THE FINE DETAILS: CLAY SOURCING AND CHEMICAL ANALYSIS IN THE TRENT-SEVERN WATERWAY

A Thesis Submitted to the Committee on Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Master of Arts in the Faculty of Arts and Science

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Abstract

The Fine Details: Clay Sourcing and Chemical Analysis in the Trent-Severn Waterway

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The objective of this thesis is to collect and analyse wild clay from the vicinity of previously identified and excavated archaeological sites near Pigeon and Rice Lakes, and comparing the characterized clay samples to archaeological pottery samples from the sites. The purpose of this research is to explore the resource exploitation in the landscapes around sites, and investigate the behaviours associated with resource exploitation and pottery manufacture. Through the application of X-Ray fluorescence spectrometry (XRF), each sample from four clay sources was analysed for its chemical composition, and compared to the chemical composition of Middle and Late Woodland Period pottery to investigate the similarities or differences between sources and finished items. The results demonstrated overlap between a source east of Rice Lake and pottery excavated from Chiminis-1 and Jacob Island-2.

Keywords: Ontario archaeology, Middle Woodland Period, Late Woodland Period, pottery, ceramic, clay, clay sourcing, X-ray fluorescence spectrometry, mobility, transition, resource exploitation

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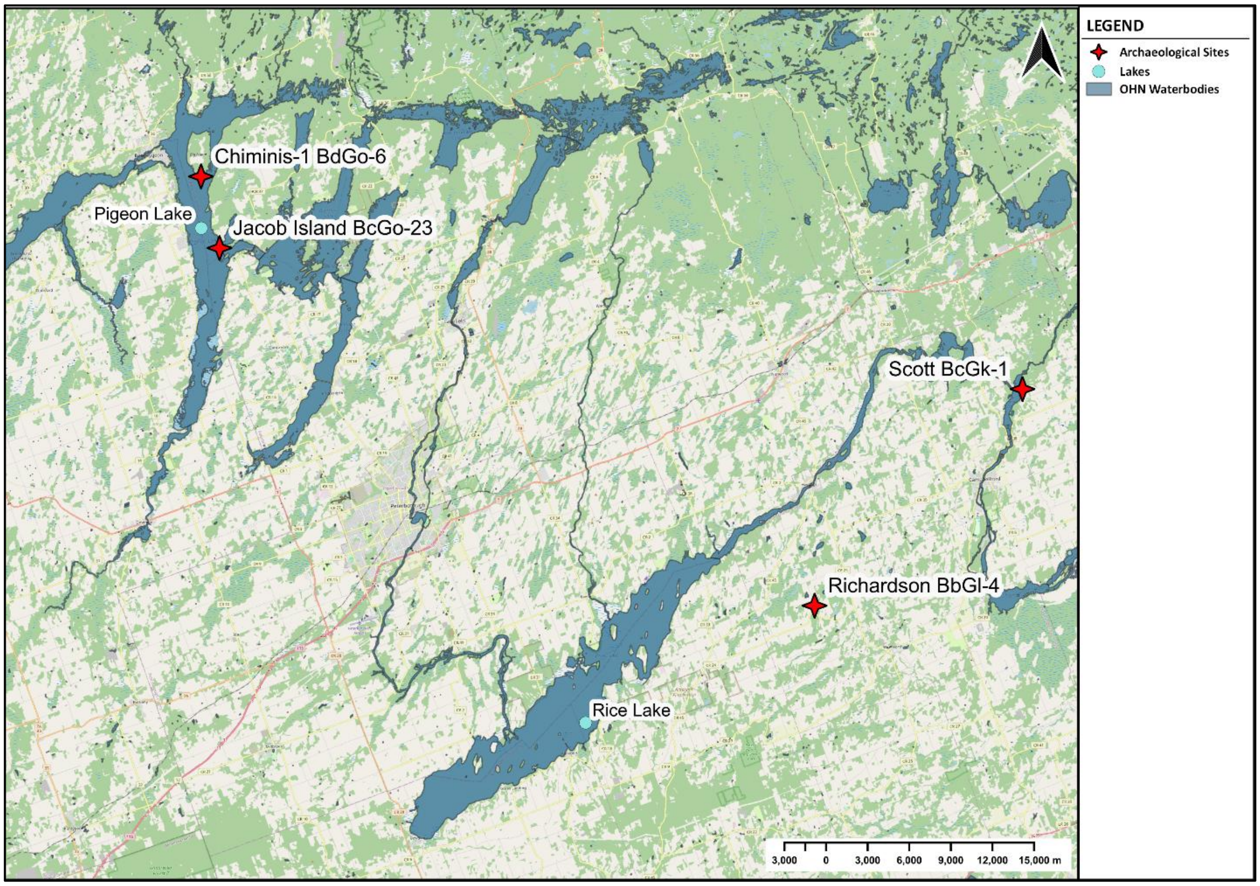
Chapter 1: Introduction

