crops grown on the farm. The hogs were fed on Indian corn while the cows were fed either turnips or mangelwurzel, a Eurasian variety of beet-root plant imported from Europe. Hutton adds that some farmers preparing sheep for market in Toronto fed them on turnips and chaff and occasionally some ground corn. While Traill remarks on the plentiful supply of fish for those living near lakes and rivers (1855:161), fish do not appear to have formed a dietary staple for settlers. Few references to fishing or fish consumption are to be found in primary accounts (such as Hutton, Tivy, Haight, and Traill), suggesting that fish played a largely supplemental role in the diet of settlers. The same can also be said for

venison.

That Hutton's personal accounts of the food grown or available can be seen as a reflection of the Belleville community as a whole is evidenced in publications of local newspapers of the time. Ads run by store proprietors offer cash for produce from local farms such as Hutton's and are particularly useful since they were run as lists (Figure 4.2). Newspapers also provide the best idea of the items that were imported. Canton Tea Store, for example, often placed advertisements in *The Hastings Chronicle* listing their most recent imports. In December of 1855 these included various sugars, molasses, coffee, tea, raisins, nuts, alcohol and spices. Catherine Parr Traill specifically notes in *The Canadian Settler's Guide* (1855:122) that although maple sugar was once considered an important source of sweetener, by the time of publication, the West India sugars were easy and cheap to procure. While Hutton bemoaned the want of available vegetable varieties in a letter to his mother December 5, 1834 (he was thanking her for the seeds she had sent from Ireland), by 1869 the Apothecaries' Hall in Belleville was advertising the availability of a variety of seeds from the "best British and foreign Seedsmen" (Figure 4.3). The Yonge Street Seed Store in Toronto was open as early as 1836 (Becker, 1979:11).



INTERESTING TO FARMERS.

CASH PAID FOR

Wheat,	Butter,
Rye,	Cheese,
Oats,	Lard,
Pease,	Eggs,
Beans,	Pork,
Corn,	Potatoes,
Barley,	Onions,
Buckwheat,	Turnips,
Apples,	Pears,
Peaches,	Plums, &c.

And for sale at the Store of the uddersigned,

Flour,	Butter,
Bran,	Cheese,
Shorts,	Lard,
Cracked Feed,	Eggs,
Corn Meal,	Pork,
Oat Meal,	Potatoes,
Pease,	Onions,
Oats,	Turnips,

Barley, Buckwheat, and Flour.

JAMES EVES, Jr.

Belleville, Oct'r 14th, 1855. 8

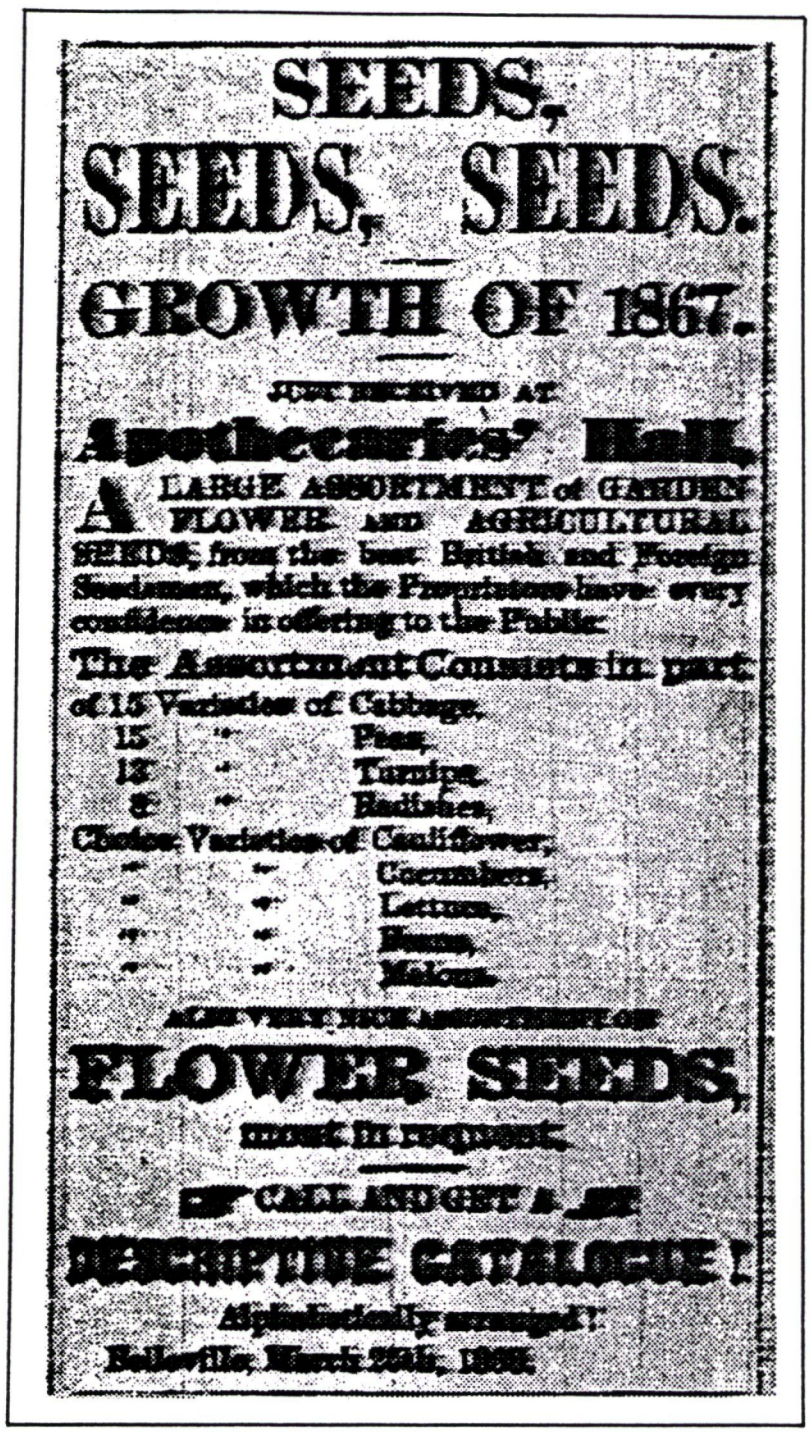
NOTICE.

A MEETING of the Directors of the County Agricultural society, will take place at the Office of B. F. Davy, Belleville, on Saturday the 20th inst., for the transaction of business, immediately after which the premiums will be paid.

S. D. FARLEY,
Secretary.

Belleville, Oct. 15th, 1855.

Figure 4.2 Advertisement for the purchase of produce from farmers.
(from The Hastings Chronicle October 1885)



SEEDS,

SEEDS, SEEDS.

GROWTH OF 1867.

JUST RECEIVED AT

Apothecaries' Hall,

A LARGE ASSORTMENT of GARDEN FLOWER AND AGRICULTURAL SEEDS, from the best British and Foreign Seedsmen, which the Proprietors have every confidence in offering to the Public.

The Assortment Consists in part of 15 Varieties of Cabbage,

15 " Peas,

12 " Turnips,

6 " Radishes,

Choice Varieties of Cauliflower,

" " Cucumbers,

" " Lettuce,

" " Beans,

" " Melons,

ALSO VERY NICE ASSORTMENT OF

FLOWER SEEDS,

most in request.

CALL AND GET A

DESCRIPTIVE CATALOGUE!

Alphabetically arranged.

Belleville, March 20th, 1869.

Figure 4.3 Advertisement for foreign stock seeds (from The Hastings Chronicle March 1869)

Food Preparation

Research on localized food preparation practices can be problematic in that it may require access to manuscript cookbooks. Many of them are, however, privately owned heirlooms and difficult to gain access to. It is fortunate for this study that some of the most prolific writers of 19th century Ontario were women who lived in Belleville and the surrounding area. It is even more significant that some of the publications were intended for potential settlers and therefore have sections devoted to food availability and processing.

> "As even the materials differ, and the method of preparing food varies greatly between the colony and the Mothercountry, I have given in this little book the most approved recipes for cooking certain dishes..."
> (Traill, 1855:preface)

The "raising and making of bread" is especially emphasized by Traill (1855:4) in *The Canadian Settler's Guide* where she describes "the making and baking of REALLY GOOD HOUSEHOLD BREAD" as a "thing of the greatest consequence to the health and comfort of a family". Bread was one of the staple items that appeared on the table at every meal and is described by Traill (1855:86) as a "most essential article of diet". Many farmers and settlers did not initially have a stove so bread was baked in an iron bake kettle before a wood fire. Recipes most often suggested by Traill and others (e.g. MacFarlane, 1831) include whole wheat and Indian meal breads. Corn is

described as of great use; "In all new settlements it is made into cakes and is almost the only bread made use of." (Grece 1819:144).

Bates (1979:28-29) describes nineteenth century recipes for vegetables as unimaginative on the whole. The most popular vegetables, which included potatoes, cabbage, cauliflower, spinach, turnip, asparagus, peas, carrots, green beans, corn, cucumbers, and onions, were cooked in boiling water, drained, and served with melted butter. Traill (1855) suggests some simple boiling recipes for potatoes, peas, and corn.

Meat was often cured by salting and stored in barrels for long term preservation. Traill (1855) recommends against salting for beef to be used within seven to ten days. As with vegetables, meat preparation was usually not diverse. Most accounts describe it as being either boiled or fried (e.g. Langton, 1964; Darling, 1849; Kennedy, 1903; and Pickering, 1831). Boiling was sometimes employed for salt-cured meats prior to frying as a means of reducing the salt content (Darling, 1849).

Kitchens in Canadian homes changed a great deal during the nineteenth century. It is also important to note that these changes were not uniform and that just as today there was a great deal of overlap of periods, methods, and utensils (Duncan, 1979:15). Before the advent of the cooking stove, settlers' kitchens were dominated by a large,

functional fireplace. Cooking was done on the open fire, over embers, or in pots hung by varying lengths of hooks from a so-called iron crane (Durand, 1897). Baking was done in brick ovens or before fires in a bake-pan (Langton, 1964). Although a closed top cooking range was patented in England in 1802, the first real references to the use of the stove in Canada do not appear until the 1830's (Duncan, 1979:17). Anne Langton (1964) writes of her first stove in 1838. Traill (1855) recommends a good cooking stove for the kitchen to emigrants. For both the stove and the fireplace, however, the cooking vessels were made of the same material; iron. Utensils were made of tin, wood, or iron.

Relative Proportions of Foods Comprising the Belleville Diet

Some of the emigrant guides from the nineteenth century attempted to provide prospective settlers with approximate quantities of provisions they might require to support their families before they had their own farms established (e.g. Anon.,1880:76; and Chessyre, 1864:76). Kenyon and Kenyon (1992:3) compiled and standardized these data along with estimates they derived from census and diary data (Table 4.1a). Daily food consumption was divided into three basic categories consisting of meat (in the form of either pork, beef, or mutton), flour, and potatoes. They standardized the data to represent pounds of flour, meat, and potatoes required daily by an adult male. Adult female equivalents

Table 4.1a
Quantities of Provisions Per Day Per Adult Male *

	Recommendations from Emigrant Guides		Estimates from Census/Diary Data		
Source: Item (lb)	Chesshyre 1864	Guide Book 1880	Census Estimate 1860	Diary Data 1830's-1840's	**Average**
Pork	.46	.31	.26	.38	.26
Beef/Mutton			.22	.26	.21
Total Meat	.46	.31	.48	.64	**.47**
Flour	1.19	1.24	.75	.55	**.93**
Potato	2.74	3.81	2.30	4.93	**3.45**
TOTAL lb/day	4.39	5.36	3.53	6.12	**4.85**

* adapted from Kenyon and Kenyon (1992:3)

Table 4.1b
Relative Contribution of Meat, Baked Items, and Vegetables to Daily Diet

Based on: (% total lb)	Chesshyre 1864	Guide Book 1880	Census Estimate 1860	Diary Data 1830's-1840's	**Average**
Pork	10.5	6.0	7.0	6.0	5.5
Beef/Mutton			7.0	4.0	4.5
Total Meat	10.5	6.0	14.0	10.0	**10.0**
Baked Goods	27.0	23.0	21.0	9.0	**20.0**
Vegetables	62.5	71.0	65.0	81.0	**70.0**
TOTAL	100	100	100	100	**100**

were calculated to represent 0.8 of the requirements of an adult male. All sources produced surprisingly similar recommendations. The data are adapted in this thesis as a means of estimating the contribution of various components relative to each other (Table 4.1b). The pound values have been converted into percentages of the total number of pounds for all categories such that 100% of the diet is represented in the sum of all three categories. The percent consumption of flour from Kenyon's table is interpreted here as the percent contribution of baked items to the diet. The percent consumption of potatoes is considered representative of the proportion of all vegetable staples to the diet. The meat category is comprised of the percent contribution of pork, beef, and mutton. This can be considered a fair estimation of both the male and female adult diet since absolute pound values have been converted to relative proportions, which are assumed to be similar for all adults.

Diet Reconstruction Summary

Although a great deal of information exits on the dietary options available during the short period of time relating to the burial population at St. Thomas Anglican Church, certain patterns and trends can be seen to emerge on the whole. To summarize:

1) The majority of meals were simply prepared. Meat and vegetable items were often just boiled or fried.

2) Meat (beef, mutton, pork), bread, and vegetables were the dietary staples. Sweetbreads and cakes were also popular.

3) Although three meals a day were generally served, the menu for each was not particularly distinct.

4) Settlers took advantage of, and clearly enjoyed, some of the sources not available in their homelands. These included corn, pumpkins, and maple sugar.

5) By 1820 the inhabitants of Belleville were beginning to get access to imported items because of the convenient location of the community.

6) Food was generally prepared in iron cookware, whether it be over a fire or in a cook stove.

7) Because of the similarity between amounts of provisions suggested by emigrant guides and reconstructed through diary and census data, information regarding the amounts of meat, flour, and potatoes required daily by an adult male can be extrapolated to estimate the relative proportion of meat, baked items, and vegetables in the diet of the adult population as a whole.

CHAPTER 5
SAMPLE SELECTION AND METHODS OF ANALYSIS

Selection of foods

Recipes were selected on the basis of several criterion. They had to not only cover a range of the foods available to the inhabitants of Belleville between 1820 and 1870, but also be recipes that would have been likely to have been chosen by the study population. As indicated in the previous chapter, primary sources of information included cookbooks, settlers' guides and newspapers dating to the 19th century. Contemporary research papers and interviews with historians and curators were of further value in reconstructing subsistence in 19th century Upper Canada. Five recipes in use by historic interpretive museums in southern Ontario were chosen. While far from exhaustive, a sample of six was chosen as a good survey of the foods available, while at the same time still manageable from the perspective of analysis. They included whole wheat bread, ginger bread, short bread, corn bread, pumpkin cake, and beef stew (see Appendix I for recipes). Where possible, all ingredients obtained were organically grown. In order to produce comparative data based on raw and processed samples, it is necessary to use the same raw material throughout. To this end, each time the same recipe was prepared, care was taken to ensure that the ingredients all came from the same

batch (e.g. the sugar used in each corn bread was from the same bag of sugar). All foods were prepared in a manner replicating as closely as possible food preparation techniques employed during the 19th century in Belleville. With the exception of the short bread, this included the use of an iron pot on loan from the Bradley Museum. It has been dated to the late 19th century. Each ingredient was sampled prior to inclusion in a recipe. Each recipe item was prepared ten times. For all the items that were baked, a sample of dough and then a sample of the cooked item was collected. For the beef stew, samples of all the ingredients were collected both raw and cooked. Samples were collected into glass vials or plastic zip-loc baggies and immediately frozen. They remained frozen until preparation for analytical procedures.

Selection of bone samples

Rib samples from the excavations of St. Thomas Anglican Church at Belleville were sent to the University of Calgary by Dr. S. Saunders of McMaster University. Sampling is restricted to the ribs for two reasons. Using the same type of bone controls for differences that may otherwise arise as a result of the use of different elements for the same study, and because the preparative methods are destructive, elements that have the least osteological significance are chosen for analysis. For the purposes of comparison with

the food in this study, only samples of documented age and sex were selected (Table 5.1). This was to ensure that the adult diet being reconstructed would be compared with known adults, and not children. Individuals of known sex were selected to determine if analytical procedures would indicate dietary sexual differences, despite the absence of any such indicators in the literature.

Preparation of food samples for mass spectrometry

Food samples require little preparation for introduction into the mass spectrometer. All food samples taken were transported and stored frozen. The samples with low fat content were freeze dried for a minimum period of 24 hours and then ground with an agate mortar and pestle to produce as homogeneous a mixture as possible. Some of the ingredients and the recipes prepared have a very high fat content and could not be freeze dried. These included butter, shortening, lard, and the raw and cooked versions of shortbread. It was also not possible to freeze dry maple syrup and molasses. These samples were submitted to the stable isotope laboratory at the University of Calgary under conditions of freezing along with the freeze-dried and ground samples, which could be stored at room temperature. Communication with the technicians at the stable isotope laboratory indicated that although samples were preferred in a freeze-dried condition where possible, high fat content

Table 5.1 Human Samples Selected for Analysis of $\delta^{13}C$

	Burial #	Age	Sex
15-45 years	B19	17	M
	B71	20	M
	B111	33	F
	B115	27	M
	B317	35	F
	B351a	22	F
	B385	35	M
	B423	22	F
	B429	43	M
	B433a	18	M
	B437	29	F
	B443	44	M
	B451	28	M
	B472	20	M
	B514	17	F
	B527a	31	M
46+ years	B31	62	M
	B97	65	F
	B103	75	M
	B108	60	F
	B124	67	F
	B156	55	M
	B188	67	F
	B287	48	M
	B303	58	M
	B304	57	F
	B336	81	M
	B339	55	M
	B374	64	M
	B375	60	M
	B397	75	M
	B405	68	M
	B435	62	F
	B436	66	M
	B446	69	M
	B462	59	M
	B464	46	F
	B467	54	M
	B470	53	F
	B516	69	F
	B544	71	F
	B548	61	M

samples do not present a problem for analysis on the mass spectrometer.

In total, 127 samples were submitted to the stable isotope laboratory. For the items that were baked this included a sample of each of the ingredients and 2 samples of each of five times a recipe was prepared; 1 sample of the dough and one of the cooked item. For the beef stew, each raw ingredient was sampled and then again once from each of five preparations of beef stew. Although each recipe was prepared ten times, the expense of running twice as many samples proved to be excessive. The extra five runs were retained for analysis in the event of loss of sample during analysis.

Preparation of bone samples for mass spectrometry

Unlike the food samples, bone samples require more involved preparation for mass spectrometry. Bone collagen extract (also called gelatin) is analyzed since it is a highly stable molecule and is less affected by diagenesis than the mineral portion of bone (Chisholm, 1989:22). The technique of extracting collagen used for this study was adapted from a method developed by Sealy (Sealy and van der Merwe, 1986). Schoeninger et al (1989) compared Sealy's method with those previously developed and found that the gelatin extracted by Sealy's method more effectively produced amino acid profiles consistent with collagen. It

is also much simpler than older techniques and requires less work. The bone samples are thoroughly washed and rinsed with distilled water. They are subsequently placed in a sonic bath for a minimum period of ten minutes to facilitate the removal of dirt from cancellous regions. Bones are air dried for twenty-four hours before they are broken into small chunks with a mortar and pestle, or a hammer for the tougher pieces. It is suggested that bone pieces should not be any smaller than $0.5cm^2$. Between 2 and 3 grams of bone are weighed into a minimum 100ml size beaker or glass bottle. A 2% solution of HCl (0.5M) is added to the sample. The solution is changed at least every other day for as long as is required for the bone to appear translucent and for no more gases to evolve from the bone. At this point the inorganic material has been dissolved, leaving a collagen replica of the original behind. The collagen replica, or gelatin, is quite rubbery and flexible. The gelatin is then rinsed to neutrality in distilled water and soaked in a solution of .125M NaOH for 20 hours. This step ensures the removal of the humic and fulvic acid contaminants. The collagen is once again rinsed to neutrality in distilled water, placed in pre-weighed scintillation vials, and frozen for a period of 24 hours. It is finally placed on a freeze-dryer for another 24 hours. The final weight of the gelatin is obtained and compared with the starting sample weight to provide a percent yield. Percent yield provides a rough

measure of preservation. Fresh bone yields approximately 25% collagen. Archaeological bone is considered well-preserved if a yield of greater than 15% is obtained, and adequate if a yield of greater than 10% is attained. Schwarcz and Schoeninger (1991) suggest that yields of greater than 25% may be an indication of incomplete demineralization, in which case the sample can simply be placed in acid again. Samples sent to the isotope laboratory at the University of Calgary require no further preparation.

Mass Spectrometry

A mass spectrometer functions to sort isotopes of an element mass-dependently and then compares the abundance of isotopes of an element to each other in a ratio that is expressed relative to a selected standard. The sample and standard are alternately introduced into the source of the mass spectrometer in the form of a gas, CO_2 for $\delta^{13}C$ and N_2 for $\delta^{15}N$. Older model mass spectrometers required that the samples be introduced directly into the machine in a gaseous form. The mass spectrometer in the Physics Department laboratory of Dr. H.R. Krouse at the University of Calgary, was used for this study. It is fitted with a Carlo Erba gas analyzer that combusts the samples and produces the correct mixture of gases required. These gases are then directly introduced into the mass spectrometer. Approximately 0.05g

of sample is weighed into a small foil cup, which is then sealed. Up to 100 foil cups can be placed into a rotating holder on the Carlo Erba.

Apart from the specialized Carlo Erba the mass spectrometer consists of three basic regions. These are the source, the analyzer, and the collector (Figure 5.1). The samples are individually introduced into the source after combustion by the gas analyzer. The source acts to ionize the sample by the application of heat and accelerates the ions out into the analyzer. The analyzer separates the ions according to mass by the use of magnets. The collector, or detector, collects and measures ion currents. At Calgary the entire process is computer controlled. Final measurements of isotope abundance are sent to a printer and corrections based on the standard are applied.

Preparation of samples for analysis of elements by atomic absorption spectroscopy

In order to analyze the metal content of an organic sample it is necessary to first decompose the organic portion of the sample entirely, thereby releasing the metals for analysis. The food samples were analyzed in the Geology Department at the University of Calgary on a micro processor-controlled Perkin Elmer 5000 atomic absorption spectrometer.

Analysis by atomic absorption spectroscopy requires

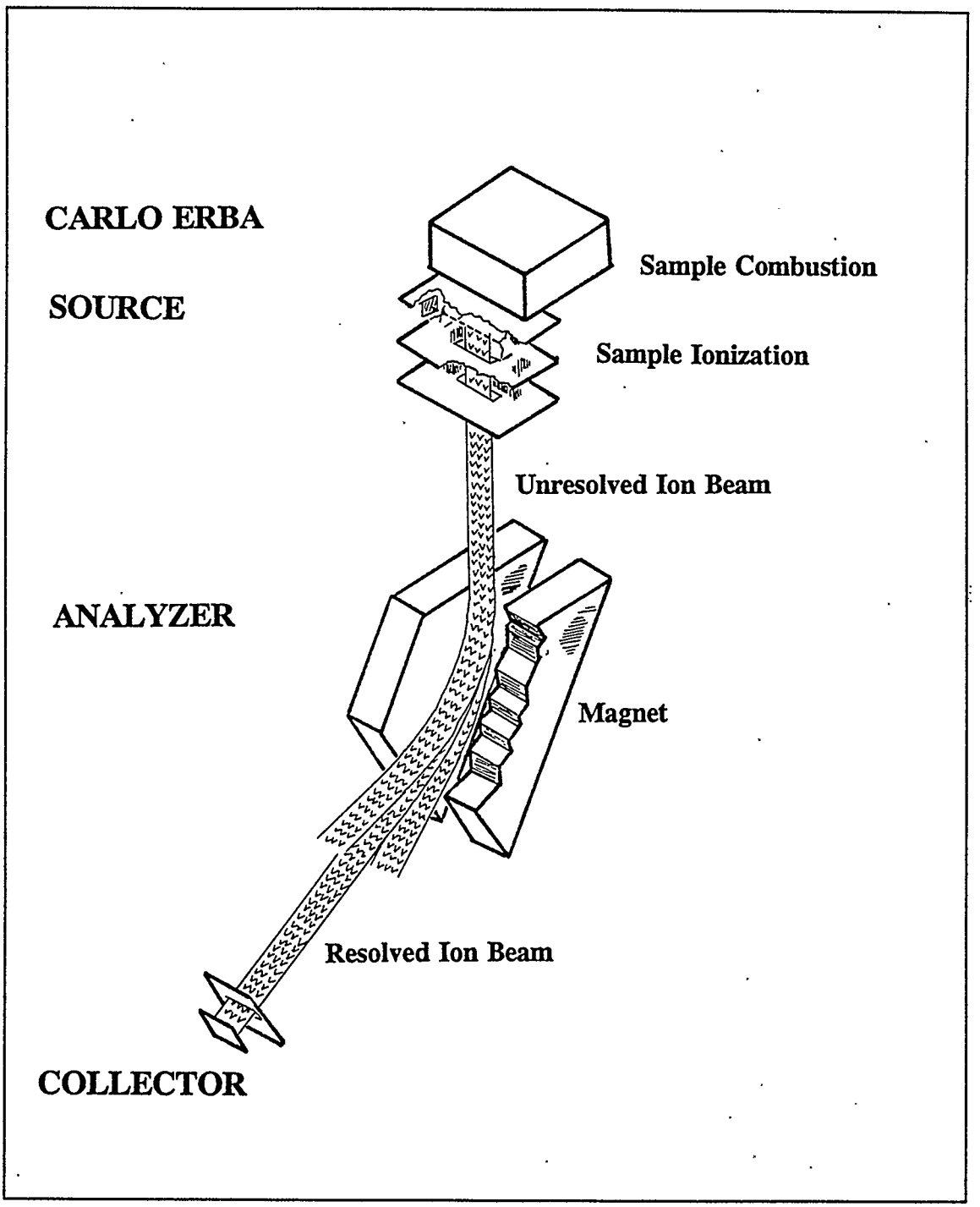


Figure 5.1 Diagram of a Mass Spectrometer with a Carlo Erba Gas Analyzer
(adapted from Rankama, 1954)

that the sample be in a liquid form. In order to release the metals from their organic matrix into solution a wet-ashing procedure is employed.

Wet-Ashing Procedure

Food samples were not subjected to any procedure prior to wet ashing to limit the potential losses of trace metals. Because atomic absorption spectroscopy provides a quantitative analysis, accurate results are critically dependant on absolutely minimizing the loss of metals at any stage in the procedure. The methodology for the digestion of each food type was adapted from those supplied by Seigniory Chemical Products Ltd, the supplier of the CEM MDS-2000 Series Microwave used for the digestion. Samples weighing between 0.5 and 1.0g were placed into teflon pressure vessels specifically designed for use with the pressure microwave. Larger sample sizes are not recommended for organic materials in this procedure to prevent the occurrence of an uncontrolled exothermic reaction inside the vessel once it has been sealed. It is possible to process up to 12 samples at a time. Once an adequate sample was weighed out into all vessels being used, 10ml of concentrated reagent-grade nitric acid was introduced. The vessels were then sealed and placed in the microwave. Pressure and temperature inside the vessels were slowly increased over a specified period of time, in a series of up

to five stages. Pressure conditions inside sample vessels are monitored and controlled by a built-in feedback control mechanism in the microwave. Sample digestion procedures were programmed into the CEM microwave system. Once the program had run to completion and the samples allowed to cool for a minimum of 10 minutes, the vessels were opened and the resulting liquid transferred into beakers. Digestion can be seen to be complete when no precipitate is seen in solution and the solution is clear in colour. Although this was not the case for the food samples digested, if a small amount of precipitate remains, it can easily be eliminated by a filtration step. Solutions were stirred on a magnetic hotplate for approximately 5 minutes to release some of the gas that was forced back into solution as a result of the pressure in the digestion vessels during digestion (Yeager, pers. com). Solutions were then transferred to borosilicate glass vials for storage prior to dilution. Dilution procedures will be described separately for each element analyzed in the next section. Diluted samples were stored in 60ml polyethylene bottles prior to use on the atomic absorption spectrometer. Because borosilicate glass bottles are both fragile and expensive, many laboratories use polyethylene plastics for storage of solutions for trace metal analysis. Polyethylene is inexpensive compared to borosilicate glass, and has been shown not to be a serious source of contaminant metals (Van

Loon, 1985:67). At each stage of the procedure where the digestate was transferred from one vessel to another, each discarded vessel was rinsed with double distilled water and the resulting solution added to the digestate in an effort to minimize metal losses.

Atomic Absorption Spectroscopy

Since the early part of the nineteenth century investigators in physics and chemistry have known that atoms absorb or emit radiation of only characteristic discrete wavelengths (MacLeod, 1973). When sodium is introduced into a normal (blue) flame, for example, a yellow flame is produced. The total amount of light energy (radiation) absorbed or emitted is equivalent to the concentration of the element in a sample. Atomic absorption spectrometers determine the concentration of individual elements in a sample by measuring the amount of external radiation absorbed by a sample introduced into a flame under controlled conditions. The radiation source applied is oriented specifically for the element of interest (MacLeod, 1973).

The atomic absorption spectrometer (Figure 5.2) requires that the element of interest in a sample be released in the form of free atoms since bound atoms do not absorb radiation at a predictable wavelength. A liquid sample is aspirated as an aerosol into a flame produced by

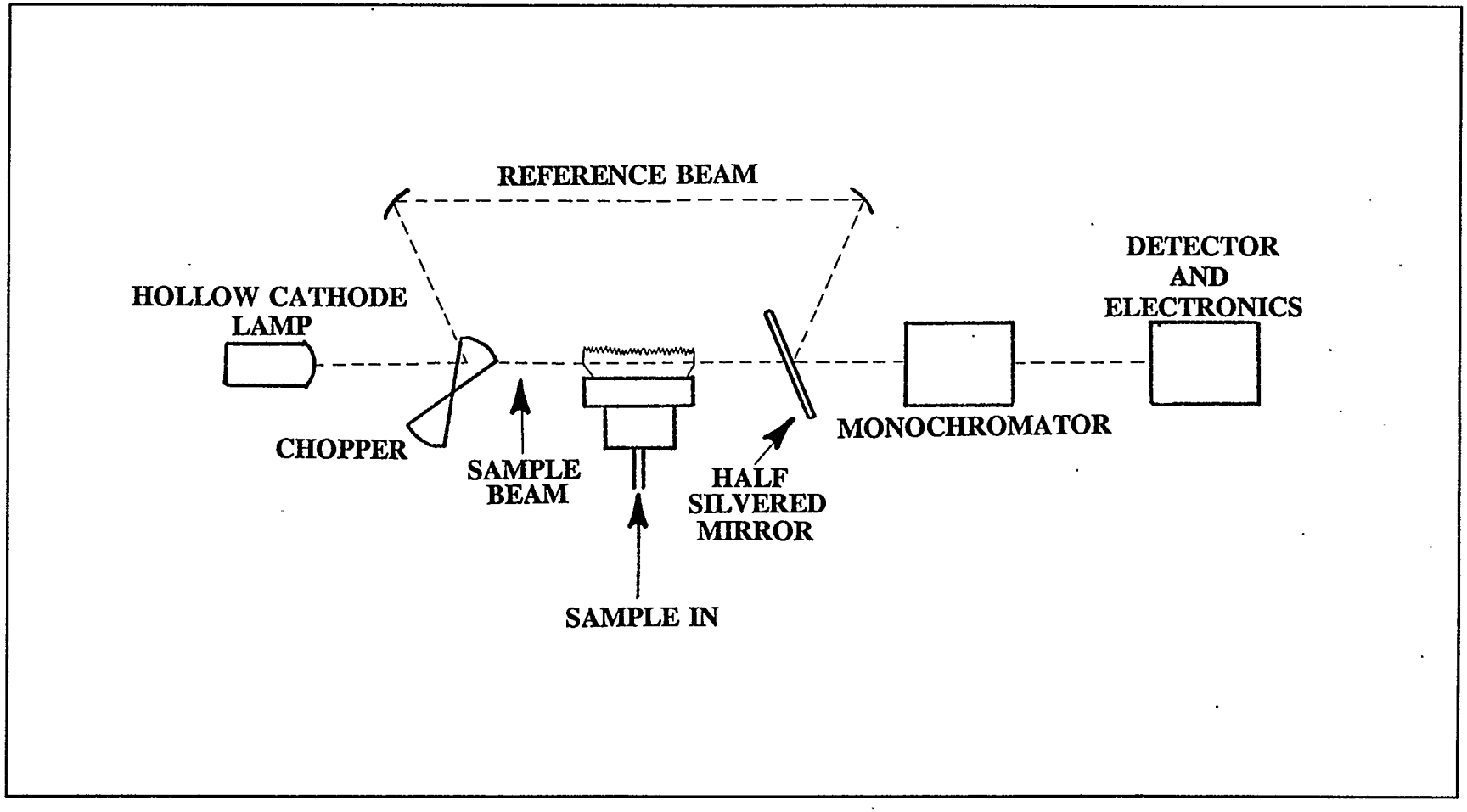


Figure 5.2 Diagram of a double-beam atomic absorption spectrometer (from MacLeod, 1973)

combinations of either nitrous oxide-acetylene, air-hydrogen, and air-acetylene. The choice of flame type is based on the temperature required to atomize the analyte. The atomizer produces free atoms from the aspirated sample. Radiation of characteristic wavelengths, commonly produced by hollow cathode lamps, is directed into the atomized sample. The intensity of the resulting radiation beam is attenuated by an amount proportional to the concentration of the element under consideration (Van Loon, 1985). The double-beam atomic absorption spectrometer used in this study alternates the path of the radiation source both through (sample beam) and around (reference beam) the flame. The two beams are then recombined and pass through a monochromator that isolates the desired wavelength from other absorbing or non-absorbing lines. This functions to increase the sensitivity of the machine. Finally, the detector and associated electronics produce a measurement of the quantity of the element of interest in the flame using the reference beam as a background reading, or blank (MacLeod, 1973). The detector is commonly a photomultiplier tube that amplifies the signal thereby further increasing the sensitivity. Absorbance (A) can be expressed as follows:

$$A = \log I_o/I = abc$$

where Io is the intensity of the incidence (reference) beam, I the intensity of the transmitted (sample) beam, a is a constant characteristic of the system in use, b the path length of the optical beam (which can be kept constant), and c the concentration of the element of interest in the atomizer (Van Loon, 1985:21). The equation predicts a linear relationship between absorbance and concentration, which in actuality only exists from the detection limit over two or three orders of magnitude. The precision drops off significantly at concentration levels around the detection limit and at very high concentrations at which the relationship between absorbance and concentration is no longer linear. Therefore the best precision is obtained at the mid-point of the straight line portion of the relationship between absorbance and concentration.

Preparation of Standards

A series of solutions containing a known concentration of the element being analyzed (standards), that bracket the range of concentration expected in the sample, are prepared. For the analyses performed in this study all standards were prepared in the Geology Department by Mr. Patrick Michael, the atomic absorption technician. Generally between three and five standards are prepared for each element. The first standard is a solution of the same acid matrix used for wet-digestion (in this case, nitric acid) that has been subject

to the same dilution procedures as the samples (described in detail below). This is the zero standard and serves as a means of controlling for background concentrations of elements present in the acid before the digestate is added to it. The rest of the standards represent known concentration intervals between the zero standard up to a point just beyond the highest anticipated sample concentration. The standards are initially used to set up a relationship between absorbance and known concentrations within the linear range and are then used as a periodic verification of the consistency of the linear relationship while the samples of unknown concentration are being run.

Dilution Series (Fig. 5.3)

Because wet-ashed food samples generally contain concentrations of elements well beyond the linear range of detection of the atomic absorption spectrometer, dilution is required. The ideal dilution places the concentration of the sample at the mid-point of the linear range.

Zinc Dilution

All samples were initially diluted to 25ml by the addition of double distilled water in a volumetric flask. Since the initial zinc concentration values for meat samples were beyond the linear range, they required an even further dilution. A 5ml aliquot was removed from the initial

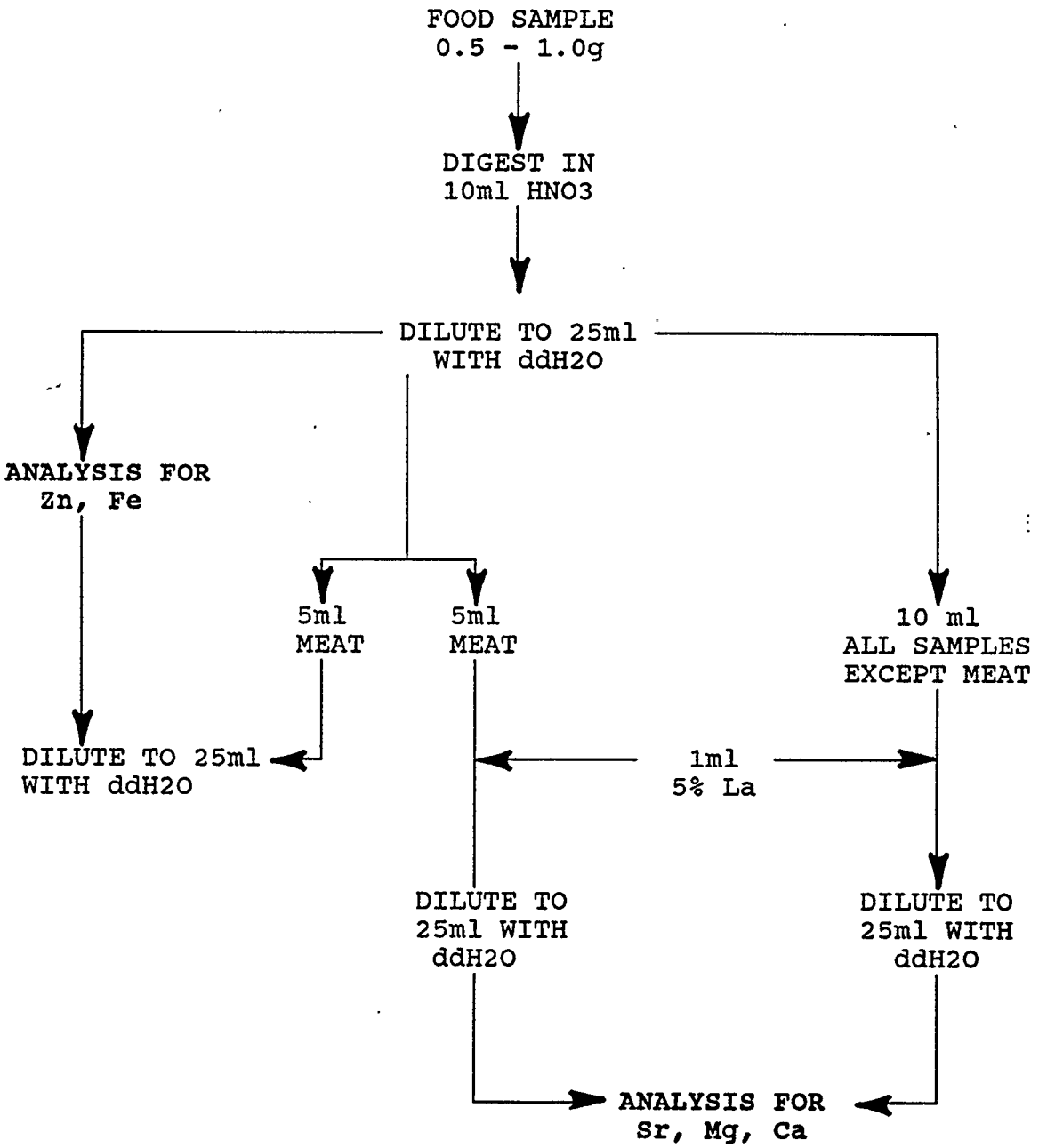


Figure 5.3 Dilution Series For Elemental Analysis of Food Samples Analysed by AAS.

dilution with a volumetric pipette and placed into another 25ml volumetric flask, which was then filled to volume with double distilled water.

Iron Dilution

The initial dilution of the original digestate to a 25ml volume by the addition of distilled water was sufficient to capture the concentration of iron in all samples.

Strontium, Calcium, and Magnesium Dilution

These three elements are problematic for flame absorption spectroscopy because their high ionization potentials may cause them to react with the products of ionization of oxygen and sodium released by the flame. The compounds formed by the reaction are outside the expected absorbance spectrum for the target element. Errors in determination of element concentration can therefore result. In order to prevent such reactions an element with a very high ionization potential is added to the solution matrix. The element commonly used is lanthanum.

The initial dilution solution for zinc and iron was used as a stock solution. A 10ml aliquot of each sample was removed from the stock solution with a volumetric pipette and placed in a 25ml volumetric flask. For the beef samples a 5ml aliquot was removed from the stock solution and placed

in a 25ml volumetric flask at the same time as another 5ml aliquot was removed for the second required zinc dilution. This was suggested (Michael, pers com) since the original 25ml stock solution was not large enough to permit both a second zinc dilution and a 10ml contribution for the analysis of the remaining elements with enough left over stock for iron analysis. A 1ml solution containing lanthanum was added and the flasks were filled to 25 ml with double distilled water.

Operating Parameters (Table 5.2)

Samples were aspirated into the atomic absorption spectrometer for a minimum period of 10 seconds during which the sample was analyzed four times. The electronic readout then provides a sample average and standard deviation, providing a means of assessing the homogeneity of the sample and ensuring that enough analyte is getting into the flame during the time that the absorption is being read. This is important since occasionally air rather than solution may be aspirated. A large standard deviation may be an indication that the flow of solution into the flame is not constant enough for an accurate reading. Analysis by atomic absorption spectroscopy also requires that the instrument

parameters be reset each time a new element is examined. The parameters used for each of the five elements examined are summarized in table 5.2. A total of eighty-four samples were analyzed for each element.

Table 5.2
Atomic Absorption Spectrometer
Operating Conditions

Element	Wavelength (nm)	Slit Width (nm)	Lamp Current (ma)	Flame	Comments
Mg	285.2	0.7	3	A-A	Burner rotated 30°
Ca	422.7	0.7	12	A-A	
Fe	248.3	0.2	18	A-A	
Zn	213.9	0.7	6	A-A	
Sr	460.7	0.4	18	NO-A	

A-A is air-acetylene
NO-A is nitrous oxide-acetylene

CHAPTER 6
RESULTS OF STABLE ISOTOPE AND MINERAL ANALYSIS

The previous chapters have provided the background for assessing the impact of food processing on stable isotope compositions and trace element levels. The use of an osteological reference population with a diet easily reconstructed through historical records affords the opportunity to provide a specific context for the results. As will be seen in the following analysis, this approach has allowed for a more detailed look at the range of inferences possible in the reconstruction of paleodiet based on chemical analyses of human remains.