My thesis research concerns resource exploitation related to the shift in settlement and mobility behaviours between Middle and Late Woodland communities (ca. CE 800 to CE 1300) around what are now known as Pigeon and Rice Lakes, near Peterborough, Ontario. Among the key resources accessed by these communities across both periods is clay, for the purpose of producing pottery. This research intends to clarify patterns of resource exploitation firstly by identifying and collecting material from clay sources near four previously excavated archaeological sites, and then by comparing the composition of the collected material to the composition of excavated archaeological material.

Pottery has been an essential part of life for millennia, for both mobile and sedentary communities, but requires the exploitation of special resources for its production, including good quality clay and effective temper materials. Understanding the geographical sources of clay and temper used to manufacture the pottery found at archaeological sites provides insight into mobility and interaction of ancient communities. An effective method of investigating the source of clays used by past potters is analysing the chemical composition of the fired clay material, pottery, in order to compare specimens of excavated materials to candidate sources of raw materials. Clay sources, by their geologic nature, are neither mobile nor relocatable as are some animal or vegetable resources, and must be accessed in situ by an individual or group, who were aware of the signs of a clay source and the traits of an appropriate quality clay. The stationary nature of these sources means that those seeking the clay were likely travelling some distance in order to access it, though that distance may vary depending on the broader behavioural patterns of that community.

Previous research by Robinson and Conolly (2021) identified differences in the chemical composition of pottery associated with Middle and Early Late Woodland sites at Chiminis-1, Scott, Jacob Island-2, and Richardson, the former two being Middle Woodland sites and the latter Early Late Woodland sites (see Figure 1



). This research seeks to investigate further potential changes in resource exploitation between the two periods by identifying clay sources within range of the four sites. This involves collecting, processing, and firing candidate clay samples, then using X-Ray Fluorescence Spectrometry (XRF) to measure the chemical composition of each sample. The chemical data of each sample is then compared both between sources and with the previously collected pottery data to explore potential differences or similarities. My research will help further our understanding of clay resource exploitation during the

Middle and Early Late Woodlad periods in the region surrounding Pigeon and Rice Lakes.

1.1 Cultural Context

The Middle Woodland period in southern Ontario is traditionally thought to have spanned approximately 1300 years, beginning with the appearance of dentate or pseudo-scallop decorated ceramics around 400 BCE, and ending around 800 CE (Williamson 2013:48, Spence et al. 1990:142). However, chronological reappraisal by Conolly (2019a) and Conolly et al. (2025) have shown that traditional date estimates are typically in the order to 200-300 years older than more recent AMS radiocarbon results show. A revised absolute estimate for the Middle Woodland, supported by direct dates from the Serpent Mounds site (Conolly 2019b) positions the Middle Woodland decorative traditions beginning at about 100 BCE, and continuing until about 1200 CE. The Middle Woodland and Late Woodland I in the Trent Valley was superseded by the emergence of village communities of the Early Late Woodland, referred to as Late Woodland II by Conolly et al. (2025). In the Middle Woodland, communities were likely seasonally mobile, beginning with larger groups in the spring near fish spawning locations and breaking out into smaller groups throughout the rest of the year to exploit other seasonal resources (Spence et al. 1990:168). Middle Woodland communities also demonstrated burial mound ceremonialism as part of their complex mortuary practices, burying their members in ornate earthen berms alongside imported grave goods (Hamilton 2013:92). The Middle Woodland sites in this study, based on the design characteristics of the pottery, are believed to date to the end of that period between approximately 800 CE and 1000 CE.

The transition to the Late Woodland I period, around 800 CE, is marked primarily by the development of maize horticulture and expanded settlement of southwestern Ontario, continuing until after contact with European colonial settlers around 1650 CE (Williamson 2013:48, Stewart 2013:33, Fox 1990:172). Larger communities established more sedentary settlements, increasingly relying upon cultivated staples such as maize and tobacco and building wooden palisades at the boundaries of the settlements, though some seasonal mobility for the purposes of resource exploitation continued (Williamson 2013:54-57). The cultural behaviours of these two periods imply differences in resource exploitation methods, from a broader geographic range of exploitation of seasonally available resources to a likely more local range of exploitation centered upon palisaded settlements. In the Trent Valley, the transition is believed to have occurred somewhat later, after 1200 CE, with the two sites in this study dating to approximately between 1300 CE to 1400 CE.

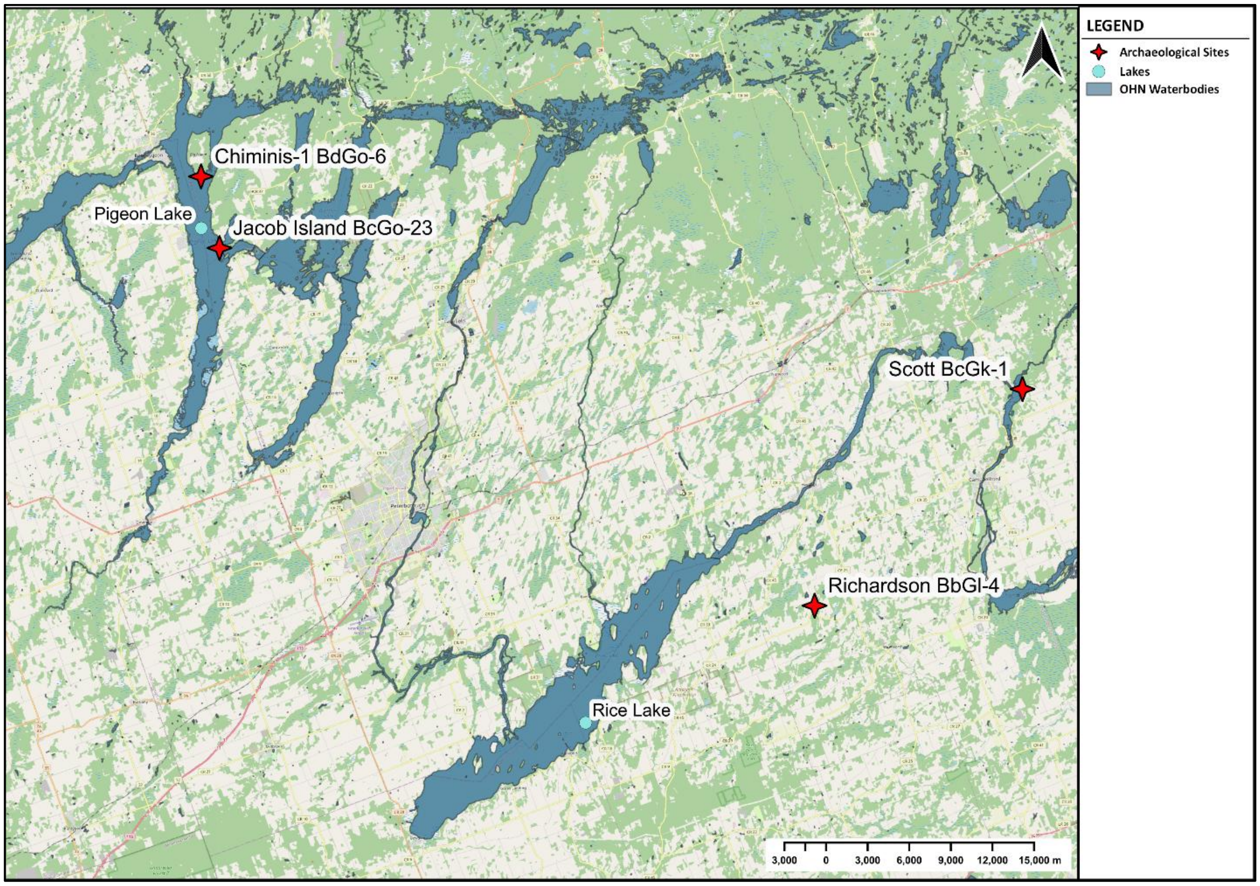


Figure 1. Location of the sites of concern near Peterborough, Ontario. Base map © OpenStreetMap 2024