Results of Analysis By Mass Spectrometry: Carbon Isotopes

Results of Analysis of Human Remains

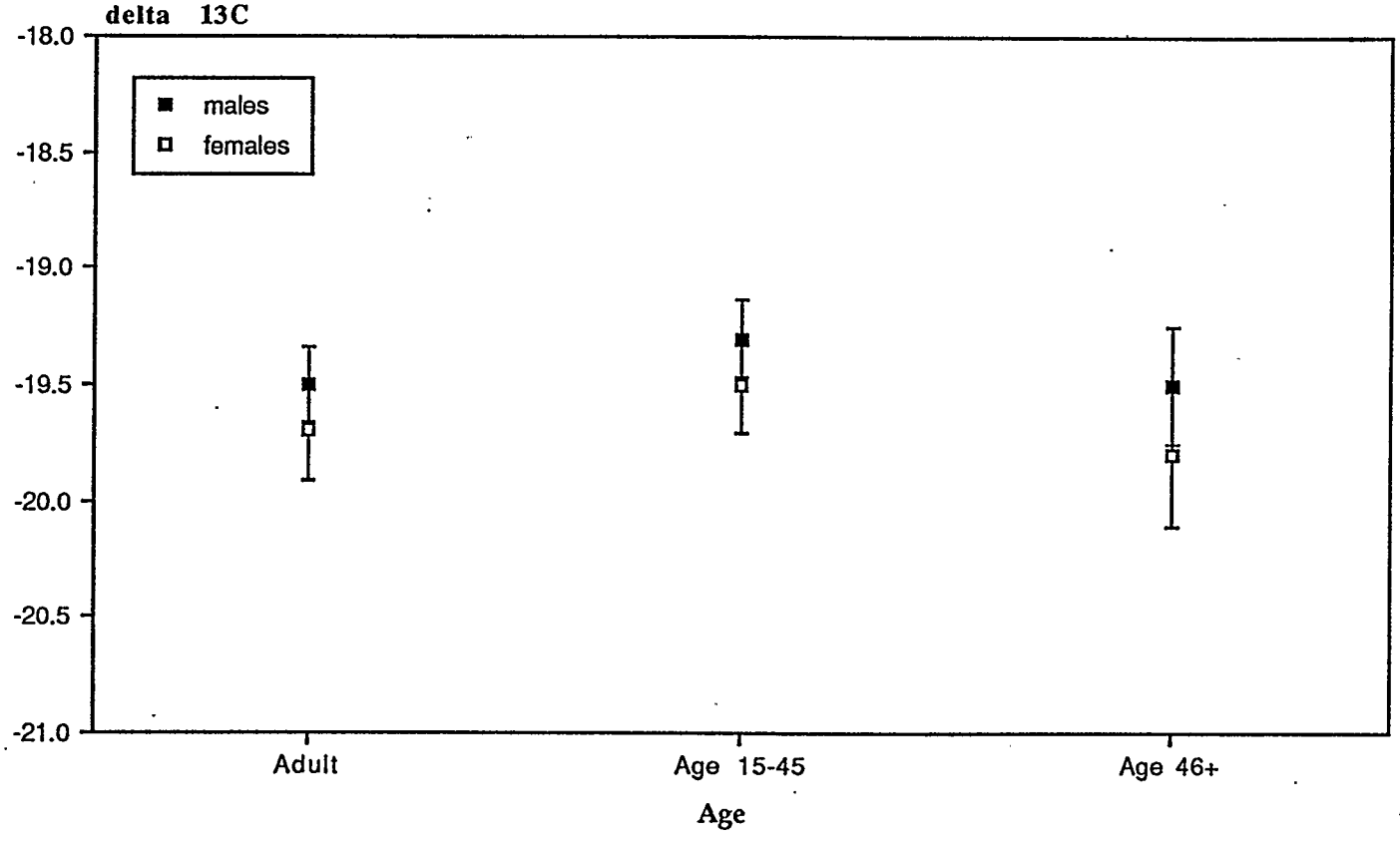
A total of 26 male and 16 females ribs were analyzed. Age and sex of each individual is known from parish records. Osteological methods of age and sex analysis conducted at McMaster University are consistent with the parish records, suggesting that they are quite reliable. The $\delta^{13}C$ values and percent collagen yield for each sample are reported with the rest of the raw data in Appendix II. Although C/N ratios are not yet available, the short term of interment, the percent collagen yield (greater than 10% for all samples), and visual assessment of good preservation, all argue for well-preserved collagen and a biogenic $\delta^{13}C$ signal. The data

were analyzed statistically using the F-test to determine if there were significant sex differences. See table 6.1 for basic descriptive and inferential statistics for the human material. No statistically significant differences were found although women are more negative for $\delta^{13}C$ than men. Figure 6.1 illustrates this point clearly. This may be a result of slight differences in the proportions of foods consumed between the sexes. Perhaps men are eating proportionately more meat and the women more vegetables. The mean $\delta^{13}C$ value of the adult population at $-19.5 \pm 1^{0}/_{00}$ is consistent with other analyses of emigrant populations of European ancestry. Katzenberg (1991) conducted chemical analysis of remains found in the nineteenth century Harvie family cemetery. The cemetery is located in Grand River between Hamilton and Kitchener, Ontario, and was in use between approximately 1825 and 1898 (Saunders, 1991). The Harvie individuals had a mean $\delta^{13}C$ of $-18.7 \pm 1.0^{0}/_{00}$. These are quite different from the historic Ontario Iroquois values around $-12^{0}/_{00}$, which indicate their reliance on corn as a dietary staple (Schwarcz et al, 1985). Katzenberg notes that the Harvie family carbon values are much more consistent with European values which Kennedy (1989) found to range around $-18^{0}/_{00}$ or $-19^{0}/_{00}$. Katzenberg concludes that the 19th century Canadian diet therefore relied more heavily on Old World staple grains rather than maize. These same

Table 6.1
Human $\delta^{13}C$ Descriptive and Inferential Statistics

Category	n	Mean	Standard Deviation	F-Test	p
Adult Males	26	-19.4	.83	1.47	.2327
Adult Females	16	-19.7	.83		
Males Age 15-45	10	-19.3	.52	0.64	.4358
Females Age 15-45	6	-19.5	.52		
Males Age 46+	16	-19.4	.99	0.91	.349
Females Age 46+	10	-19.8	.99		

Figure 6.1
Carbon Isotope Ratios of the St. Thomas Anglican Church Burial Population
Age and Sex Comparisons



conclusions are suggested for the individuals interred at St. Thomas Anglican Cemetery, Belleville between 1820 and 1870.

Results of Food Analysis

Table 6.2 reports the mean and standard deviation for the raw and processed foods examined. F-tests of significance were conducted between raw and processed versions of each recipe and are also included in table 6.2. As figure 6.2 illustrates, all of the baked items and most of the beef stew ingredients did not differ significantly between raw and processed at the 0.01 or the 0.05 levels. While the carrots and potatoes in the beef stew did differ significantly at the 0.01, and 0.05 levels, respectively, the actual $\delta^{13}C$ difference this represents is only $-1.2^{0}/_{00}$ for the carrots and $+1.0^{0}/_{00}$ for the potatoes.

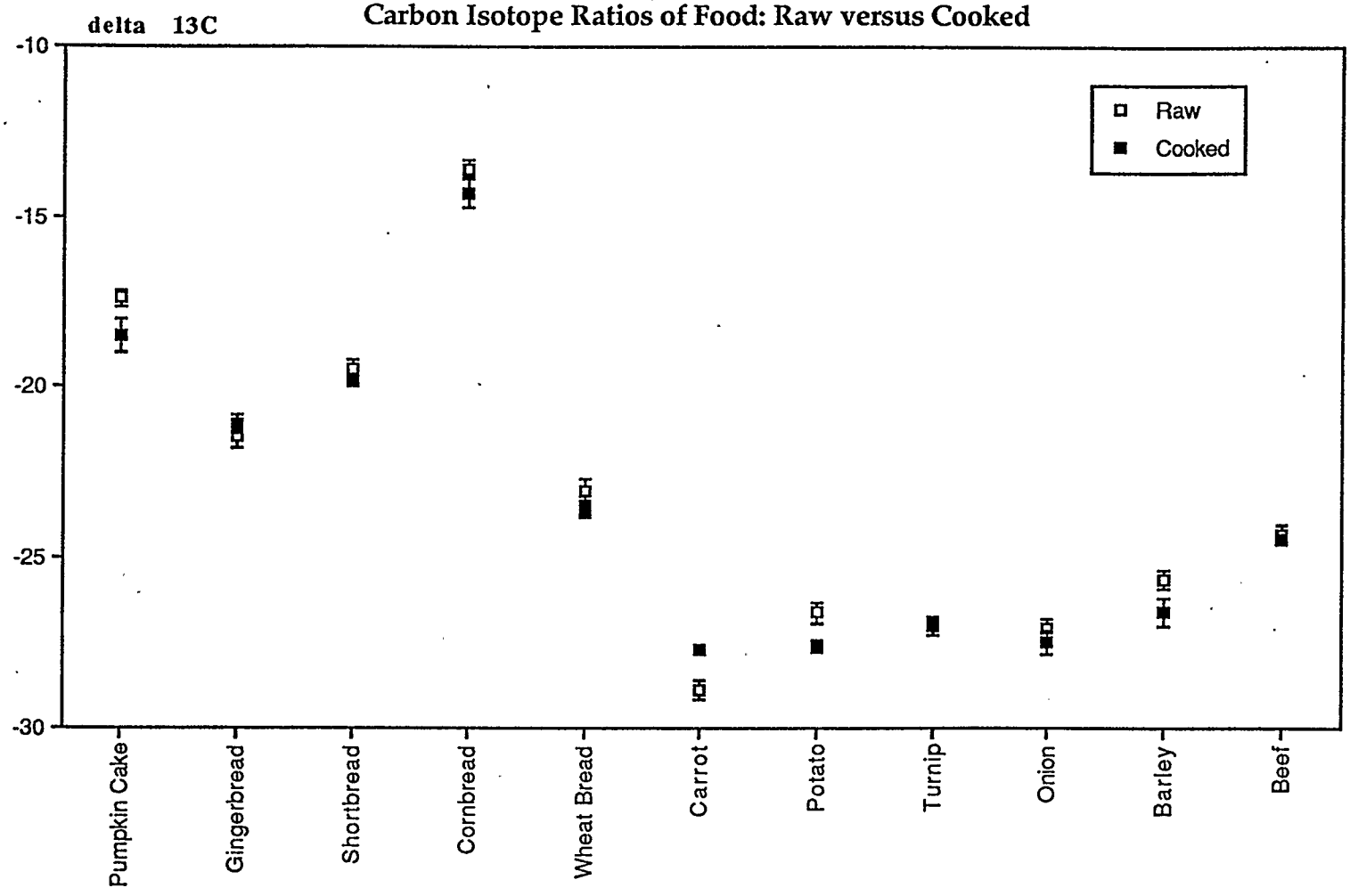
Weighted $\delta^{13}C$ of Food

The $\delta^{13}C$ food values in table 6.2 represent the mixed ingredients before and after processing. The results concur with those of other researchers, as reviewed in the introduction. None of the other studies have, however, gone one step further and looked at actual food processing practices, which include combining and mixing foods together. In this study, as well as analyzing the raw and processed mixed ingredients, each individual ingredient was

Table 6.2
$\delta^{13}C$ Results for Food Items
Descriptive and Inferential Statistics (Raw versus Cooked)

Item	Treatment	n	Mean $\delta^{13}C$	Standard Deviation	F-Test	p
Baked:						
Pumpkin Cake	raw	5	-17.4	.53	3.68	.0913
	cooked	5	-18.5	1.16		
Gingerbread	raw	5	-21.4	.86	.25	.6278
	cooked	5	-21.1	.65		
Shortbread	raw	5	-19.5	.62	.80	.3973
	cooked	5	-19.8	.42		
Cornbread	raw	5	-13.6	.63	1.91	.2047
	cooked	5	-14.3	.98		
Whole Wheat Bread	raw	5	-23.0	.65	2.82	.1318
	cooked	5	-23.6	.50		
Beef Stew:						
Carrot	raw	3	-28.9	.50	29.84	.0016
	cooked	5	-27.7	.11		
Barley	raw	3	-25.6	.46	2.94	.1374
	cooked	5	-26.6	.90		
Potato	raw	3	-26.6	.54	9.98	.0196
	cooked	5	-27.6	.40		
Turnip	raw	3	-27.0	.50	.04	.8453
	cooked	5	-26.9	.21		
Onion	raw	3	-27.1	.50	.55	.4868
	cooked	5	-27.5	.74		
Beef	raw	3	-24.3	.50	.38	.5587
	cooked	5	-24.4	.20		

Figure 6.2
Carbon Isotope Ratios of Food: Raw versus Cooked



analyzed. Knowing the proportions of each ingredient in a recipe, and having determined the $\delta^{13}C$ of each of these ingredients, it was possible to calculate the expected $\delta^{13}C$ of the whole recipe (Table 6.3). The weighted $\delta^{13}C$ value was calculated as:

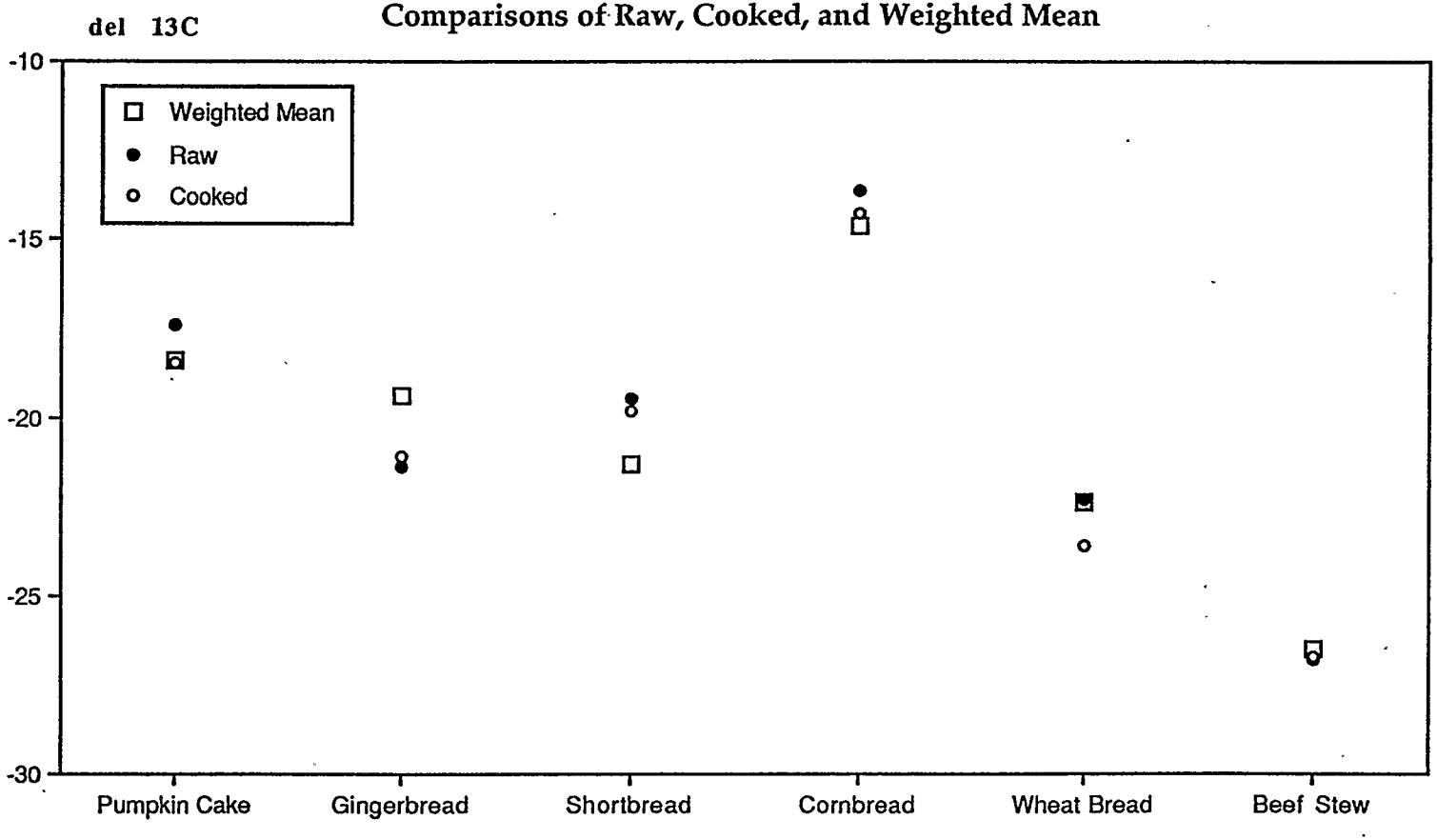
$$\text{weighted } \delta^{13}C = \Sigma[(\%I_r) \times (\delta^{13}C\ I_r)]$$

where I_r represents each individual ingredient in a recipe. Theoretically, if food processing does not alter $\delta^{13}C$, then the weighted $\delta^{13}C$ of the individual ingredients should predict the $\delta^{13}C$ of the cooked product. A comparison of the weighted $\delta^{13}C$ with the raw and cooked $\delta^{13}C$ indicates that this is not strictly the case (Figure 6.3). The weighted $\delta^{13}C$ of the pumpkin cake and corn bread is almost exactly the same as the final, cooked product. The weighted $\delta^{13}C$ of the whole wheat bread is essentially the same as the raw, mixed ingredients. Since there is no statistically significant difference in any of the above-mentioned groups between raw and processed, the weighted $\delta^{13}C$ can be said to be an accurate prediction of the final $\delta^{13}C$ of the cooked product. For the same reasons, the weighted $\delta^{13}C$ of the components of the beef stew can also be considered no different from the final product. A slightly different picture emerges for the gingerbread and shortbread, however. At a $\delta^{13}C$ of $-21.3^{0}/_{00}$, the shortbread prediction is approximately $1.5^{0}/_{00}$ more

Table 6.3
Weighted $\delta^{13}C$ Mean of Foods Based on Ingredient Proportions

Recipe	Ingredient	Quantity (ml)	$\delta^{13}C$	Mean $\delta^{13}C$
Whole Wheat Bread	flour	1500	-23.4	-22.4
	milk	500	-21.9	
	brown sugar	125	-12.7	
	lard	30	-17.1	
	salt	10	-26.3	
	yeast	10	-23.3	
Short-bread	flour	1000	-23.5	-21.3
	butter	500	-21.7	
	sugar	250	-11.7	
Pumpkin Cake	flour	250	-23.4	-18.4
	sugar	250	-11.7	
	pumpkin	250	-25.4	
	corn meal	250	-11.0	
	buttermilk	250	-22.3	
	lard	125	-17.1	
	egg	50	-17.9	
	baking powder	20	-11.6	
	baking soda	5	-10.1	
	salt	5	-26.3	
Corn-bread	corn meal	500	-11.0	-14.6
	milk	180	-21.0	
	egg	50	-17.9	
	butter	45	-22.9	
	maple syrup	7.5	-24.9	
	salt	3	-26.3	
Ginger-bread	molasses	500	-14.5	-19.3
	flour	500	-23.7	
	eggs	150	-17.9	
	butter	125	-21.7	
	ginger	30	-26.5	
	baking soda	5	-10.1	
	cream of tartar	5	-21.5	
Beef Stew	beef	125	-24.3	-26.5
	carrot	125	-28.9	
	onion	125	-27.1	
	potato	125	-26.5	
	turnip	125	-27.0	
	barley	125	-25.7	

Figure 6.3
Carbon Isotope Food Values
Comparisons of Raw, Cooked, and Weighted Mean



depleted in ^{13}C than the actual values for either the raw or cooked mixed ingredients. The opposite is true for ginger bread where the predicted $\delta^{13}C$ is actually enriched in ^{13}C by approximately $\pm 1.5^{0}/_{00}$ compared to the mixed ingredients. In both of these situations it would appear that while heat has altered $\delta^{13}C$ by *less* than $\pm 1^{0}/_{00}$, the act of initially combining the ingredients has resulted in chemical reactions that alter $\delta^{13}C$ by slightly *more* than $\pm 1^{0}/_{00}$.

$\delta^{13}C$ of the Belleville Diet

Schoeninger (1989) made an initial attempt at proposing diets for prehistoric populations by combining information from identification of excavated food items with the results of stable isotope analysis of these food items. The diets proposed were ones that might be expected to produce the $\delta^{13}C$ and $\delta^{15}N$ values she found for bone collagen. A similar attempt has been in this study with a few very significant differences. The diet of the Belleville people was reconstructed *independent* of any isotope data through historical records with the result being an estimate of the proportions of foods comprising the whole diet. See Table 4.1 and chapter 4 for a discussion on the historical basis for this estimate. Meat products (primarily beef and pork) were found to comprise 10% of the whole diet, baked goods 20%, with the 70% majority of diet being made up of vegetables. The $\delta^{13}C$ value for each of these components was

estimated from values determined for the individual ingredients and whole recipes prepared for this study and is presented in table 6.4. The following discussion explains how these values were determined.

Table 4.1b suggests that the meat portion of the diet is made up of 45% beef/mutton and 55% pork. Although mutton was not analyzed in this study, it is assumed that beef and mutton from Belleville can be expected to have similar $\delta^{13}C$ values reflective of a C_3 diet. While the $\delta^{13}C$ value for C_3 plants can range from $-20^0/_{00}$ to $-35^0/_{00}$ (Troughton, 1972), both cattle and lamb grazed on or were fed the same foods (see chapter 4). The $\delta^{13}C$ value determined for beef was therefore considered representative of the beef/mutton portion of the Belleville diet. Pig feed was supplemented with corn resulting in the expectation that pork will be more enriched in ^{13}C than beef or mutton. Because pork meat was also not analyzed in this study, the $\delta^{13}C$ value for lard, a porcine-derived product, was utilized. Although the carbon isotope ratio in fat may be as much as $5^0/_{00}$ lighter than muscle (see Vogel, 1978), the 5% weighted contribution of pork to the whole diet is small enough that the difference between pork meat and fat does not have a meaningful impact on the final whole diet $\delta^{13}C$ estimate. A weighted mean of the pork and beef/mutton values was calculated and the resulting $\delta^{13}C$ of $-20.4^0/_{00}$ represents an estimate of the total meat component of the diet.

Table 6.4
Calculation of $\delta^{13}C$ of Meat, Baked Goods, and Vegetable Components of Belleville Diet

Item	Average % Contribution (from table 4.1b)	$\delta^{13}C$
Pork	(5.5)	-17.1
Beef/Mutton	(4.5)	-24.4
TOTAL MEAT	**10**	**-20.4**
Gingerbread	(4)	-21.1
Pumpkin Cake	(4)	-18.5
Cornbread	(4)	-14.3
Wheat Bread	(4)	-23.4
Shortbread	(4)	-19.8
TOTAL BAKED	**20**	**-19.5**
Onions	(14)	-27.5
Potatoes	(14)	-27.6
Turnips	(14)	-26.9
Barley	(14)	-26.6
Carrot	(14)	-27.7
TOTAL VEGETABLE	**70**	**-27.6**

The five recipes for baked items were chosen for this study because they are a typical sample of the recipes prepared by nineteenth century settlers of the Belleville area. The $\delta^{13}C$ for the total baked goods component was therefore derived from a calculation of average $\delta^{13}C$ of the five items baked in this study, with equal weight given to each. The resulting 20% contribution of the corn bread to the total baked goods $\delta^{13}C$ value is considered a reasonable estimate of the probable C_4 contribution to baking in nineteenth century Belleville. As the human $\delta^{13}C$ values suggest, while corn was utilized, it did not assume as important a dietary role as the Old World staple grains.

As with the baked items, the beef stew was intentionally chosen for preparation in part because it contains a representative sample of the vegetables exploited in nineteenth century Belleville. The ingredients were averaged, with equal weight given to each, to arrive at an estimated $\delta^{13}C$ of $-27.6^{0}/_{00}$ for the vegetable component of the diet.

With an estimate of the proportionate contribution of meat, baked goods, and vegetables to the whole diet, and a similar estimate of the $\delta^{13}C$ of each of these components, a whole diet $\delta^{13}C$ was calculated as:

Weighted $\delta^{13}C = [(\%M)(\delta^{13}C\ M) + (\%B)(\delta^{13}C\ B) + (\%V)(\delta^{13}C\ V)]$

where M represents meat, B represents baked goods, and V represents vegetables. From these calculations, the Belleville population whole diet $\delta^{13}C$ can be estimated at approximately $-25.0^{0}/_{00}$ (Figure 6.4).