1.2 Site Selection

Two sites from each period were used as reference for identification of clay sources and for comparison of excavated pottery to collected clay samples: Chiminis-1 and Scott, sites associated with the Middle Woodland period, and Jacob Island-2 and Richardson, sites associated with the Late Woodland period. Chiminis-1 (BdGo-6) presents as a multicomponent site on the southern end of Boyd or Big Island, situated within Pigeon Lake, with a strong Middle Woodland component (Figure 1). Scott (BcGk-1) is also a multicomponent site on the Trent River, though similarly has a predominant Middle

Woodland component. Jacob Island-2 (BcGo-23) demonstrates Middle and Late Woodland occupation, situated on the island the site is named for, and represents a portion of the Late Woodland samples considered. Finally, Richardson is a Late Woodland village situated east of Rice Lake (Robinson and Conolly 2021:5,8).

1.3 Previous Research

Sarah Robinson and James Conolly (2021) undertook research to examine the chemical composition of pottery sherds from the sites above with the intention of exploring any potential differences which may be associated with the two cultural periods. Powdered samples of clay fabric were ground and collected from 70 sherds, 30 associated with the Middle Woodland period and 40 from the Late Woodland. The powdered samples were then sent to McMaster University for XRF analysis, and the data collected therein compared through Principal Components Analysis (PCA) to determine the most relevant variables within the dataset. The results indicated that each pottery from each period demonstrated compositional commonalities with its contemporaneous cohort, though some overlap between the two does exist. The existence of these compositional cohorts implies changes in the exploitation of clay sources, which may align with the broader changes in resource exploitation between periods.

1.4 Importance of Research

The evidence of cultural change between the Middle and Late Woodland periods is clear in the archaeological record; the appearance of palisaded settlements and an increased reliance upon cultivated resources in the Late Woodland period implies significant shifts in resource exploitation from the much more seasonally-driven mobility required of Middle Woodland communities to access available resources.

The purpose of this research is to further investigate changes in technological resources as a complement to studies that have focused on food resources across the Middle to Late Woodland transition. Clay was a critical resource within a community's material landscape, though the location and relative distance may differ based on where the community is based and what their other exploitation strategies may enable them to accomplish. With this considered, a highly mobile community may exploit more distant sources than a more sedentary, locally subsistent community.

To my knowledge, no chemically-analysed clay sourcing research has been completed in Ontario, despite decades of intense analysis of Indigenous ceramics. This research therefore presents the first instance of chemical clay sourcing in the province.

1.5 Research Questions

Through the results of my research, I will attempt to explain the following questions:

1) Can the sources of archaeological ceramic material be identified?
2) Is there variation within clay sources which could affect source identification?
3) Do these sources have implications for the cultural patterns of the people who exploited them?
4) Can cultural patterns be explored through the exploitation of ceramic resources?

1.6 Chapter Summaries

The second chapter of this thesis, *Clay*, considers the definition of clay and its geological origins, as well as the techniques involved with collecting, processing, and firing clay to create pottery. It then discusses Middle and Late Woodland Period pottery traits, methods of pottery analysis, and the instances wherein they have been applied to archaeological specimens from Ontario and the broader northeastern region.

Chapter 3: *Hunter-Gatherer Pottery*, investigates the theoretical framework of and other research regarding ceramic technology and pottery use by mobile hunter gatherer communities in Europe and Africa, despite the association of pottery use with agriculturalism. It then discusses early pottery use in southern Ontario, specifically Vinette I pottery used by Early Woodland communities and the cultural behaviours and preferences which may have encouraged the continued evolution of ceramic technology in the region.

Chapter 4: *Methods*, concerns the methods utilized in several aspects of the development of this thesis. Firstly, those involved with locating clay sources and collecting samples within range of the four established sites. Secondly, the processing, firing, and grinding of the collected clay samples. Thirdly, the process of X-Ray Fluorescence Spectrometry (XRF) as applied to the samples. Finally, the chapter establishes the method of statistical analysis applied to the chemical data obtained through the XRF analysis.