Results of Atomic Absorption Spectroscopy: The Minerals

In looking at the changes in mineral concentration from raw to processed it is of value to consider potential sources for increases in mineral concentrations and conversely, explanations for decreases. In this study there are three potential sources of elemental increases. First, water was used to either clean the cooking vessel between uses or to actually cook some of the foods in (i.e. the beef stew). Second, minerals may leach out of the walls of the cooking vessel and end up in the cooked product. Finally, minerals leached from one ingredient may be absorbed by another (e.g. individual beef stew ingredients). Elemental decreases are easier to account for. Elements may be lost from food either through leaching or volatilization.

Chemical composition of the water source and the iron pot

The water source was hard water from a deep water well. Hard water contains calcium and magnesium bicarbonates with little iron or zinc (Schroeder, 1973). More detailed

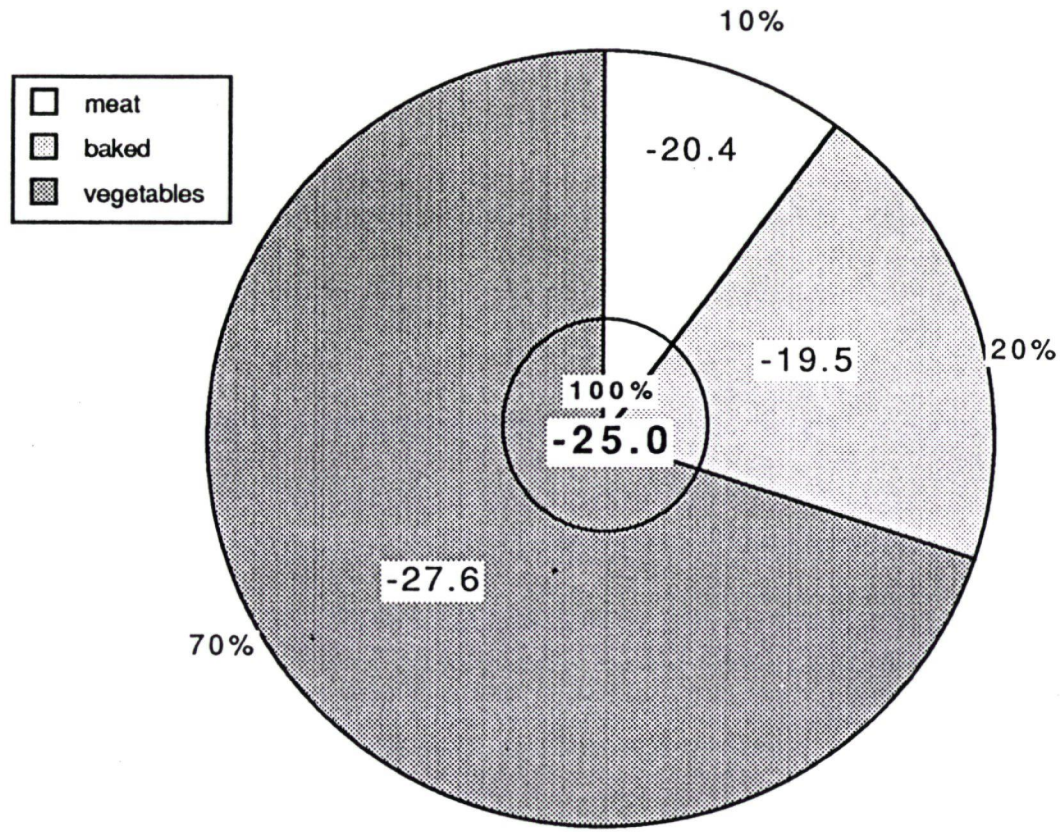


Figure 6.4 Estimated delta 13C of Belleville diet based on weighted mean contribution of baked goods, meat and vegetables to the whole diet

mineral content of the water source is not known since the sample was lost during transport. The iron pot is an artifact that was on loan from a museum, and a sample could not be removed for analysis. Studies of the chemical content of iron artifacts have found the composition to be variable depending upon smelting practices and iron source. Commonly found minerals in metallic iron include Cu, Ni, Co, Bi and Zn with Ca, Mg, Ti, Cr, V, Ba, and Mn concentrated in slag inclusions (Salter, 1989; Scott, 1977). These data are derived from European analyses of iron artifacts since no literature values for iron artifacts could be found for North America.

While it is unfortunate that more detailed data on the chemical composition of the iron pot and water are not available, the general information is sufficient to account for all of the observed changes in element concentration from raw to processed.

Basic descriptive and inferential statistics for calcium, magnesium, zinc, iron, and strontium concentration in food are presented in tables 6.5 through 6.9. The raw dough and baked product were analyzed for the shortbread, ginger bread, corn bread, whole wheat bread, and pumpkin cake. The individual stew ingredients, both raw and cooked were also analyzed for mineral content. Because the individual ingredients of the baked items were not analyzed in this study, comparable literature values (from Ensminger

et al, 1983b; Watt and Merrill, 1975; and Schroeder et al, 1972) are used as a means of explaining the source of unusual concentrations. Literature values for the ingredients used in this study have been compiled in table 6.10 and will occasionally be referred to in the following discussion of the results for each element.

Calcium (Table 6.5)

All of the baked items increased in calcium concentration from raw to cooked. The calcium increase in pumpkin cake was statistically significant at the 0.01 level. Of the beef stew ingredients, some calcium was lost from the carrots and turnips, and some was gained by potatoes. However, none of these changes was significant. Calcium concentration in barley and beef did, however, increase significantly. These increases are in no way comparable to the losses incurred by carrots and potatoes. Any more significant increase in element concentration from raw to processed must therefore originate from the water used or the iron pot. The probable source of the calcium increase in all of the recipes prepared is water. Calcium is not present in high enough concentrations in iron to account for such a large increase. The impact of water is particulary evident in the beef stew. The stew ingredients are boiled in water as part of the preparation procedure. The resulting calcium increase in barley is the most

Table 6.5
Calcium Concentration for Food Items
Descriptive and Inferential Statistics (Raw versus Cooked)

Item	Treatment	n	Mean mg/100g	Standard Deviation	F-Test	p
Baked:						
Pumpkin Cake	Raw	5	38.79	2.36	27.26	.0008
	Cooked	5	50.36	4.36		
Gingerbread	Raw	5	142.43	25.83	1.65	.235
	Cooked	5	167.46	35.11		
Shortbread	Raw	5	20.05	1.12	2.75	.1356
	Cooked	5	21.87	2.17		
Cornbread	Raw	4	42.61	1.66	4.98	.0608
	Cooked	5	52.09	8.26		
Whole Wheat Bread	Raw	5	72.52	2.06	.10	.7596
	Cooked	5	73.01	2.74		
Beef Stew:						
Carrot	Raw	3	46.86	.24	2.52	.1635
	Cooked	5	40.98	6.21		
Barley	Raw	3	28.05	.07	85.76	.0001
	Cooked	5	129.29	18.33		
Potato	Raw	3	21.05	.17	5.68	.0545
	Cooked	5	25.85	3.38		
Turnip	Raw	3	31.42	.11	4.51	.0779
	Cooked	5	26.79	3.65		
Beef	Raw	3	26.5	.03	28.38	.0018
	Cooked	5	60.62	10.74		

striking. When barley is cooked it increases significantly in size. As it expands it absorbs water, and as a result, a sample not only of the minerals present in water but also those that have leached out of other ingredients during cooking. With the exception of the gingerbread, calcium concentration, particularly in the uncooked samples, is not highly variable between baked items, meat, and vegetables (Figure 6.5). The calcium concentration of gingerbread is very high even in its uncooked form, because molasses, (especially blackstrap) contains very high levels of calcium. Literature values (Ensminger et al, 1983b; and Watt and Merrill, 1975) report concentration in medium molasses at 290mg/100g and in blackstrap molasses at 684mg/100g (Table 6.10).

Magnesium (Table 6.6)

Magnesium concentration changed significantly from raw to processed in all foods tested except gingerbread, shortbread, and whole wheat bread. In baked items the trend is towards an increase in magnesium concentration. It may be that magnesium was volatilized or leached from the iron pot during the cooking process or resulted from washing the pot between uses in the calcium- and magnesium-rich hard water. Among the vegetables, carrots and turnips acquired magnesium, while potatoes lost some. Barley gained a significant amount of magnesium, while beef conversely lost

Figure 6.5
Calcium Concentration: Raw versus Cooked

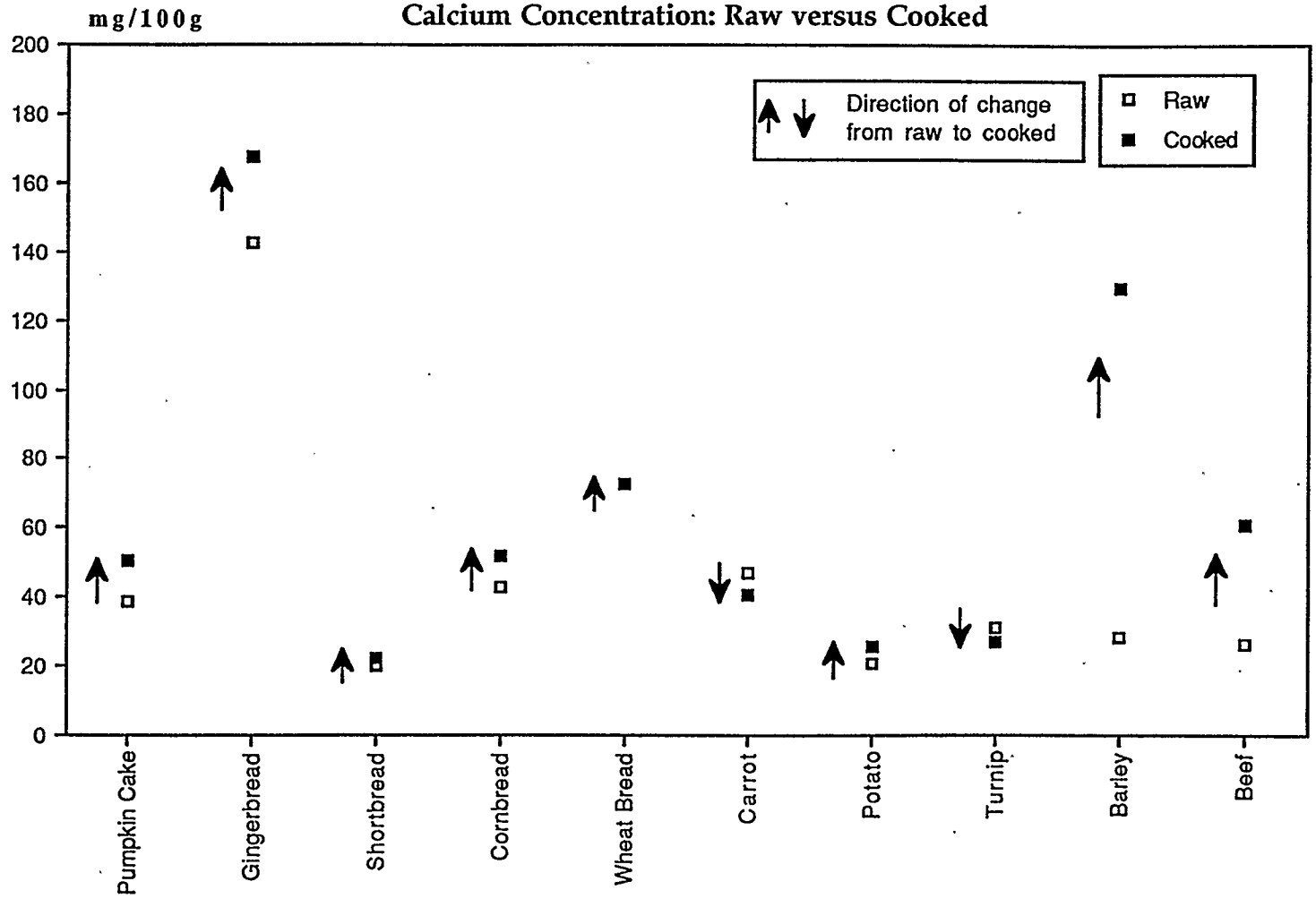


Table 6.6
Magnesium Concentration for Food Items
Descriptive and Inferential Statistics (Raw versus Cooked)

Item	Treatment	n	Mean mg/100g	Standard Deviation	F-Test	p
Baked:						
Pumpkin Cake	Raw	5	32.12	5.58	6.29	.0365
	Cooked	5	40.25	2.07		
Gingerbread	Raw	5	61.64	9.54	1.54	.2501
	Cooked	5	70.36	12.49		
Shortbread	Raw	5	60.92	3.13	12.75	.0073
	Cooked	5	70.58	5.18		
Cornbread	Raw	4	48.79	3.86	3.73	.0948
	Cooked	5	57.18	7.88		
Whole Wheat Bread	Raw	5	143.54	2.68	.12	.7411
	Cooked	5	141.56	12.68		
Beef Stew:						
Carrot	Raw	3	15.72	.09	29.00	.0017
	Cooked	5	19.92	1.31		
Barley	Raw	3	91.75	.15	21.92	.0034
	Cooked	5	114.37	8.10		
Potato	Raw	3	27.64	.19	14.60	.0087
	Cooked	5	18.84	1.73		
Turnip	Raw	3	12.94	.07	12.86	.0116
	Cooked	5	17.33	2.05		
Beef	Raw	3	81.77	.30	105.18	.0001
	Cooked	5	54.82	4.40		

a comparable amount of magnesium. Even without considering the effects of water, magnesium leached from the potatoes and beef is roughly comparable to the magnitude of the increases in carrots, turnips and barley. It is interesting that the effects of cooking on magnesium concentration in carrots, potatoes, turnips, and beef are exactly opposite to the effects observed with calcium. In comparing just the meat to the vegetables (carrots, potatoes, and turnips), it is apparent that despite the effects of processing the vegetables cluster at concentrations between 15mg/100g and 27mg/100g while the magnesium concentration in beef is almost double at between 50mg/100g and 80mg/100g (Figure 6.6). Worthy of note, however, is that the range of concentration in baked items falls neatly between the ranges for meat and vegetables. The very high concentration of magnesium in whole wheat bread reflects the high proportion of whole wheat flour in the recipe; which literature values suggest has a Mg concentration around 160mg/100g (Table 6.10).

Zinc (Table 6.7)

Of the baked items, only gingerbread and shortbread increased significantly in zinc concentration from raw to cooked. Zinc concentration in barley increased significantly while it decreased significantly in potatoes. Pumpkin cake and corn bread acquired some zinc, while whole

Figure 6.6
Magnesium Concentration: Raw versus Cooked

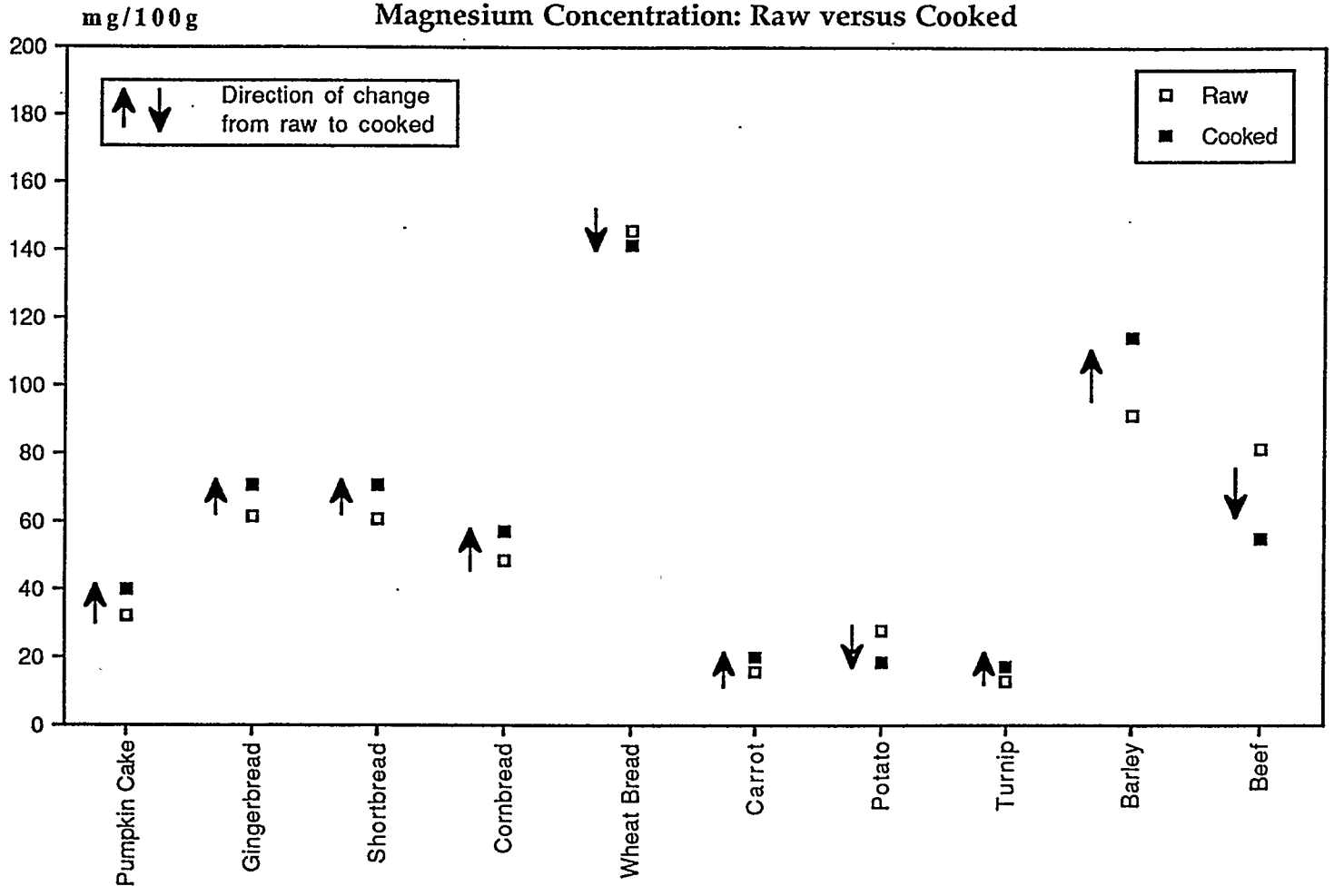


Table 6.7
Zinc Concentration for Food Items
Descriptive and Inferential Statistics (Raw versus Cooked)

Item	Treatment	n	Mean mg/100g	Standard Deviation	F-Test	p
Baked:						
Pumpkin Cake	Raw	5	1.06	.26	1.61	.2395
	Cooked	5	1.22	.13		
Gingerbread	Raw	5	.92	.03	4.91	.0576
	Cooked	5	1.53	.27		
Shortbread	Raw	5	1.52	.05	8.53	.0193
	Cooked	5	1.72	.15		
Cornbread	Raw	5	1.35	.18	2.16	.1798
	Cooked	5	1.49	.12		
Whole Wheat Bread	Raw	5	4.98	.09	.52	.4918
	Cooked	5	4.89	.23		
Beef Stew:						
Carrot	Raw	3	.33	.01	1.07	.3402
	Cooked	5	.30	.05		
Barley	Raw	3	3.16	.04	20.10	.0042
	Cooked	5	3.52	.06		
Potato	Raw	3	.47	.003	8.59	.0263
	Cooked	5	.32	.08		
Turnip	Raw	3	.30	.002	.02	.8949
	Cooked	5	.31	.10		
Beef	Raw	3	19.57	.11	1.66	.2456
	Cooked	5	15.47	5.34		

wheat bread and beef lost some. The values for turnips and carrots essentially remained the same. The pattern of loss or gain for zinc is the same as was observed for magnesium. It is especially significant that all of the baked items and vegetables have zinc concentrations of less than 5mg/100g while zinc in beef is three times as concentrated, even after the losses incurred by cooking (Figure 6.7).

Iron (Table 6.8)

Iron concentration increased significantly in all foods except gingerbread and shortbread. The shortbread was cooked on an enamelled cookie sheet and not in the iron pot, suggesting that the increases in iron concentration in all other recipes is indeed a result of cooking in an iron vessel. While the baked items increased in iron by a factor of about one half, all of the beef stew ingredients essentially doubled in iron concentration from raw to cooked. Iron in the cooked barley is five times as concentrated as it was in the raw barley. Beef stew requires time periods of an hour or more to simmer to completion. The baked items all require half an hour or less of cooking. It is likely that more iron leached into the beef stew broth as a result of the length of the cooking time, causing an increase in iron availability for uptake by the ingredients. Because the barley expands and absorbs surrounding water or broth as it cooks, it is not

Figure 6.7
Zinc Concentration: Raw versus Cooked

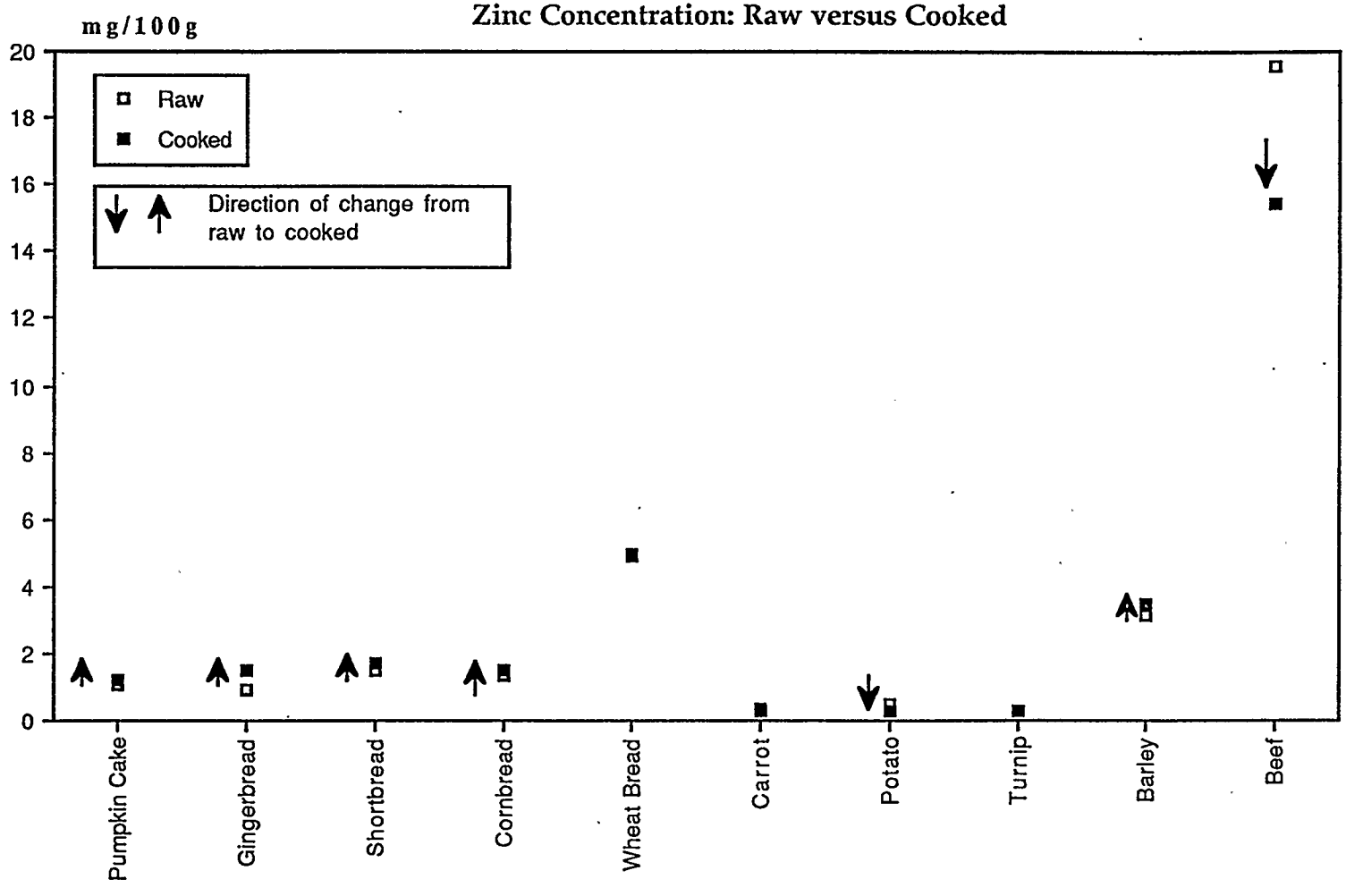


Table 6.8
Iron Concentration for Food Items
Descriptive and Inferential Statistics (Raw versus Cooked)

Item	Treatment	n	Mean mg/100g	Standard Deviation	F-Test	p
Baked:						
Pumpkin Cake	Raw	5	1.77	.29	13.66	.0061
	Cooked	5	2.33	.18		
Gingerbread	Raw	5	3.76	.54	3.08	.1173
	Cooked	5	4.44	.68		
Shortbread	Raw	5	2.35	.24	1.70	.2283
	Cooked	5	2.52	.15		
Cornbread	Raw	5	2.12	.31	10.83	.011
	Cooked	5	4.64	1.68		
Whole Wheat Bread	Raw	5	4.22	.22	7.57	.025
	Cooked	5	5.6	1.10		
Beef Stew:						
Carrot	Raw	3	0.80	.01	8.75	.0253
	Cooked	5	1.51	.40		
Barley	Raw	3	3.12	.02	8.53	.0266
	Cooked	5	15.54	7.14		
Potato	Raw	3	.76	.002	19.15	.0047
	Cooked	5	1.42	.25		
Turnip	Raw	3	.56	.02	9.89	.02
	Cooked	5	1.48	.49		
Beef	Raw	3	30.59	.41	12.82	.0116
	Cooked	5	54.55	11.27		

unexpectedthat it exhibits the most significant increase. As with zinc, the iron concentration in meat is approximately six times higher than in all of the baked items or vegetables, even after cooking (Figure 6.8).

Strontium (Table 6.9)

Strontium analysis unfortunately proved to be very problematic from an analytical perspective. As is only too apparent from a quick look at the data presented in table 6.9, the standard deviations are exceedingly large. This is the inevitable result of the strontium concentration in almost all foods being around the detection limit for strontium on the AAS. Operating within the constraints of loss of analytical precision, the results can still provide a generalized picture of the effects of cooking on strontium levels. For the baked items, no particular pattern of increase or decrease as a result of cooking emerges. Pumpkin cake, corn bread, and shortbread lost strontium, while gingerbread and whole wheat bread gained a small amount. The vegetables, however, all lost statistically significant amounts of strontium, while the value for beef remained essentially unchanged. As would be expected, based on its absorption of water during cooking, barley increased significantly in strontium concentration. This is comparable to the increase in calcium and magnesium originating from the hard water used in the recipe. A look

Figure 6.8
Iron Concentration: Raw versus Cooked

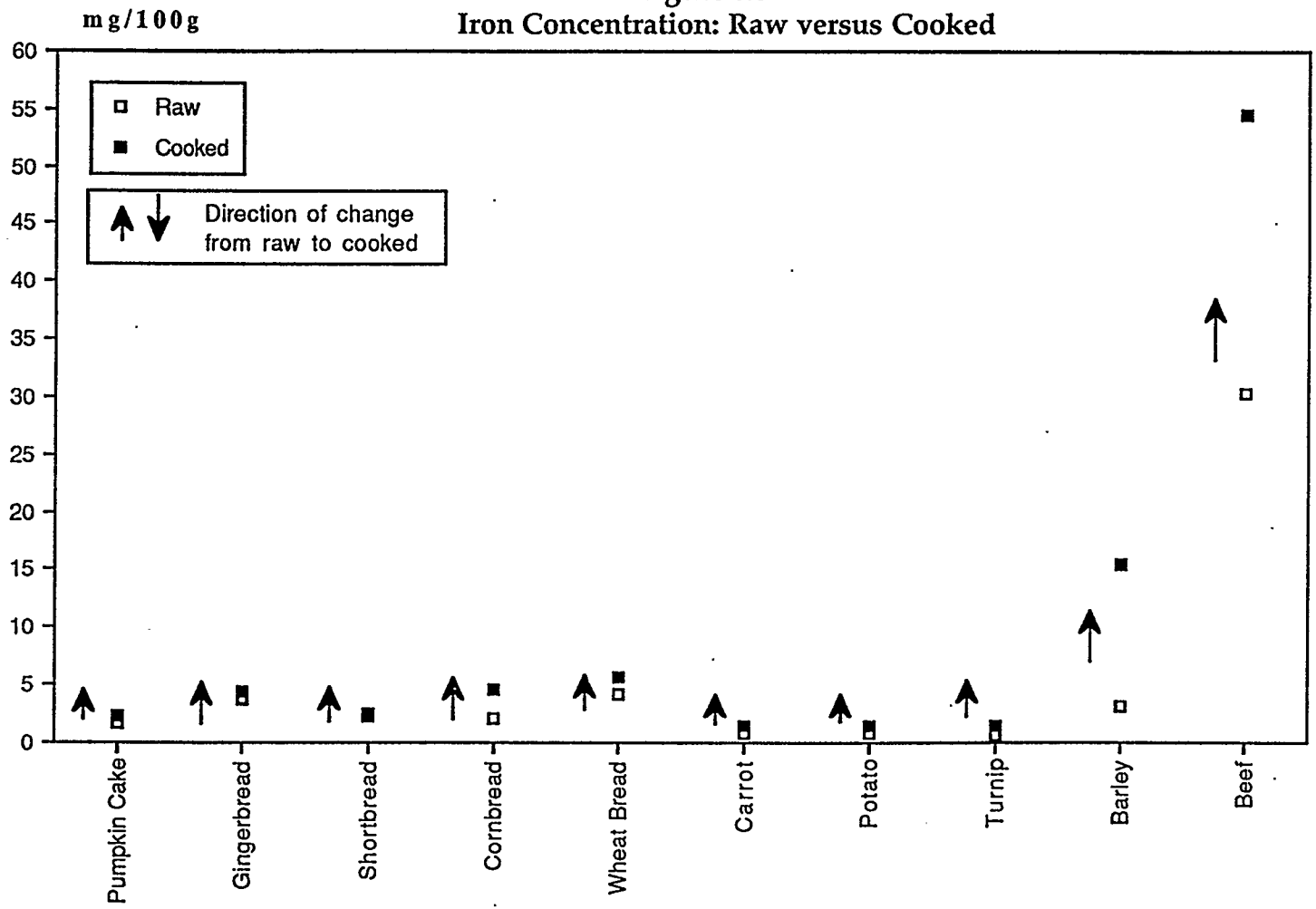


Table 6.9
Strontium Concentration for Food Items
Descriptive and Inferential Statistics (Raw versus Cooked)

Item	Treatment	n	Mean mg/100g	Standard Deviation	F-Test	p
Baked:						
Pumpkin Cake	Raw	5	.3	.09	3.76	.0885
	Cooked	5	.6	.34		
Gingerbread	Raw	5	.64	.13	.40	.5455
	Cooked	5	.69	.14		
Shortbread	Raw	5	.37	.12	.21	.6592
	Cooked	5	.33	.15		
Cornbread	Raw	4	.82	.83	1.41	.3221
	Cooked	5	.42	.21		
Whole Wheat Bread	Raw	5	.44	.18	.72	.4208
	Cooked	5	.71	.69		
Beef Stew:						
Carrot	Raw	3	1.06	.05	102.55	.0001
	Cooked	5	.53	.08		
Barley	Raw	3	.7	.03	15.00	.0082
	Cooked	5	1.31	.27		
Potato	Raw	3	.32	.01	6.63	.042
	Cooked	5	.26	.03		
Turnip	Raw	3	1.24	.01	27.76	.0019
	Cooked	5	.58	.21		
Beef	Raw	3	.46	.24	.003	.9601
	Cooked	5	.45	.16		

at the concentration of strontium in the vegetables and meat before cooking indicates that carrots and turnips start out with at least twice the concentration of beef. However, after cooking the distinction between these vegetables and beef has been lost (Figure 6.9). It is also worthy of note that the potatoes actually contained less strontium than beef both before and after cooking. As with magnesium, the range of concentration in the other foods examined generally falls between the high values for vegetables and the low value for beef.

Figure 6.9
Strontium Concentration: Raw versus Cooked

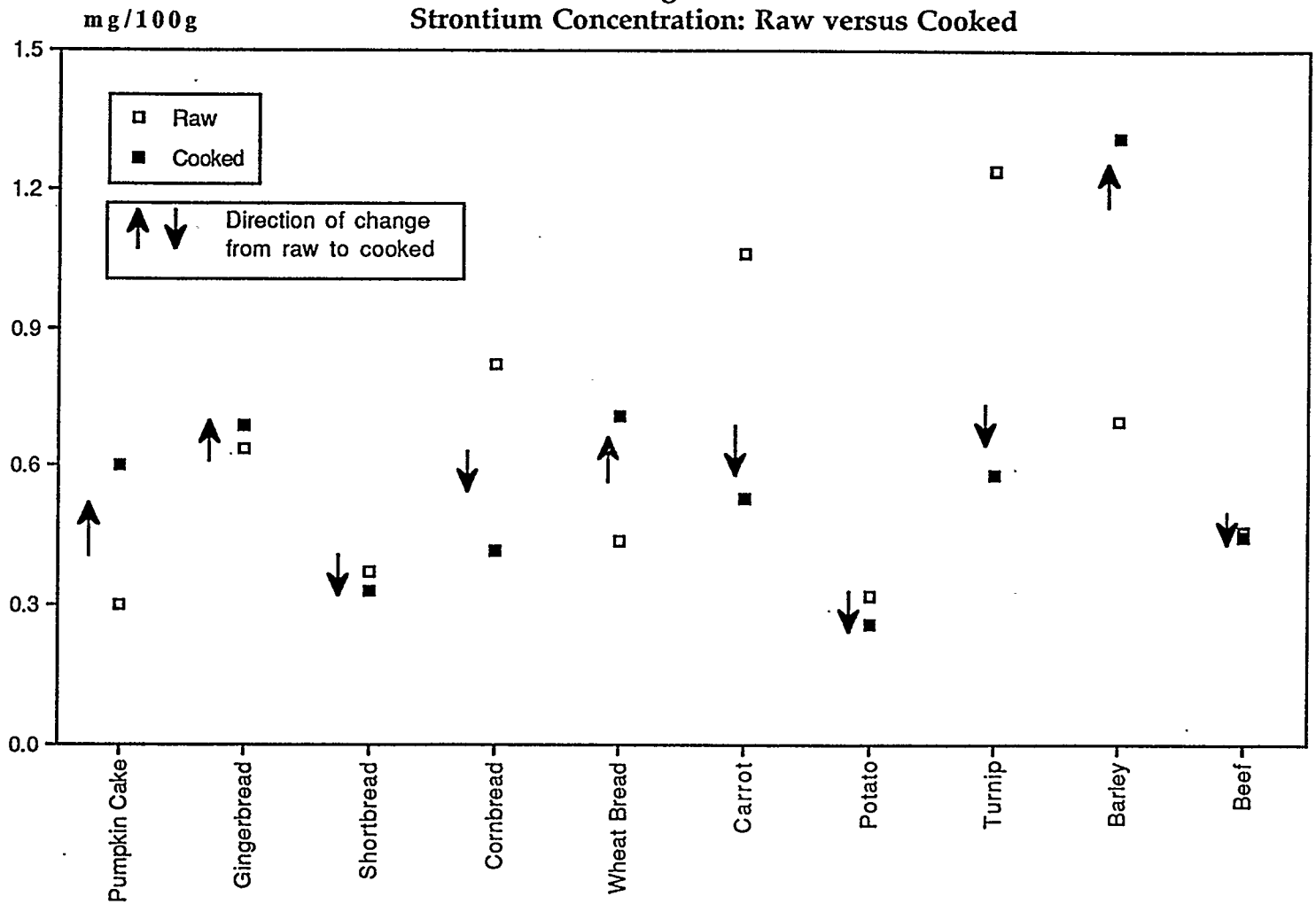


Table 6.10
Literature Values for Mineral Concentration in Ingredients

Ingredients	Ca	Mg	Fe	Zn	Sr
			(mg/100g)		
BAKED ITEMS					
flour (whole wheat)	41	160	3.3	2.4	0.35
brown sugar	85	-	3.4	0.1	-
lard	0	-	0	0.1	-
salt	253	119	0.1	-	-
yeast	44	59	16.1	-	-
butter	20	2	0	-	-
sugar	0	trace	0.1	0.02	0.46
flour (white)	17	26	0.5	0.3	-
pumpkin	21	38	0.8	0.2	-
corn meal	17	106	1.8	0.2	-
buttermilk	121	14	0.1	0.4	-
lard	0	-	0	0.1	-
egg	54	11	2.3	1.4	-
baking powder	5778	9	trace	-	-
baking soda	-	-	-	-	-
milk (2%)	143	14	0.1	0.4	
maple syrup	104	10	1.2	-	0.28
molasses (dark)	684	258	16.1	2.2	1.20
molasses (medium)	290	81	6.0	0.35	-
ginger	116	164	11.3	4.7	-
cream of tartar	-	-	-	-	-
BEEF STEW					
beef-raw	10	22	2.6	6.2	0.19
beef-cooked	10	28	3.1	-	-
carrot-raw	37	23	0.7	0.4	0.27
carrot-cooked	33	-	0.6	0.3	-
potato-raw	7	34	0.6	0.3	-
potato-cooked	7	-	0.6	0.3	-
turnip-raw	39	20	0.5	0.4	0.20
turnip-cooked	35	-	0.4	0.28	-
barley-raw	34	124	2.7	0.02	0.98

Data for Ca, Mg, Fe, and Zn compiled from Ensminger et al (1983b) and Watt and Merrill (1975). Sr data from Schroeder et al (1972).

Summary of Results

The following summary highlights the results that have implications for paleodietary reconstruction and will form the focus for the discussion:

1) The human $\delta^{13}C$ bone collagen values for the inhabitants of Belleville average $-19.5\pm1^{0}/_{00}$. These are consistent with European values and suggest a diet largely based on Old World staples. There are no significant age- or gender-related differences in the adult human $\delta^{13}C$ values for individuals interred at St. Thomas Anglican Church in Belleville between 1820-1870.

2) The difference in $\delta^{13}C$ in food as a result of cooking food is less than $\pm1^{0}/_{00}$.

3) The chemical reactions that occur as a result of mixing foods (e.g. as in dough manufacture for baking) results in a shift in $\delta^{13}C$ of $\pm1.5^{0}/_{00}$ or less.

4) Based on historical documentation, the whole diet $\delta^{13}C$ of the Belleville population can be estimated at $-25.0^{0}/_{00}$.

5) From the data summarized in 1) and 4), the fractionation factor from diet to collagen can be calculated at $+5.5^{0}/_{00}$.

6) Mineral concentration is significantly affected by food processing.

7) The mineral content of water and cooking vessels have a potentially significant impact on mineral concentration in food.

CHAPTER 7
DISCUSSION

Stable isotope and trace element analysis of human remains have become popular methods of paleodietary reconstruction. They are based on the assumption that the significant differences in stable isotope and trace element levels that exist between plants and animals in nature are preserved and accurately reflected in human bone. One of the basic premises is that processing of food resources does not significantly alter the differences found in nature. Up to this point the possible impact of food processing has only been superficially addressed for stable isotope analysis and not at all for trace element analysis. The purpose of this study has been to assess in more detail the impact of food processing and its implications for chemical methods of paleodietary reconstruction.

Food Processing and Stable Carbon Isotopes

The results of this study agree with the results of DeNiro and his colleagues, as reviewed in the introduction. The levels of heat used in baking and boiling do not alter carbon isotope values between a raw and cooked product by more than $\pm 1^{0}/_{00}$.

The mixing of ingredients does, however, in some cases appear to produce minimum shifts of at least $\pm 1.5^{0}/_{00}$. The

chemical reactions that occur when ingredients are mixed provide adequate potential for shifts in carbon isotope values. In the manufacture of baked products, the mixing stage results in constant contact between potential reactants. Dough rises as a result of not only the introduction of gases from mixing, but also from CO_2 production by baking soda/powder or yeast fermentation. The result is a loss of carbon from the initial ingredients. Primary kinetic isotope effects result from differences in the rate of a chemical reaction between isotopes of an element at the reaction site. Because light isotopes tend to react more readily than their heavier counterparts, the expectation is that more $^{12}CO_2$ than $^{13}CO_2$ will be lost. The predicted result is that the dough and resulting baked product will become more enriched with respect to the heavy isotope. In one case the relationship between the weighted ingredients and the dough and cooked product followed this expectation. The dough and cooked product were more enriched in ^{13}C relative to the weighted mean of the ingredients. Unfortunately this expectation was not supported in each case. The predicted $\delta^{13}C$ value from a weighted mean of the individual ingredients, was in one case more *depleted* in ^{13}C relative to both the dough and cooked product. In other situations the weighted $\delta^{13}C$ of the ingredients did not deviate from the $\delta^{13}C$ of the mixed and cooked product. In other words, kinetic isotope effects do

not appear to be a significant factor in the chemical reactions that occur as a result of both mixing of ingredients and cooking. Kinetic isotope effects are influenced by the size and vibrational properties of the molecule undergoing reaction. Fractionation kinetics are less complicated and easier to predict in a small molecule composed of only a few atoms (e.g two amino acids), than in a large and complex molecule (e.g quaternary polypeptide). Considerations such as temperature, pH, the location of isotopes of an element in a large molecule relative to reaction sites, and structure of the transition state of a molecule are just a few factors that may influence the isotope effect; resulting in values contrary to initial expectations.

Collagen Enrichment Factor

While the carbon isotope fractionation that takes place in plants is preserved in higher organisms, additional fractionation has been noted during the incorporation of dietary carbon by animals (DeNiro and Epstein, 1978). Fractionation factors for different tissues have been calculated, based on laboratory experiments on animals, by DeNiro and Epstein (1978). Bone collagen $\delta^{13}C$ was found to be displaced from the $\delta^{13}C$ of the diet by $+3^{0}/_{00}$. This initial value was subsequently amended to $+3.9^{0}/_{00}$ (DeNiro and Epstein, 1981). Other researchers have cited collagen

enrichment factors of as much as $+5.3^0/_{00}$ (Chisholm et al, 1982; van der Merwe, 1982; van der Merwe and Vogel, 1978). The larger collagen enrichment factor is based on the results of a study by Vogel (1978) conducted on kudus. The discrepancy between the studies is explained as a difference in metabolism between the short-lived mice in the DeNiro-Epstein study and the longer-lived kudus in the Vogel study, and also as a difference in their diets (van der Merwe, 1982). While it is clearly not possible to conduct feeding experiments on humans to determine the collagen enrichment factor, a collagen enrichment factor for human collagen can be estimated based on the results of this study. The $\delta^{13}C$ of the bone collagen from the adult Belleville population was determined to be $-19.5 \pm 1^0/_{00}$. The whole diet $\delta^{13}C$ value of this population was estimated at $-25.0^0/_{00}$. This suggests a collagen enrichment factor for human bone of $+5.5^0/_{00}$. Considering the relatively rough nature of the dietary estimate, the collagen enrichment factor calculated from the results of this study agrees very well with that proposed by Vogel (1978). Since the actual collagen enrichment factor of human bone collagen does appear to have been most closely approximated in the Vogel study, it is suggested that a collagen enrichment factor for human bone of no less than $+5.1^0/_{00}$ be applied in future calculations of paleodiet values.

Implications for Paleodietary Reconstruction

The magnitude of isotopic shift produced by food processing must be considered in the context of its potential impact on paleodietary reconstruction. Plants following the C_3 pathway of carbon fixation are enriched in ^{12}C by approximately 12-14$^0/_{00}$ over plants following the C_4 pathway (Troughton, 1972). Shifts produced by the food processing procedures examined in this study were no greater than $\pm 1.5^0/_{00}$. Because this does not seriously alter the $\delta^{13}C$ spread between C_3 and C_4 plants, it is concluded that shifts in values caused by cooking are not likely to cause large errors in paleodietary reconstruction based on bone collagen isotope ratios.

Food Processing and Mineral Concentration

The assumption that food processing does not have a potentially significant impact on paleodiet reconstruction based on mineral analysis can no longer be accepted. The results of this study indicate that food processing is indeed a further complicating factor in reconstructing paleodiet based on mineral concentration.

Calcium

Because of its high concentration in bone, calcium levels are used as a constant in paleodietary reconstruction against which to compare concentrations of strontium and

phosphorous. While it is not directly applicable, it is of interest to look at calcium behaviour during food processing since excess dietary calcium may interact with phosphorous, iron, strontium, and zinc and as a result affect their concentrations. The calcium increases in many of the recipes prepared were highly significant and attributable to the water source used. The pervasive use of water in food processing and its potentially significant contribution to mineral concentrations does not appear to have been thus far factored into paleodietary reconstruction. The calcium results alone from this study suggest that water must be considered as a separate food item with potentially significant contributions to mineral concentration.

Magnesium

While the results indicate that magnesium concentration is altered by food processing, the change in concentration was not always statistically significant. Most important from the perspective of paleodietary reconstruction is that the values for vegetables cluster at an observably *lower* concentration than beef. Although it is encouraging that an observable difference in mineral concentration between meat and vegetables is maintained despite processing, the results of this study are converse to expectation, which predicts that plants will be significantly *higher* than meat values. More problematic, however, is that the cereal grains (e.g.

barley and whole wheat) have concentrations intermediate between the beef and vegetables. The result is that if cereal crop-based foods form a significant part of the diet, magnesium concentration may not be a useful means of distinguishing a predominantly vegetarian from a meat diet.

Zinc

The results of this study suggest that zinc is the most promising element for paleodietary reconstruction in terms of its stability during food processing. It is already very important in the reconstruction of paleodiet since it appears not to be sensitive to diagenetic activity (Lambert et al, 1979, 1982, 1984; Szpunar, 1977; Vlasak, 1983). While statistically significant changes in concentration did occur as a result of processing, they had absolutely no impact on the spread between meat and vegetable concentrations. Even more significant is that unlike magnesium, the zinc concentration in cereal crop-based foods is as low as the vegetables. They are therefore not a complicating factor in using zinc concentration to distinguish vegetarian and meat diets.

Iron

The results of this study suggest that like zinc, iron is potentially useful as a means of distinguishing meat and vegetable products. Vegetables, baked items, and barley all

have low concentrations of iron relative to meat; even after cooking. High iron concentration in bone is, however, widely considered to be a result of diagenetic activity, particularly when surrounding soil levels are high in iron. Because of this apparent sensitivity to diagenesis iron is not considered a reliable element for paleodietary reconstruction. Iron analysis was incorporated in this study to look at the impact of the cooking vessel on mineral concentration in foods. Iron concentration did increase significantly, especially in the foods that were boiled. The increase in the beef was particularly noteworthy. The potential transfer of minerals from cooking vessels to food has been suggested previously. Kent et al (1990) indicated that food preparation techniques and cooking utensils may result in either harmful or beneficial results. They based their conclusions on studies by Underwood (1977) and Bothwell and Finch (1962) that found that iron cooking pots used by the South African Bantu to prepare kaffir beer may supply an additional 2-3mg of iron each day, and was cited as a causal factor in the incidence of siderosis among Bantu adults. Baumslag and Petering (1976) suggest that the absence of iron deficiency anaemia in the !Kung may in part be as a result of the use of iron cooking vessels. The results of this study supports the findings of other researchers and suggests that water merits further consideration as a separate food source.

Strontium

Strontium is one of the most frequently used elements in paleodietary reconstruction. One of the reasons for this is that it does not appear to be as sensitive to diagenetic influences as many of the other elements (e.g. Lambert et al, 1979, 1982, 1984; Szpunar, 1977; Vlasak, 1983). High strontium concentrations in bone are believed to reflect a predominantly vegetarian diet. Despite the analytical problems encountered with strontium analysis, several important observations merit discussion. The plants analyzed in this study lost a significant amount of strontium as a result of processing. While strontium concentration in meat did also decrease, the loss was not of the same magnitude as seen in the vegetables. The loss in vegetables was significant enough that strontium concentration in the cooked vegetables was no longer distinguishable from the meat value. One of the vegetables (potatoes) actually had a lower strontium value than the meat even before cooking. As with magnesium, the baked items appear to be a potentially confounding factor. The range of strontium concentration in the cereal crop-based foods appears to conceal any otherwise perceptible difference between the vegetables and meat.

Implications for Paleodietary Reconstruction

Notwithstanding the rather preliminary nature of the results and assorted analytical difficulties, the implications for the use of mineral analysis in paleodietary reconstruction are unquestionable. Food processing has a substantial impact on some of the minerals that are most frequently utilized for reconstructing paleodiet. It significantly decreases, if not entirely eliminates, the predicted spread in element concentration between food types that forms the basis for the application of this technique.

Although it may not rank with the problem of diagenesis, the effects of food processing on mineral concentration are undoubtedly worthy of further attention. Buikstra et al (1989) have pointed out the lack of information on expected values for traditional non-western dietary items. While this study has not been helpful to that end since the population in question had a decidedly western diet, future research endeavors could, metaphorically speaking, kill two birds with one stone. Non-western dietary staples could easily be the focus for a more detailed study on the effects of food processing on mineral concentration. A simple cooking practice such as the boiling of food should be looked at in a much broader range of elements than was possible for this study. Equally worthy of consideration are the paraphernalia used in food preparation. This study clearly indicates that the transfer of minerals from items

such pottery or manos/metates, or from something more ubiquitous such as water, may have a significant impact on the mineral content of food by the time it is ready for ingestion.

CHAPTER 8
CONCLUSIONS

Dietary reconstruction is an important objective of research in paleo-populations. The more conventional archaeological methods of analysis, which include the analysis of settlement patterns, faunal remains, botanical remains, type- and use-wear of tools, protein residues on artifacts, and iconography (just to name a few), produce generalizations on entire populations. Analysis of skeletal morphology/pathology potentially offers details on health, nutrition and lifestyle of individuals, but does not resolve details of diet on an individual level. Chemical analysis of human remains makes it possible to look at diet from an individual level. This has made it possible to speculate on age-, gender-, status-, and culture-based differences in diet, independent of archaeological evidence. The potential of chemical analysis to corroborate or refute archaeological evidence is obvious.

Because stable isotope and mineral analysis are relatively new to the discipline, many of the assumptions underlying their applicability have yet to be adequately substantiated. This study has investigated the assumption that food processing does not significantly influence stable isotope and mineral levels in food such that they would introduce errors in paleodietary reconstruction. The

results have the following implications for paleodietary reconstruction based on chemical analysis of human remains:

1) Mixing of foods and heat treatment do not significantly alter stable isotope levels in food such that they would introduce errors in paleodietary reconstruction based on the analysis of bone collagen.

2) The collagen enrichment factor for human bone collagen is more likely on the order of $+5.3^{0}/_{00}$ as suggested by Vogel (1978) rather than the $+3.9^{0}/_{00}$ suggested by DeNiro and Epstein (1981).

3) With the exception of zinc and iron, food processing has a substantial impact on the mineral concentration of many of the minerals most commonly used for the reconstruction of paleodiet. This may result in errors in paleodietary reconstruction based on this method of analysis. Further research using non-western dietary staples as the focus is recommended.

References Cited

Abelson, P.H. and T.C. Hoering
1961 Carbon isotope fractionation in formation of amino acids in photosynthetic organisms. *Biochem.* 47:623- 632.

Adrian, J.
1982 The maillard reaction. In *Handbook of the Nutritive Value of Food, Vol 1: Food for Human Use*. Miloslav Rechcigl Jr., ed. CRC Press, Florida. Pp.529-608.

Ambrose, S.H.
1993 Isotopic analysis of paleodiet: Methodological and interpretive considerations. In *Investigations of Ancient Human Tissue: Chemical Analyses in Anthroplogy*. M.K. Sandford, ed. Gordon and Breach Science Publishers, Langhorne, PA.

Anon.
1880 *Emigration: The British Farmer's and Farm Labourer's Guide to Ontario*. C. Blackett Robinson, Toronto.

Bada, J.L., M.J. Schoeninger and A. Schimmelmann
1989 Isotopic fractionation during peptide bond hydrolysis. *Geochim.Cosmochim.Acta* 53:3337-3341.

Bates, C.
1979 Garden vegetables in nineteenth century recipes. *OMA Quarterly* 8(3):28-30.

Baumslag, N. and A.G. Petering
1976 Trace metal studies in bushmen hair. *Arch.Environ. Health* 31:254-257.

Beck, L.A.
1985 Bivariate analysis of trace elements in bone. *J.Human Evol.* 14:493-502.

Becker, R.
1979 Nineteenth century vegetable varieties. *OMA Quarterly* 8(3):11-14.

Becker, R.O., J.A. Spadaro, and E.W. Berg
1968 The trace elements in human bone. *J.Bone and Joint Surgery*. 50A:326-334.

Bellstedt, I.
1969 *St. Thomas' Anglican Church 1818-1968. The Parish Story*. Sesquicentennial Publication, Belleville, ON.

Bender, M.M.
1971 Variations in $^{13}C/^{12}C$ ratios of plants in relation to the pathway of photosynthetic carbon dioxide fixation. *Phytochemistry* 10:1239-1244.

Benfer, R.A.
1984 The challenges and rewards of sedentism: the preceramic village of Paloma, Peru. In *Paleopathology at the Origins of Agriculture*. M.N. Cohen and G.J. Armelagos, eds. Academic Press, New York.

Bisel, S.L.C.
1980 A pilot study in aspects of human nutrition in the ancient eastern Mediterranean, with particular attention to trace minerals in several populations from different time periods. PhD Dissertation, University of Minnesota, Minneapolis.

Björck, I., A. Noguchi, N-G. Asp, J-C. Cheftel, and A. Dahlqvist.
1983 Protein nutritional value of a biscuit processed by extrusion cooking: Effects on available lysine. *J.Agric. Food Chem.* 31(3):488-492.

Blakely, R.L. and L.A. Beck
1981 Trace elements, nutritional status, and social stratification at Etowah, Georgia. *Ann.N.Y.Acad.Sci.* 376:417-431.

Bloksma, A.H.
1986 Rheological aspects of structural changes during baking. In *Chemistry and Physics of Baking. Materials, Processes, Products*. J.M.V. Blanshard, P.J. Frazier, and T. Galliard, eds. J.W. Arrowsmith Ltd., Bristol. Pp.170-178.

Bothwell, T.H. and C.A. Finch
1962 *Iron Metabolism*. Little, Brown and Co., Boston.

Boyce, Gerald E.
1967 *Historic Hastings*. Ontario Intelligencer, Ltd., Belleville, ON.

1972 *Hutton of Hastings. The Life and Letters of William Hutton, 1801-61*. Hastings County Council, Belleville.

Bressani, R., R. Paz, Y. Paz, and N.S. Scrimshaw
1958 Chemical changes in corn during the preparation of tortillas. *J.Agric.Food Chem.* 6(10):770-774.

Brown, A.F.B.
1973 Bone strontium content as a dietary indicator in human skeletal populations. PhD Dissertation, Department of Anthropology, University of Michigan.

Brown, A.B. and R.L. Blakely
1985 Biocultural adaptation as reflected in trace element distribution. *J.Human Evol.* 14:461-468.

Buikstra, J.E., S. Frankenberg, J.B. Lambert and L. Xiu.
1989 Multiple elements: multiple expectations. In *The Chemistry of Prehistoric Human Bone*. T.D. Price, ed. Cambridge University Press, Cambridge.

Canniff, W.
1869 *The Settlement of Upper Canada*. 1971 reprint, Mika Silk Screening, Ltd., Belleville.

Chessyre, H.T.N.
1864 *Canada in 1864: A Handbook for Settlers*. Sampson Low, Son, and Marston.

Chisholm, B.S.
1989 Variation in diet reconstructions based on stable carbon evidence. In *The Chemistry of Prehistoric Human Bone*. T.D. Price, ed. Cambridge University Press, Cambridge. Pp.10-37.

Chisholm, B.S.,D.E. Nelson, and H.P. Schwarcz
1982 Stable isotope ratios as a measure of marine versus terrestrial protein in ancient diets. *Science* 216:1131-1132.

Comar, C.L., R.S. Russell and R.H. Wasserman
1957 Strontium-calcium movement from soil to man. *Science* 126:485-492.

Coultate, T.P.
1989 *Food. The Chemistry of its Components*. Royal Society of Chemistry, London.

Craig, H.
1957 Isotopic standards for carbon and oxygen. Correction factors for mass spectrometric analysis of carbon dioxide. *Geochim.Cosmochim.Acta* 12:133-149.

1953 The geochemistry of stable carbon isotopes. *Geochim.Cosmochim.Acta* 3:53-92.

Darling, W.S.
1849 *Sketches of Canadian Life; Lay and Ecclesiastical.* Bogue, London.

Davies, A.P.
1986 Protein functionality in bakery products. In *Chemistry and Physics of Baking. Materials, Processes and Products.* J.M.V. Blanshard, P.J. Frazier, and T. Galliard, eds. J.W. Arrowsmith Ltd., Bristol. Pp.89-104.

DeNiro, M.J.
1987 Stable isotopy and archaeology. *American Scientist* 75:182-191.

1985 Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to paleodietary reconstruction. *Nature* 317:806-809.

DeNiro, M.J. and S. Epstein
1978 Influence of diet on the distribution of carbon isotopes in animals. *Geochim.Cosmochim.Acta* 42:495-506.

1981 Influence of diet on the distribution of nitrogen isotopes in animals. *Geochim.Cosmochim.Acta* 45:341-351.

DeNiro, M.J. and C.A. Hastorf
1985 Alteration of $^{15}N/^{14}N$ and $^{13}C/^{12}C$ ratios of plant matter during the initial stages of diagenesis: Studies utilizing archaeological specimens from Peru. *Geochim. Cosmochim.Acta* 49:97-115.

DeNiro, M.J., M.J. Schoeninger and C.A. Hastorf.
1985 Effects of heating on stable carbon and nitrogen isotope ratios of bone collagen. *J.Arch.Sci.* 12:1-7.

Duncan, D.
1979 The nineteenth century kitchen. *OMA Quarterly* 8(3): 15-18.

Durand, C.
1897 *Reminiscences of Charles Durand of Toronto, Barrister.* Hunter, Rose, Toronto.

Elias, M.
1980 The feasibility of dental strontium analysis for diet assessment of human populations. *Am.J.Phys.Anth.* 53:1-4.

Emrich, K., D.H. Enhalt and J.C. Vogel
1970 Carbon isotope fractionation during the precipitation of calcium carbonate. *Earth and Planetary Science Letters* 8:363-371.

Ensminger, A.H., M.E. Ensminger, J.E. Konlande, and J.R.K. Robson
1983a *Foods and Nutrition Encyclopedia Vol.I:A-H.* Pegus Press; Clovis, California.

1983b *Foods and Nutrition Encyclopedia Vol.II:I-Z.* Pegus Press; Clovis, California.

Fry, A.
1964 Application of the successive labelling technique to some carbon, nitrogen, and chlorine isotope effect studies of organic reaction mechanisms. In *Isotope Mass Effects in Chemistry and Biology*. Proceedings of the Symposium on isotope mass effects in chemistry and biology held in Vienna, Austria December 9-13 1963. International Union of Pure and Applied Chemistry, Butterworths, London.

Fry, B. and E.B. Sherr
1984 $\delta^{13}C$ measurements as indicators of carbon flow in marine and freshwater ecosystems. *Contrib.Mar.Sci.* 27: 13-47.

Gaebler, O.H., H.C. Choitz, T.G. Vitti and R. Vumirovich
1963 Significance of ^{15}N excess in nitrogenous compounds of biological origin. *J.Biochem.Phys.* 41:1089-1097.

Geidel, A.A.
1981 Paleonutrition and social stratification: a study of trace elements in human skeletons from the Dallas archaeological culture of eastern Tennessee. M.A. Thesis, Pennsylvania State University.

1982 Trace element studies for Mississipian skeletal remains: findings from neutron activation analysis. *Masca Journal* 2:13-16.

Gilbert, R.I., Jr.
1975 Trace Element Analyses of Three Skeletal Amerindian Populations at Dickson Mounds. PhD dissertation, Department of Anthropology, University of Massachusetts.

Grece, C.F.
1819 *Facts and Observations Respecting Canada and the United States of America*. Harding, London.

Haight, C.
1885 *Country Life In Canada Fifty Years Ago: Personal Recollections and Reminiscences of a Sexagenarian.* Hunter, Rose & Co., Toronto.

Hastorf, C.A., and M.J. DeNiro
1985 Reconstruction of prehistoric plant production and cooking practices by a new isotopic method. *Nature* 315: 489-491.

Hatch, J.W. and A.A. Geidel
1983 Tracing status and diet in prehistoric Tennessee. *Archaeology* Jan-Feb:56-59.

1985 Status-specific dietary variation in two world cultures. *J.Human Evol.* 14:469-476.

Herring, A., S. Saunders, and G. Boyce
1991 *Bones and burial registers: Reconstructing a 19th century pioneer community from skeletal evidence and cemetery records.* Paper presented at the Council for Northeast Historical Archaeology, Newark, Delaware. October 6 1991.

Hoefs, J.
1973 *Stable Isotope Geochemistry.* Springer-Verlag, New York, NY.

Hoering, T.C.
1955 Variations of nitrogen-15 abundance in naturally occurring substances. *Science* 122:1233-1234.

Howison, J.
1821 *Sketches of Upper Canada.* Oliver and Boyd, Edinburgh.

Isermann, K.
1981 Uptake of stable strontium by plants and effects on plant growth. In *Handbook of Stable Strontium,* Stanley C. Skoryna, editor, Plenum Press, New York.

Katz, J.J., R.A. Uphaus, H.L. Crespi, and M.I. Blake.
1975 Isotope chemistry and biology. In *Isotopes and Chemical Principles.* ACS Symposium Series 11. Peter A. Rock, ed. American Chemical Society, Washington, DC. Pp. 84-205.

Katz, S., M.L. Hediger, and L.A. Valleroy
1975 The anthroplogical and nutritional significance of traditional maize processing techniques in the New World. In *Biosocial Interrelations in Population Adaptation*. E.S Watts, F.E Johnston, and G.W. Laskers, eds. Morton Publishers, Paris. Pp.195-231.

Katzenberg, M.A.
1991 Stable isotope analysis of remains from the Harvie family. In *The Links that Bind. The Harvie Family Nineteenth Century Burying Ground*. S. Saunders and R. Lazenby, eds. Copetown Press, Dundas. Pp.65-70.

1984 Chemical analysis of prehistoric human bone from five temporally distinct populations in southern Ontario. Archaeological Survey of Canada Paper No.129, National Museum of Man Mercury Series.

Katzenberg, M.A., Shelley R. Saunders
n.d. Diet and health among 19th century residents of Upper Canada. SSHRC grant # 410-91-1408.

Keeling, C.D.
1961 The concentration and isotopic abundances of carbon dioxide in rural and marine air. *Geochim.Cosmochim.Acta* 24:277-298.

Kennedy, D.
1903 *Incidents of Pioneer Days at Guelph and the County of Bruce*. 1973 reprint, Bruce County Historical Society.

Kennedy, B.V.
1989 Variation in 13C values of post-medieval Europeans. PhD Dissertation, University of Calgary, Calgary.

Kent, S., E.D. Weinberg, and P. Stuart-Macadam
1990 Dietary and prophylactic iron supplements: Helpful or harmful. *Human Nature* 1:53-79.

Kenyon, I. and S. Kenyon
1992 Pork and potatoe, flour and tea: Descriptions of food and meals in Upper Canada, 1814-1867. *KEWA* 92(5): 2-25.

Klepinger, L.
1984 Nutritional assessment from bone. *Ann.Rev.Anthr.* 13:75-96.

Kulp, J.L., W.R. Eckelmann and A.R. Schulert
1957 Strontium-90 in man. *Science* 125:219.

Lambert, J.B., C.B. Szpunar, and J.E. Buikstra
1979 Chemical analysis of excavated human bone from Middle and Late Woodland sites. *Archaeometry* 21:115-129.

Lambert, J.B., S.M. Vlasak, A.C. Thometz, and J.E. Buikstra
1982 A comparative study of the chemical analysis of ribs and femurs in Woodland populations. *Am.J.Phys.Anth.* 62:409-423.

Lambert, J.B., S.V. Simpson, J.E. Buikstra, and D. Hanson
1984 Analysis of soils associated with Woodland burials. In *Archaeological Chemistry III*, J.B. Lambert, ed., American Chemical Society: Washington, D.C.

Langton, A.
1964 *A Gentlewoman in Upper Canada: The Journals of Anne Langton*. H.H. Langton, ed., Clark, Irwin & Co., Toronto.

Lund, D.
1982 Effect of processing on nutrient content and nutritional content of food: Heat processing. In *Handbook of Nutritive Value of Processed Food, Vol 1: Food for Human Use*. Miloslav Rechcigl, Jr., ed., CRC Press, Florida. Pp.3-9.

MacFarlane, J.
1831 *The Cook Not Mad or Rational Cookery*. 1972 reprint, The Cherry Tree Press, Toronto.

MacLeod, A.J.
1973 *Instrumental Methods of Food Analysis*. Unwin Brothers Limited, London.

MacRitchie, F.
1986 Physicochemical processes in mixing. In *Chemistry and Physics of Baking. Materials, Processes, and Products*. J.M.V. Blanshard, P.J. Frazier, and T. Galliard, eds. J.W. Arrowsmith Ltd., Bristol. Pp.132-146.

Marfo, E.K., B.K. Simpson, J.S. Idown, and O.L. Oke.
1990 Effect of local food processing on phytate levels in cassava, cocoyam, yam, maize, sorghum, rice, cowpea, and soybean. *J.Agric.Food Chem.* 38:1580-1585.

Marino, B.D. and M.J. DeNiro
1987 Isotopic analysis of archaeobotanicals to reconstruct past climates: Effects of activities associated with food preparation on carbon, hydrogen, and oxygen isotope ratios of plant cellulose. *J.Arch.Sci.* 14:537-548.

Mariotti, A.
1983 Atmospheric nitrogen is a reliable standard for natural 15N abundance measurements. *Nature* 303:685-687.

Mauron, J.
1982 Effect of processing on nutritive value of processed food: Protein. In *Handbook of Nutritive Value of Processed Food, Vol 1: Food for Human Use*. Miloslav Rechcigl, Jr., ed. CRC Press, Florida. Pp.429-471.

McLean, F.C., and M.R. Urist
1961 *Bone*, 2nd ed., University of Chicago Press, Chicago.

Mika, N. and H. Mika
1978 *Historic Belleville*. Mika Publishing Company, Belleville, ON.

1975 *Belleville. The Good Old Days*. Mika Publishing Company, Belleville, ON.

1973 *Belleville. Friendly City*. Mika Publishing Company, Belleville, ON.

Moodie, S.
1853 *Life in the Clearings versus the Bush*. 1989 reprint copy, McClelland and Stewart, Inc., Toronto.

New Canada Publications
1988 *Pioneer Cooking in Ontario. Recipes from Ontario Historic Sites*. NC Press Ltd., Toronto.

Norr, L.
1982 A new chemical analysis for the determination of a marine fauna component in prehistoric diets. *Am.J.Phys. Anth.* 57:514.

Norse, Mrs.
1845 *Modern Practical Cookery*. Armour and Ramsay, Montreal.

O'Leary, M.
1981 Carbon isotope fractionation in plants. *Phytochemistry* 20:553-567.

Parwell, A., R. Ryhage and F. Wickman
1957 Natural variations in the relative abundances of the nitrogen isotopes. *Geochim.Cosmochim.Acta* 11:165-170.

Peterson, B.J. and B. Fry
1987 Stable isotopes in ecosystem studies. *Ann.Rev.Ecol. Syst.* 18:293-320.

Pickering, J.
1831 *Inquiries of an Emigrant*. Longman, Rees, Orme, Brown, and Green, London.

Price, T.D., M.J. Schoeninger, and G.J. Armelagos
1985 Bone chemistry and past behaviour: An overview. *J.Human Evol.* 14:419-447.

Price, T.D. and M. Kavanagh
1982 Bone composition and the reconstruction of diet: Examples from the mid-western United States. *Midcont.J. Arch.* 7:61-79.

Proudfoot, W.
1915 The proudfoot Papers: Part I. 1832. collected by Miss Harriet Priddis. *Transactions of the London and Middlesex Historical Society, Part VI.*

Purcell, A.E., and W.M. Walter, Jr.
1982 Stability of amino acids during cooking and processing of sweet potatoes. *J.Agric.Food Chem.* 30:443-444.

Rankama, K.
1954 *Isotope Geology*. McGraw-Hill, New York.

Runia, L.T.
1987 *The Chemical Analysis of Prehistoric Bones. A Paleodietary and Ecoarchaeological Study of Bronze Age West-Friesland*. BAR International Series 363, Oxford.

Salter, C.
1989 The scientific investigation of the iron industry in Iron Age Britain. In *Scientific Analysis in Archaeology*, J. Henderson, ed. Short Run Press, Exeter. Pp.250-273.

Saunders, S.
1991 Historical background. In *The Links that Bind. The Harvie Family Nineteenth Century Burying Ground*. S. Saunders and R. Lazenby, eds. Copetown Press, Dundas. Pp.11-20.

Schoeninger, M.
1989 Reconstructing prehistoric human diet. In *The Chemistry of Prehistoric Human Bone*. T.D. Price, ed. Cambridge University press, Cambridge. Pp. 38-67.

1985 Trophic level effects on 15N/14N and 13C/12C ratios in bone collagen and strontium levels in bone mineral. *J.Human Evol*. 14:515-525.

Schoeninger, M.J., K.M. Moore, M.L. Murray, and J.D. Kingston
1989 Detection of bone preservation in archaeological and fossil samples. *Applied Geochemistry* 4:281-292.

Schoeninger, M. and M. DeNiro
1984 Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochim. Cosmochim.Acta* 48:625-639.

Schoeninger, M., M. DeNiro, and H. Tauber
1983 Stable nitrogen isotope ratios of bone collagen reflect marine and terrestrial components of prehistoric human diet. *Science* 220:1381-1383.

Schroeder, H.A.
1973 *The Trace Elements and Man. Some Positive and Negative Aspects*. The Devin-Adair Co., Connecticut.

Schroeder H.A., A.P. Nason, and I.H. Tipton
1969 Essential metals in man: Magnesium. *J.Chronic Diseases* 21:815-841.

Schroeder, H.A., I.H. Tipton, and A.P. Nason
1972 Trace elements in man: Strontium and Barium. *J. Chronic Diseases* 25:491-517.

Schwarcz, H.P. and M.J. Schoeninger
1991 Stable isotope analysis in human nutritional ecology. *Yearbook Phys.Anth*. 34:283-321.

Schwarcz, H.P., F.J. Melbye, M.A. Katzenberg and M. Knyf
1985 Stable isotopes in human skeletons of southern Ontario: Reconstructing paleodiet. *J.Arch.Sci*. 12:187-206.

Scott, B.G.
1977 Metallographic study of some early iron tools and weapons from Ireland. *Proc.Roy.Irish Acad*. 77(C)12:301-317.

Sealy, J.C. and A. Sillen
1988 Sr and Sr/Ca in marine and terrestrial food webs in the Southwestern Cape, South Africa. *J.Arch.Sci.* 15:425-438.

Sealy, J. and N. van der Merwe
1986 Reconstructing prehistoric human diet. *Homo* 39: 78-99.

Shahied, I.I.
1977 *Biochemistry of Food and the Biocatalysts*. Vantage Press, New York.

Shiner, V.J., Jr.
1975 Isotope effects and reaction mechanisms. In *Isotopes and General Principles*. ACS Symposium Series 11. Peter A. Rock, ed. American Chemical Society, Washington, DC.

Sillen, A., J.C. Sealy, and N. van der Merwe
1989 Chemistry and paleodietary research: No more easy answers. *American Antiquity* 54(3):504-512.

Spadaro, J.A., R.O. Becker, C.H. Bachman
1970a The distribution of trace element ions in bone and tendon. Cal.Tissue Res. 6:49-54.

1970b Size-specific metal complexing sites in native collagen. *Nature* 225:1134-1136.

Spencer, H., M. Li, J. Samachson, and D. Laszlo
1960 Metabolism of strontium-85 and calcium-45 in man. *Metabolism* 9:916-925.

Spencer, H., J.M. Warren, L. Kramer, and J. Samachson
1973 Passage of calcium and strontium across the intestine in man. *Clin.Orth.Rel.Res.* 91:225-234.

Stedt, P.
1979 Trace element analysis of two prehistoric populations, the Fremont and the Anasazi. M.A. thesis, Department of Anthropology, San Diego State University.

Szpunar, C.B.
1977 Atomic Absorption Analysis of Archaeological Remains: Human Ribs from Woodland Mortuary Sites. PhD dissertation, Department of Chemistry, Northwestern University.

Talbot, E.A.
1824 *Five Years' Residence in the Canadas*. Longman, Hurst, Rees, Orme, Brown, and Green, London.

Tivy, L.
1972 *Your Loving Anna. Letters from the Ontario Frontier*. University of Toronto Press, Toronto.

Traill, C.P.
1836 *The Backwoods of Canada*. 1966 reprint, McClelland and Stewart, Toronto.

1855 *The Canadian Settler's Guide*. 1969 reprint copy, McLelland and Stewart Ltd., Toronto.

Troughton, J.H.
1972 Carbon isotope fractionation in plants. *Proc. 8th Conf., Radiocarbon Dating, Wellington, 1972*, 2:C43, C55.

Turkenian, K.K. and J.L. Kulp
1956 The geochemistry of strontium. *Geochim.Cosmochim. Acta* 10:245-296.

Underwood, E.J.
1977 *The Trace Elements in Human and Animal Nutrition*. 4th ed. Academic Press, New York.

1975 Trace elements and their physiological role in the animal. In *Trace Elements in Soil-Plant-Animal Systems*. D.J.D. Nicholas and Adrian R. Egan, eds., Academic Press Inc., New York. Pp.227-242.

van Dam, H.W.
1986 The biotechnology of baker's yeast: Old or new business. In *Chemistry and Physics of Baking. Materials Processes and Products*. J.M.V. Blanshard, P.J. Frazier, and T. Galliard, eds. J.W. Arrowsmith Ltd., Bristol. Pp.117-131.

van der Merwe, N.J.
1989 Natural variation in 13C concentration and its effect on environmental reconstruction using 13C/12C ratios in animal bones. In *The Chemistry of Prehistoric Human Bone*. T.D. Price, ed. Cambridge University Press, Cambridge. Pp.105-125.

1982 Carbon isotopes, photosynthesis, and archaeology. *American Scientist* 70:596-606.

van der Merwe, N.J. and J.C. Vogel
1978 13C content of human collagen as a measure of prehistoric diet in Woodland North America. *Nature* 276: 815-816.

Van Loon, J.C.
1985 *Selected Methods of Trace Metal Analysis: Biological and Environmental Samples*. John Wiley & Sons, New York, NY.

Vlasak, S.M.
1983 Elemental analysis of excavated human bone: a study of post-mortem deterioration. PhD Dissertation, Northwestern University, Illinois.

Vogel, J.C.
1978 Isotopic assessment of the dietary habits of ungulates. *South Afr.J.Sci.* 75:209-215.

Walker, P., M. DeNiro
1986 Stable nitrogen and carbon isotope ratios in bone collagen as indices of prehistoric dietary dependence on marine and terrestrial resources in southern California. *Am.J.Phys.Anth.* 71:51-61.

Walser, M. and B. Robinson
1963 Renal excretion and tubular reabsorption of calcium and strontium. In *The Transfer of Calcium and Strontium across Biological Membranes*. R.H. Wasserman, ed., Academic Press, New York. Pp.305-326.

Watt, B.K. and A.L. Merrill
1975 *Composition of Foods*. Agriculture Handbook No.8. USDA; Washington, D.C.

Witting, L.A. and P.S. Dimick
1982 Effects of processing on food lipids. In *Handbook of Nutritive Value of Processed Food, Vol I: Food for Human Use*. Miloslav Rechcigl, Jr., ed., CRC Press, Boca Raton. Pp.403-428.

Ziderman, I., and M. Friedman
1985 Thermal and compositional changes of dry wheat gluten-carbohydrate mixtures during simulated crust baking. *J.Agric.Food Sci.* 33:1096-1102.

APPENDIX I
Recipes Used

Whole Wheat Bread: Watson's Mill Whole Wheat Bread

Ingredients:

1500ml stone-ground whole wheat flour
500ml warm milk
160ml warm water
125ml brown sugar
30ml shortening
10ml salt
10ml dry active yeast

Heat milk over low heat until warm. Measure brown sugar, salt, and shortening into a large bowl. Pour warm milk over brown sugar mixture and stir until shortening is melted. Cool to lukewarm. Dissolve sugar in warm water and sprinkle yeast on top. Add to milk mixture and stir.

Stir in 750ml of stone ground flour and beat until smooth. Gradually add remaining flour, using rotating motion of the hand. Turn dough onto a lightly floured board and knead until smooth; 8 to 10 minutes. Place dough into a lightly greased warm bowl; grease top of dough slightly by turning over once or twice in the bowl.

Cover with wax paper and a clean tea towel and let rise in a warm place until doubled in bulk (about 1 hour). Punch down dough and turn onto a lightly-floured board. Divide in half forming each piece into a smooth ball. Cover and let rest 10-15 minutes. Shape into two loaves. Place in greased loaf pans. Cover and let rise until doubled (about 1 hour).

Bake in a pre-heated oven, 400°F (200°C) for 35-40 minutes. Cool on wire rack.

From: New Canada Publications (1988:31)

Barley Broth (Beef Stew)

Ingredients:

barley	125ml	
beef	125ml	
carrots	125ml	
turnips	125ml	
potatoes	125ml	
onions	125ml	
parsley	pinch	
thyme	pinch	
salt	pinch	
water	375ml	(approximate)

The recipe was adapted from the following description:

"Take beef or mutton, any of which is most convenient; put the meat in cold water, add a teacup full of barley; be careful the pot and cover are clean in the inside, or it will blacken the broth a little before it comes to the boil, skim it well and wipe the inside of the cover, cut down some carrots and turnips in dices, a little parsley, a sprig of thyme and a few young onions; if you have no young onions you may put in a whole onion or two, and take them out before you dish; skim the pot again and put in the roots; if the meat is fresh add a little salt; let it boil till the roots are done, and the broth is rich and good; when ready, take off the pot, cover it close, and let it stand off the fire fifteen minutes before you serve it."

From: Nourse (1845)

Shortbread
Ingredients:
1000ml flour
500ml butter
250ml sugar
pinch salt

Sift flour, sugar, and salt and rub in the butter. Roll or pat the dough onto a cookie sheet and prick with a fork. Bake at 350°F (150°C) for an hour or until pale brown. While still warm cut into fingers.

From: New Canada Publications (1988:46)

Ginger Bread
Ingredients:
500ml molasses
500ml flour
125ml butter
 30ml ginger
  5ml salaratus (baking soda)
  5ml cream of tartar
  3 eggs

"To a pint of molasses add half cup butter, three eggs, half cup sour milk, one teaspoon salaratus, one ditto cream of tartar, two cups flour, two table-spoonfuls of ginger."

Although this recipe as originally written calls for sour milk, interpreters at the Bradley Museum have found that such a large quantity makes the dough far too runny in consistency. Instead, they use a small amount of either water or milk; just enough to make the dough sticky. As a result, a small amount of water was used in place of the recommended sour milk.

From Traill (1855:100)

Corn Bread
Ingredients:
500ml corn meal
180ml milk or water
45ml melted butter or drippings
7.5ml sugar or maple syrup
3ml salt
1 egg

Generously grease a loaf pan and put in a hot oven until the grease spits. Beat the egg in a bowl and add it, along with the milk, butter, sugar and salt to the corn flour. Mix together fairly well. Pour into the pan and bake at 400°F (200°C) for about fifteen minutes or until done.

From: New Canada Publications (1988:30)

Pumpkin Cake
Ingredients:
250ml flour
250ml white sugar
250ml pumpkin puree
250ml corn meal
250ml sour milk or buttermilk
125ml shortening
20ml baking powder
5ml baking soda
5ml salt
1 egg

Sift together flour, corn meal, baking powder, and salt. Cream shortening and sugar, adding well-beaten egg. Mix soda in sour milk and add to creamed ingredients, mixing well. Beat with pumpkin. Fold in sifted ingredients. Turn into a well-greased 8in (20cm) square cake tin at 375°F (190°C) for 30 minutes. Before baking, sprinkle top with brown sugar.

From: New Canada Publications (1988:37)

APPENDIX II
Raw Data for $\delta^{13}C$ of Human Bones and Food and Mineral Concentration in Food

Human $\delta^{13}C$ Data: St. Thomas Anglican Church, Belleville

Males				Females			
Cat #	Age	δ ^{13}C	collagen % yield	Cat #	Age	δ ^{13}C	collagen % yield
B19	17	-19.7	18	B97	65	-21.8	25
B31	62	-19.0	14	B108	60	-20.0	26
B71	20	-19.4	27	B111	33	-20.1	25
B103	75	-19.2	25	B124	67	-20.6	26
B115	27	-20.0	25	B188	67	-20.2	22
B156	55	-19.5	26	B304	57	-18.7	25
B287	48	-19.7	22	B317	35	-19.8	16
B303	58	-18.0	25	B351a	22	-19.1	25
B336	81	-19.2	24	B423	22	-19.8	24
B339	55	-19.6	26	B435	62	-19.0	15
B374	64	-19.9	24	B437	29	-18.7	23
B375	60	-21.0	14	B464	46	-19.2	12
B385	35	-18.5	24	B470	53	-18.6	27
B397	75	-19.3	25	B514	17	-19.6	26
B405	68	-21.4	20	B516	69	-20.3	25
B429	43	-19.3	20	B544	71	-19.6	27
B433a	18	-18.6	10				
B436	66	-17.9	25				
B443	44	-19.5	18				
B446	69	-19.3	25				
B451	28	-18.7	21				
B462	59	-18.6	20				
B467	54	-20.7	25				
B472	20	-19.8	21				
B527a	31	-19.5	24				
B548	61	-18.5	24				

$\delta^{13}C$ Values for Raw and Cooked Foods

Corn Bread				Shortbread			
Raw	δ ^{13}C	Cooked	δ ^{13}C	Raw	δ ^{13}C	Cooked	δ ^{13}C
CB1a	-13.9	CB1b	-14.6	SB1a	-18.7	SB1b	-19.7
CB2a	-13.3	CB2B	-13.9	SB2a	-19.1	SB2b	-19.7
CB3a	-12.8	CB3b	-13.7	SB3a	-19.6	SB3b	-19.4
CB4a	-13.4	CB4b	-13.5	SB4a	-20.2	SB4b	-19.9
CB5a	-14.5	CB5b	-15.9	SB5a	-20.1	SB5b	-20.5
Whole Wheat Bread				Pumpkin Cake			
Raw	δ ^{13}C	Cooked	δ ^{13}C	Raw	δ ^{13}C	Cooked	δ ^{13}C
WWB1a	-23.8	WWB1b	-23.7	PC1a	-17.9	PC1b	-18.6
WWB2a	-23.5	WWB2b	-24.2	PC2a	-16.9	PC2b	-18.4
WWB3a	-22.4	WWB3b	-23.8	PC3a	-16.8	PC3b	-16.6
WWB4a	-22.3	WWB4b	-22.9	PC4a	-17.3	PC4b	-19.0
WWB5a	-22.8	WWB5b	-23.3	PC5a	-17.9	PC5b	-19.7
WWB11a	-22.3	WWB11b	-22.7				
WWB12a	-23.0	WWB12b	-23.4				
Ginger Bread				Barley			
Raw	δ ^{13}C	Cooked	δ ^{13}C	Raw	δ ^{13}C	Cooked	δ ^{13}C
GB1a	-20.2	GB1b	-20.6	BSBa	-25.7	BSB1b	-26.7
GB2a	-21.0	GB2b	-21.7	BSBa	-26.2	BSB2b	-27.5
GB3a	-21.9	GB3b	-20.7	BSBa	-25.2	BSB3b	-27.0
GB4a	-22.4	GB4b	-22.0			BSB4b	-25.1
GB5a	-21.5	GB5b	-20.6			BSB5b	-26.9

Onion				Turnip			
Raw	δ ^{13}C	Cooked	δ ^{13}C	Raw	δ ^{13}C	Cooked	δ ^{13}C
BSOa	-27.1	BSO1b	-26.8	BSTa	-27.0	BST1b	-27.0
BSOa	-27.4	BSO2b	-27.8	BSTa	-27.6	BST2b	-26.9
BSOa	-26.6	BSO3b	-27.6	BSTa	-26.5	BST3b	-26.6
		BSO4b	-28.5			BST4b	-27.0
		BSO5b	-26.7			BST5b	-27.2
Potato				Carrot			
Raw	δ ^{13}C	Cooked	δ ^{13}C	Raw	δ ^{13}C	Cooked	δ ^{13}C
BSPa	-26.6	BSP1b	-27.4	BSCa	-28.9	BSC1b	-27.6
BSPa	-27.2	BSP2b	-28.2	BSCa	-29.4	BSC2b	-27.9
BSPa	-26.3	BSP3b	-27.6	BSCa	-28.5	BSC3b	-27.6
		BSP4b	-27.8			BSC4b	-27.7
		BSP5b	-27.1			BSC5b	-27.7
Beef							
Raw	δ ^{13}C	Cooked	δ ^{13}C				
BSMa	-24.3	BSM1b	-24.6				
BSMa	-24.8	BSM2b	-24.6				
BSMa	-23.7	BSM3b	-24.1				
		BSM4b	-24.4				
		BSM5b	-24.6				

Key of Foods in the Mineral Concentration Tables

Baked Items:
WWB - whole wheat bread
CB - corn bread
SB - short bread
GB - ginger bread
PC - pumpkin cake
a= raw (dough)
b= cooked

Beef Stew Ingredients:
BSP - potato(raw)
BS*P - potato (cooked)
BST - turnip (raw)
BS*T - turnip (cooked)
BSC - carrot (raw)
BS*C - carrot (cooked)
BSB - barley (raw)
BS*B - barley (cooked)
BSM - beef (raw)
BS*M - beef (cooked)

Calcium Concentration of Food Samples					
Sample	mg/l	Std Dev	weight (g)	mg/100g	Std Dev
SB6a	1.60	0.01	0.482	20.71	0.17
SB7a	1.59	0.01	0.497	19.94	0.13
SB8a	1.51	0.00	0.519	18.20	0.06
SB9a	1.81	0.01	0.536	21.08	0.08
SB10a	1.78	0.01	0.546	20.33	0.09
SB6b	1.85	0.01	0.508	22.80	0.15
SB7b	1.75	0.00	0.533	20.56	0.03
SB8b	1.60	0.01	0.523	19.17	0.13
SB9b	1.98	0.00	0.498	24.86	0.05
SB10b	1.83	0.01	0.521	21.94	0.15
WWB6a	6.75	0.02	0.555	76.01	0.20
WWB7a	5.77	0.02	0.499	72.21	0.19
WWB8a	5.76	0.01	0.500	71.96	0.18
WWB9a	6.02	0.02	0.523	71.89	0.21
WWB10a	6.07	0.03	0.538	70.54	0.39
WWB11a	5.47	0.02	0.477	71.63	0.20
WWB12a	5.37	0.01	0.552	60.82	0.13
WWB6b	5.78	0.03	0.513	70.36	0.40
WWB7b	5.67	0.02	0.507	69.91	0.28
WWB8b	6.05	0.02	0.510	74.14	0.23
WWB9b	6.25	0.02	0.513	76.18	0.29
WWB10b	5.98	0.03	0.502	74.45	0.34
WWB11b	5.20	0.01	0.501	64.85	0.16
WWB12b	4.97	0.03	0.546	56.85	0.37
CB1a	3.54	0.01	0.522	42.35	0.15

CB2a	3.36	0.02	0.497	42.27	0.26
CB3a	3.63	0.01	0.505	44.90	0.13
CB4a	3.43	0.02	0.523	40.93	0.20
CB5a			0.531		
CB1b	3.47	0.01	0.549	39.45	0.07
CB2b	4.07	0.01	0.511	49.82	0.06
CB3b	5.10	0.02	0.518	61.47	0.21
CB4b	4.29	0.01	0.502	53.42	0.13
CB5b	4.59	0.02	0.509	56.31	0.19
PC1a	2.86	0.01	0.502	35.55	0.08
PC2a	3.07	0.01	0.505	38.02	0.09
PC3a	3.27	0.01	0.536	38.16	0.06
PC4a	3.43	0.02	0.520	41.20	0.28
PC5a	3.32	0.02	0.506	41.01	0.21
PC1b	3.78	0.03	0.514	45.91	0.34
PC2b	4.20	0.02	0.510	51.52	0.21
PC3b	4.51	0.02	0.495	56.89	0.29
PC4b	4.15	0.05	0.512	50.60	0.63
PC5b	3.89	0.02	0.518	46.88	0.22
GB2a	14.22	0.08	0.518	171.57	0.92
GB3a	12.24	0.07	0.523	146.27	0.78
GB4a	11.66	0.05	0.544	133.96	0.57
GB5a	12.63	0.05	0.503	156.93	0.57
GB8a	9.00	0.05	0.544	103.40	0.54
GB2b	18.16	0.05	0.526	215.78	0.63
GB3b	14.54	0.07	0.522	174.09	0.89
GB4b	13.85	0.09	0.539	160.60	0.99
GB5b	14.23	0.04	0.525	169.40	0.46

GB8b	9.49	0.02	0.505	117.45	0.22
BSP	3.54	0.03	1.050	21.05	0.17
BS3P	4.54	0.02	0.996	28.48	0.13
BS4P	3.84	0.03	0.972	24.70	0.16
BS5P	4.68	0.02	0.976	29.97	0.12
BS7P	3.44	0.01	1.001	21.50	0.05
BS8P	3.90	0.01	0.990	24.61	0.07
BST	6.59	0.02	1.311	31.42	0.11
BS3T	5.09	0.02	1.125	28.28	0.09
BS4T	5.15	0.02	1.082	29.77	0.11
BS5T	5.10	0.03	1.079	29.52	0.19
BS7T	4.56	0.01	1.353	21.08	0.04
BS8T	4.00	0.03	0.988	25.32	0.18
BSB	2.38	0.01	0.530	28.05	0.07
BS1B	13.58	0.04	0.539	157.47	0.48
BS2B	9.37	0.05	0.542	108.05	0.53
BS3B	10.00	0.01	0.518	120.66	0.10
BS4B	10.99	0.02	0.542	126.73	0.24
BS5B	11.73	0.07	0.549	133.54	0.80
BSC	7.31	0.04	0.975	46.86	0.24
BS3C	5.48	0.02	0.901	38.04	0.16
BS4C	6.08	0.01	0.950	40.01	0.09
BS5C	8.10	0.05	0.983	51.50	0.31
BS7C	5.39	0.02	0.957	35.20	0.11
BS8C	7.03	0.04	1.095	40.13	0.21

BSM	1.16	0.00	0.548	26.51	0.03
BS1M	2.29	0.01	0.527	54.22	0.20
BS2M	2.22	0.01	0.549	50.46	0.19
BS3M	2.26	0.01	0.514	55.06	0.18
BS4M	2.95	0.01	0.549	67.12	0.13
BS5M	3.21	0.01	0.527	76.23	0.26

Magnesium Concentration of Food samples					
Sample	mg/l	Std Dev	weight (g)	mg/100g	Std Dev
SB6a	4.62	0.01	0.482	59.85	0.18
SB7a	4.91	0.02	0.497	61.71	0.26
SB8a	4.75	0.01	0.519	57.17	0.18
SB9a	5.63	0.03	0.536	65.69	0.29
SB10a	5.25	0.02	0.546	60.14	0.28
SB6b	5.38	0.04	0.508	66.20	0.46
SB7b	5.95	0.01	0.533	69.79	0.15
SB8b	5.58	0.01	0.523	66.69	0.15
SB9b	6.30	0.04	0.498	79.07	0.55
SB10b	5.93	0.03	0.521	71.15	0.32
WWB6a	13.12	0.07	0.555	147.75	0.73
WWB7a	11.25	0.03	0.499	140.91	0.40
WWB8a	11.39	0.08	0.500	142.38	1.04
WWB9a	12.09	0.01	0.523	144.48	0.12
WWB10a	12.24	0.06	0.538	142.19	0.74
WWB11a	10.44	0.03	0.477	136.79	0.37
WWB12a	12.15	0.08	0.552	137.57	0.93
WWB6b	11.14	0.04	0.513	135.72	0.43
WWB7b	10.94	0.11	0.507	134.86	1.31
WWB8b	11.60	0.07	0.510	142.16	0.86
WWB9b	10.82	0.02	0.513	131.82	0.26
WWB10b	13.11	0.04	0.502	163.22	0.49
WWB11b	10.96	0.06	0.501	136.73	0.69
WWB12b	11.49	0.04	0.546	131.52	0.42
CB1a	4.54	0.03	0.522	54.35	0.38

CB2a	3.70	0.01	0.497	46.50	0.18
CB3a	3.91	0.01	0.505	48.44	0.12
CB4a	3.84	0.02	0.523	45.89	0.24
CB5a			0.531		
CB1b	5.21	0.04	0.549	59.36	0.47
CB2b	5.03	0.02	0.511	61.57	0.22
CB3b	5.40	0.02	0.518	65.19	0.27
CB4b	4.42	0.02	0.502	55.08	0.22
CB5b	3.64	0.03	0.509	44.70	0.36
PC1a	2.79	0.00	0.502	34.77	0.05
PC2a	2.95	0.01	0.505	36.45	0.14
PC3a	2.01	0.01	0.536	23.40	0.08
PC4a	2.47	0.02	0.520	29.71	0.25
PC5a	2.94	0.01	0.506	36.26	0.12
PC1b	3.19	0.02	0.514	38.83	0.22
PC2b	3.84	0.02	0.510	47.03	0.24
PC3b	2.93	0.02	0.495	37.05	0.21
PC4b	2.92	0.01	0.512	35.66	0.10
PC5b	3.54	0.01	0.518	42.69	0.16
GB2a	6.11	0.04	0.518	73.72	0.43
GB3a	5.44	0.03	0.523	65.00	0.30
GB4a	5.04	0.01	0.544	57.88	0.12
GB5a	5.13	0.03	0.503	63.71	0.34
GB8a	4.17	0.02	0.544	47.92	0.24
GB2b	7.42	0.03	0.526	88.17	0.34
GB3b	6.21	0.03	0.522	74.35	0.32
GB4b	5.65	0.03	0.539	65.50	0.38
GB5b	5.86	0.01	0.525	69.76	0.08

GB8b	4.36	0.04	0.505	54.01	0.49
BSP	4.64	0.03	1.050	27.64	0.19
BS3P	2.11	0.02	0.996	13.24	0.11
BS4P	3.00	0.02	0.972	19.31	0.12
BS5P	2.68	0.01	0.976	17.17	0.08
BS7P	3.40	0.02	1.001	21.24	0.11
BS8P	3.68	0.01	0.990	23.25	0.07
BST	2.72	0.01	1.311	12.94	0.07
BS3T	3.01	0.01	1.125	16.74	0.07
BS4T	3.30	0.02	1.082	19.09	0.14
BS5T	2.95	0.01	1.079	17.06	0.06
BS7T	4.21	0.02	1.353	19.43	0.09
BS8T	2.27	0.01	0.988	14.34	0.08
BSB	7.78	0.01	0.530	91.75	0.15
BS1B	10.80	0.09	0.539	125.23	1.01
BS2B	9.77	0.09	0.542	112.66	1.00
BS3B	9.41	0.06	0.518	113.54	0.69
BS4B	10.19	0.08	0.542	117.50	0.91
BS5B	9.04	0.06	0.549	102.91	0.68
BSC	2.45	0.01	0.975	15.72	0.09
BS3C	2.58	0.01	0.901	17.90	0.08
BS4C	3.15	0.02	0.950	20.74	0.10
BS5C	3.21	0.02	0.983	20.39	0.11
BS7C	2.97	0.00	0.957	19.42	0.02
BS8C	3.71	0.01	1.095	21.18	0.08

BSM	3.58	0.01	0.548	81.75	0.24
BS1M	2.35	0.01	0.527	55.83	0.35
BS2M	2.07	0.01	0.549	47.11	0.21
BS3M	2.30	0.01	0.514	55.86	0.27
BS4M	2.52	0.02	0.549	57.42	0.37
BS5M	2.44	0.00	0.527	57.85	0.10

Zinc Concentration in Food Samples					
Sample	mg/l	Std Dev	weight (g)	mg/100g	Std Dev
SB6a	0.30	0.02	0.482	1.54	0.11
SB7a	0.31	0.00	0.497	1.56	0.01
SB8a	0.30	0.00	0.519	1.43	0.01
SB9a	0.33	0.00	0.536	1.55	0.00
SB10a	0.33	0.00	0.546	1.51	0.01
SB6b	0.35	0.00	0.508	1.70	0.01
SB7b	0.36	0.00	0.533	1.70	0.01
SB8b	0.33	0.00	0.523	1.58	0.01
SB9b	0.39	0.00	0.498	1.97	0.02
SB10b	0.35	0.00	0.521	1.67	0.01
WWB6a	1.15	0.01	0.555	5.19	0.03
WWB7a	1.03	0.00	0.499	5.16	0.01
WWB8a	0.99	0.01	0.500	4.95	0.03
WWB9a	0.98	0.00	0.523	4.69	0.01
WWB10a	1.06	0.01	0.538	4.93	0.03
WWB11a	0.65	0.00	0.477	3.40	0.01
WWB12a	0.74	0.00	0.552	3.35	0.01
WWB6b	1.00	0.01	0.513	4.88	0.03
WWB7b	0.99	0.00	0.507	4.87	0.01
WWB8b-	1.01	0.00	0.510	4.93	0.02
WWB9b	0.94	0.00	0.513	4.56	0.00
WWB10b	1.04	0.00	0.502	5.19	0.02
WWB11b	0.66	0.00	0.501	3.28	0.01
WWB12b	0.70	0.00	0.546	3.22	0.01
CB1a	0.29	0.00	0.522	1.39	0.01

CB2a	0.26	0.00	0.497	1.32	0.00
CB3a	0.33	0.00	0.505	1.62	0.02
CB4a	0.27	0.00	0.523	1.29	0.01
CB5a	0.24	0.00	0.531	1.13	0.01
CB1b	0.31	0.00	0.549	1.43	0.00
CB2b	0.34	0.00	0.511	1.66	0.00
CB3b	0.32	0.00	0.518	1.56	0.00
CB4b	0.30	0.00	0.502	1.48	0.00
CB5b	0.27	0.00	0.509	1.34	0.01
PC1a	0.19	0.00	0.502	0.96	0.00
PC2a	0.22	0.00	0.505	1.09	0.00
PC3a	0.15	0.00	0.536	0.71	0.01
PC4a	0.30	0.00	0.520	1.42	0.01
PC5a	0.22	0.00	0.506	1.11	0.00
PC1b	0.24	0.00	0.514	1.18	0.00
PC2b	0.29	0.00	0.510	1.41	0.01
PC3b	0.21	0.00	0.495	1.05	0.01
PC4b	0.25	0.00	0.512	1.20	0.00
PC5b	0.27	0.00	0.518	1.28	0.00
GB2a	0.19	0.00	0.518	0.93	0.00
GB3a	0.20	0.00	0.523	0.95	0.01
GB4a	0.19	0.00	0.544	0.87	0.01
GB5a	0.19	0.00	0.503	0.93	0.01
GB8a	0.21	0.00	0.544	0.95	0.01
GB2b	0.23	0.00	0.526	1.10	0.01
GB3b	0.54	0.00	0.522	2.59	0.01
GB4b	0.27	0.00	0.539	1.27	0.00
GB5b	0.32	0.00	0.525	1.51	0.01

GB8b	0.24	0.00	0.505	1.19	0.01
BSP	0.20	0.00	1.050	0.47	0.00
BS3P	0.12	0.00	0.996	0.30	0.00
BS4P	0.10	0.00	0.972	0.24	0.00
BS5P	0.10	0.00	0.976	0.25	0.00
BS7P	0.15	0.00	1.001	0.38	0.00
BS8P	0.17	0.00	0.990	0.44	0.00
BST	0.16	0.00	1.311	0.30	0.00
BS3T	0.11	0.00	1.125	0.23	0.00
BS4T	0.12	0.00	1.082	0.27	0.00
BS5T	0.13	0.00	1.079	0.30	0.00
BS7T	0.26	0.00	1.353	0.48	0.00
BS8T	0.11	0.00	0.988	0.27	0.00
BSB	0.67	0.01	0.530	3.16	0.04
BS1B	0.79	0.00	0.539	3.65	0.02
BS2B	0.77	0.00	0.542	3.57	0.01
BS3B	0.73	0.00	0.518	3.51	0.02
BS4B	0.72	0.00	0.542	3.30	0.02
BS5B	0.78	0.01	0.549	3.55	0.03
BSC	0.13	0.00	0.975	0.33	0.00
BS3C	0.12	0.00	0.901	0.34	0.00
BS4C	0.10	0.00	0.950	0.27	0.00
BS5C	0.15	0.00	0.983	0.37	0.00
BS7C	0.09	0.00	0.957	0.24	0.00
BS8C	0.12	0.00	1.095	0.28	0.00

BSM	0.86	0.00	0.548	19.57	0.11
BS1M	0.62	0.00	0.527	14.63	0.09
BS2M	0.65	0.00	0.549	14.87	0.08
BS3M	0.51	0.00	0.514	12.38	0.06
BS4M	1.08	0.00	0.549	24.57	0.09
BS5M	0.46	0.00	0.527	10.91	0.07

Iron Concentration of Food Samples					
Sample	mg/l	Std Dev	weight (g)	mg/100g	Std Dev
SB6a	0.53	0.01	0.482	2.72	0.03
SB7a	0.49	0.01	0.497	2.47	0.05
SB8a	0.44	0.00	0.519	2.12	0.02
SB9a	0.48	0.00	0.536	2.24	0.02
SB10a	0.48	0.00	0.546	2.20	0.01
SB6b	0.53	0.01	0.508	2.63	0.03
SB7b	0.52	0.01	0.533	2.43	0.03
SB8b	0.50	0.00	0.523	2.39	0.01
SB9b	0.54	0.00	0.498	2.72	0.02
SB10b	0.51	0.00	0.521	2.43	0.02
WWB6a	1.01	0.01	0.555	4.54	0.02
WWB7a	0.87	0.01	0.499	4.34	0.04
WWB8a	0.79	0.00	0.500	3.97	0.02
WWB9a	0.86	0.00	0.523	4.11	0.01
WWB10a	0.89	0.00	0.538	4.15	0.02
WWB11a	0.89	0.00	0.477	4.65	0.02
WWB12a	0.99	0.01	0.552	4.47	0.03
WWB6b	1.02	0.01	0.513	4.95	0.04
WWB7b	1.00	0.00	0.507	4.94	0.01
WWB8b	0.94	0.01	0.510	4.60	0.03
WWB9b	1.47	0.01	0.513	7.16	0.03
WWB10b	1.27	0.01	0.502	6.33	0.04
WWB11b	0.90	0.01	0.501	4.50	0.04
WWB12b	1.14	0.00	0.546	5.22	0.01
CB1a	0.41	0.01	0.522	1.96	0.04

CB2a	0.37	0.00	0.497	1.84	0.02
CB3a	0.53	0.00	0.505	2.63	0.02
CB4a	0.43	0.00	0.523	2.04	0.01
CB5a	0.45	0.00	0.531	2.13	0.01
CB1b	1.00	0.00	0.549	4.57	0.02
CB2b	0.92	0.00	0.511	4.50	0.02
CB3b	0.71	0.01	0.518	3.40	0.03
CB4b	0.66	0.01	0.502	3.27	0.03
CB5b	1.52	0.01	0.509	7.46	0.03
PC1a	0.32	0.01	0.502	1.60	0.06
PC2a	0.37	0.00	0.505	1.82	0.01
PC3a	0.30	0.00	0.536	1.39	0.02
PC4a	0.45	0.00	0.520	2.14	0.02
PC5a	0.39	0.00	0.506	1.91	0.02
PC1b	0.45	0.01	0.514	2.17	0.03
PC2b	0.52	0.01	0.510	2.56	0.03
PC3b	0.49	0.01	0.495	2.48	0.03
PC4b	0.45	0.00	0.512	2.17	0.01
PC5b	0.47	0.00	0.518	2.28	0.02
GB2a	0.91	0.01	0.518	4.38	0.03
GB3a	0.80	0.00	0.523	3.84	0.02
GB4a	0.75	0.01	0.544	3.44	0.03
GB5a	0.83	0.00	0.503	4.13	0.02
GB8a	0.66	0.01	0.544	3.02	0.03
GB2b	1.10	0.00	0.526	5.24	0.02
GB3b	0.93	0.00	0.522	4.46	0.02
GB4b	0.91	0.00	0.539	4.24	0.01
GB5b	1.02	0.00	0.525	4.84	0.01

GB8b	0.69	0.00	0.505	3.44	0.01
BSP	0.32	0.00	1.050	0.76	0.00
BS3P	0.69	0.00	0.996	1.74	0.01
BS4P	0.47	0.00	0.972	1.22	0.01
BS5P	0.45	0.00	0.976	1.15	0.00
BS7P	0.56	0.00	1.001	1.39	0.01
BS8P	0.64	0.00	0.990	1.62	0.01
BST	0.29	0.01	1.311	0.56	0.02
BS3T	1.00	0.00	1.125	2.22	0.01
BS4T	0.72	0.00	1.082	1.67	0.01
BS5T	0.62	0.01	1.079	1.43	0.01
BS7T	0.61	0.01	1.353	1.13	0.01
BS8T	0.38	0.00	0.988	0.97	0.01
BSB	0.66	0.00	0.530	3.12	0.02
BS1B	5.84	0.01	0.539	27.10	0.06
BS2B	3.24	0.02	0.542	14.94	0.10
BS3B	3.37	0.01	0.518	16.25	0.06
BS4B	2.28	0.01	0.542	10.53	0.03
BS5B	1.96	0.01	0.549	8.90	0.05
BSC	0.31	0.00	0.975	0.80	0.01
BS3C	0.80	0.00	0.901	2.21	0.01
BS4C	0.54	0.00	0.950	1.41	0.01
BS5C	0.53	0.00	0.983	1.34	0.00
BS7C	0.51	0.00	0.957	1.33	0.01
BS8C	0.54	0.00	1.095	1.24	0.01

BSM	1.32	0.01	0.548	30.16	0.21
BS1M	2.76	0.02	0.527	65.44	0.42
BS2M	2.70	0.01	0.549	61.36	0.16
BS3M	2.49	0.01	0.514	60.43	0.31
BS4M	2.05	0.01	0.549	46.61	0.21
BS5M	1.64	0.01	0.527	38.90	0.18

Strontium Concentration of Food Samples					
Sample	mg/l	Std Dev	weight	mg/100g	Std Dev
			(g)		
SB6a	0.026	0.004	0.482	0.34	0.06
SB7a	0.046	0.008	0.497	0.58	0.10
SB8a	0.026	0.005	0.519	0.31	0.06
SB9a	0.033	0.008	0.536	0.38	0.09
SB10a	0.022	0.006	0.546	0.25	0.07
SB6b	0.049	0.019	0.508	0.60	0.23
SB7b	0.023	0.002	0.533	0.27	0.03
SB8b	0.021	0.008	0.523	0.25	0.09
SB9b	0.018	0.004	0.498	0.23	0.05
SB10b	0.026	0.009	0.521	0.31	0.11
WWB6a	0.032	0.002	0.555	0.36	0.02
WWB7a	0.027	0.004	0.499	0.34	0.05
WWB8a	0.060	0.009	0.500	0.75	0.11
WWB9a	0.027	0.004	0.523	0.32	0.04
WWB10a	0.038	0.006	0.538	0.44	0.07
WWB11a	0.037	0.010	0.477	0.48	0.14
WWB12a	0.078	0.009	0.552	0.88	0.10
WWB6b	0.159	0.004	0.513	1.94	0.05
WWB7b	0.030	0.004	0.507	0.37	0.04
WWB8b	0.043	0.006	0.510	0.53	0.07
WWB9b	0.028	0.004	0.513	0.34	0.05
WWB10b	0.031	0.003	0.502	0.39	0.04
WWB11b	0.078	0.009	0.501	0.97	0.11
WWB12b	0.032	0.001	0.546	0.37	0.01
CB1a	0.176	0.003	0.522	2.11	0.03

CB2a	0.056	0.003	0.497	0.70	0.04
CB3a	0.026	0.004	0.505	0.32	0.05
CB4a	0.019	0.006	0.523	0.23	0.08
CB5a			0.531		
CB1b	0.018	0.005	0.549	0.20	0.06
CB2b	0.021	0.006	0.511	0.26	0.08
CB3b	0.058	0.004	0.518	0.70	0.05
CB4b	0.029	0.005	0.502	0.36	0.06
CB5b	0.045	0.002	0.509	0.55	0.03
PC1a	0.023	0.006	0.502	0.29	0.07
PC2a	0.020	0.006	0.505	0.25	0.07
PC3a	0.015	0.002	0.536	0.17	0.03
PC4a	0.034	0.002	0.520	0.41	0.03
PC5a	0.029	0.007	0.506	0.36	0.09
PC1b	0.071	0.004	0.514	0.86	0.04
PC2b	0.028	0.007	0.510	0.34	0.08
PC3b	0.085	0.005	0.495	1.07	0.07
PC4b	0.036	0.004	0.512	0.44	0.05
PC5b	0.025	0.007	0.518	0.30	0.08
GB2a	0.066	0.003	0.518	0.80	0.03
GB3a	0.057	0.002	0.523	0.68	0.03
GB4a	0.059	0.006	0.544	0.68	0.07
GB5a	0.048	0.007	0.503	0.60	0.09
GB8a	0.039	0.005	0.544	0.45	0.06
GB2b	0.074	0.005	0.526	0.88	0.06
GB3b	0.062	0.005	0.522	0.74	0.06
GB4b	0.063	0.002	0.539	0.73	0.02
GB5b	0.050	0.002	0.525	0.60	0.02

GB8b	0.042	0.006	0.505	0.52	0.08
BSP	0.053	0.002	1.050	0.32	0.01
BS3P	0.041	0.004	0.996	0.26	0.02
BS4P	0.035	0.004	0.972	0.23	0.03
BS5P	0.044	0.002	0.976	0.28	0.01
BS7P	0.039	0.005	1.001	0.24	0.03
BS8P	0.049	0.007	0.990	0.31	0.04
BST	0.259	0.002	1.311	1.23	0.01
BS3T	0.079	0.007	1.125	0.44	0.04
BS4T	0.153	0.003	1.082	0.88	0.02
BS5T	0.089	0.004	1.079	0.52	0.03
BS7T	0.082	0.004	1.353	0.38	0.02
BS8T	0.111	0.006	0.988	0.70	0.04
BSB	0.059	0.002	0.530	0.70	0.03
BS1B	0.139	0.011	0.539	1.61	0.13
BS2B	0.087	0.003	0.542	1.00	0.04
BS3B	0.096	0.008	0.518	1.16	0.10
BS4B	0.106	0.004	0.542	1.22	0.04
BS5B	0.138	0.003	0.549	1.57	0.04
BSC	0.165	0.008	0.975	1.06	0.05
BS3C	0.065	0.004	0.901	0.45	0.03
BS4C	0.100	0.004	0.950	0.66	0.02
BS5C	0.086	0.005	0.983	0.55	0.03
BS7C	0.079	0.005	0.957	0.52	0.03
BS8C	0.086	0.005	1.095	0.49	0.03

BSM	0.020	0.010	0.548	0.46	0.24
BS1M	0.018	0.006	0.527	0.43	0.14
BS2M	0.013	0.005	0.549	0.30	0.10
BS3M	0.013	0.004	0.514	0.32	0.10
BS4M	0.030	0.009	0.549	0.68	0.20
BS5M	0.022	0.005	0.527	0.52	0.11