Chapter 5: *Results*, discusses first the results and characteristics of the collected samples, after both processing and firing, comparing the four sources with regard to plasticity, texture, and how the samples survived firing. The chapter then discusses the results of the analysis of the chemical composition of the samples, and compares these results with those previously collected by Robinson and Conolly (2021).

Chapter 6: *Discussion and Conclusions*, explores the potential interpretations of the patterns that exist within the collected data, their implications for the cultural behaviours in the four Middle and Late Woodland communities considered, and examines how this may answer each of the four established research questions. This chapter also summarizes my thesis, the intentions of my research, the results, and the potential pathways of future research.

Chapter 2: Clay and Pottery in Ontario Archaeology

2.1 Introduction

This chapter discusses the origins and definition of clay, as well as the formation of pottery and modern archaeological analysis of pottery. It begins with defining clay, functionally and chemically, and explains what allows for the plasticity of clay materials, and discusses the basic methods of the collection and processing of clay. It then examines the definition of pottery, and subsequently, methods of analysis applied to archaeological pottery specimens, with specific examples of those methods as applied to specimens collected in Ontario and the broader northeastern region.

2.2 Clay

2.2.1 What is clay?

Clay minerals typically consist of fine-grained, water-insoluble minerals which, when combined with water, demonstrate plasticity. To decode this: the material usually considered to be "clay" is made of small particles which do not dissolve in water, and when these particles come into contact with an appropriate amount of water, the combined material becomes self-contained and malleable until dried (Moreno-Maroto and Alonso-Azcárate 2018:62; Guggenheim and Martin 1995:255). These characteristics have made it an invaluable material for humans throughout our history, and are tied to its unique chemical and physical properties.

Clay is not defined as consisting of one specific element, but there is a framework which gives it these characteristics. Many clay minerals consist of "phyllosilicates", materials which occur in flat sheets of silicate crystals and can also become mica and talc in other environmental conditions (Nelson 2015). These sheets consist of layers of silicates with tetrahedral and octahedral positively charged ion sites, or cations, which are usually occupied by Silicon(4+) and Aluminum (3+) or Iron(3+), and Aluminum(3+), Iron(3+), Magnesium(2+), Iron (2+), and other cations, respectively (Railsback 2020). These cation bonds cause the clay minerals to be stable, insoluble materials with flatter, more linear cross sections (Railsback 2020).

Clay also demonstrates what is known as "plasticity," which is now considered to be the defining trait of the material (Moreno-Maroto and Alonso-Azcárate 2018:62). Plasticity in clay occurs at a point when the dry clay material has been sufficiently hydrated, and the material develops the ability to be deformed by force without breakage while also maintaining the shape created by the deforming force when it is removed (Perkins 1995 in Andrade et al. 2010:1). The material, as long as it is properly hydrated, is almost infinitely mouldable and has the inherent ability to hold most forms after being moulded, assuming it is sufficiently supported. This support may be internal – the form is stable enough to sustain its own position, through its own thickness or inherent rigidity – or external – resting on a support structure until the material has dried and has developed an increased rigidity – depending on the conditions of the clay, the form, and its immediate environment.

Clay materials do not need to be phyllosilicates, but phyllosilicates are more likely to demonstrate the fine texture and plastic characteristics which are used to distinguish clay from other sedimentary materials due to their cross-sectional organization.

2.2.2 How is clay formed?

Clay, typically, is the result of naturally occurring geologic processes, namely chemical weathering, and are usually "secondary" minerals developed early on in the overall weathering process of "primary" materials (Boggs 2014:11) (Figure 1). The weathering of primary or parent materials in this sense is the process wherein larger, solid deposits – i.e., bedrock – are broken down into smaller pieces or particles, such as sand, soils, gravel, and other looser materials.

While different forms of mechanical weathering, including freeze-thaw and abrasion, *can* result in the formation of fine-particle clay materials, it is more efficiently and effectively produced through chemical weathering as a result of organic processes (Blatt 1980:247, 249). More primitive plants, such as mosses and lichens, are more effective at transforming the rock surfaces they grown on, usually creating clay when growing on mafic and silicic rocks in many different climatic environments (Blatt 1980:250; Jackson 2015; Ramos et al. 2024:2). These and other organisms acidize soils as their respiration creates carbon dioxide, and after death, the decomposition of organic remains generates organic acids which contribute to the weathering of the rocks and soils they come in contact with (Blatt 1980:250, 251).

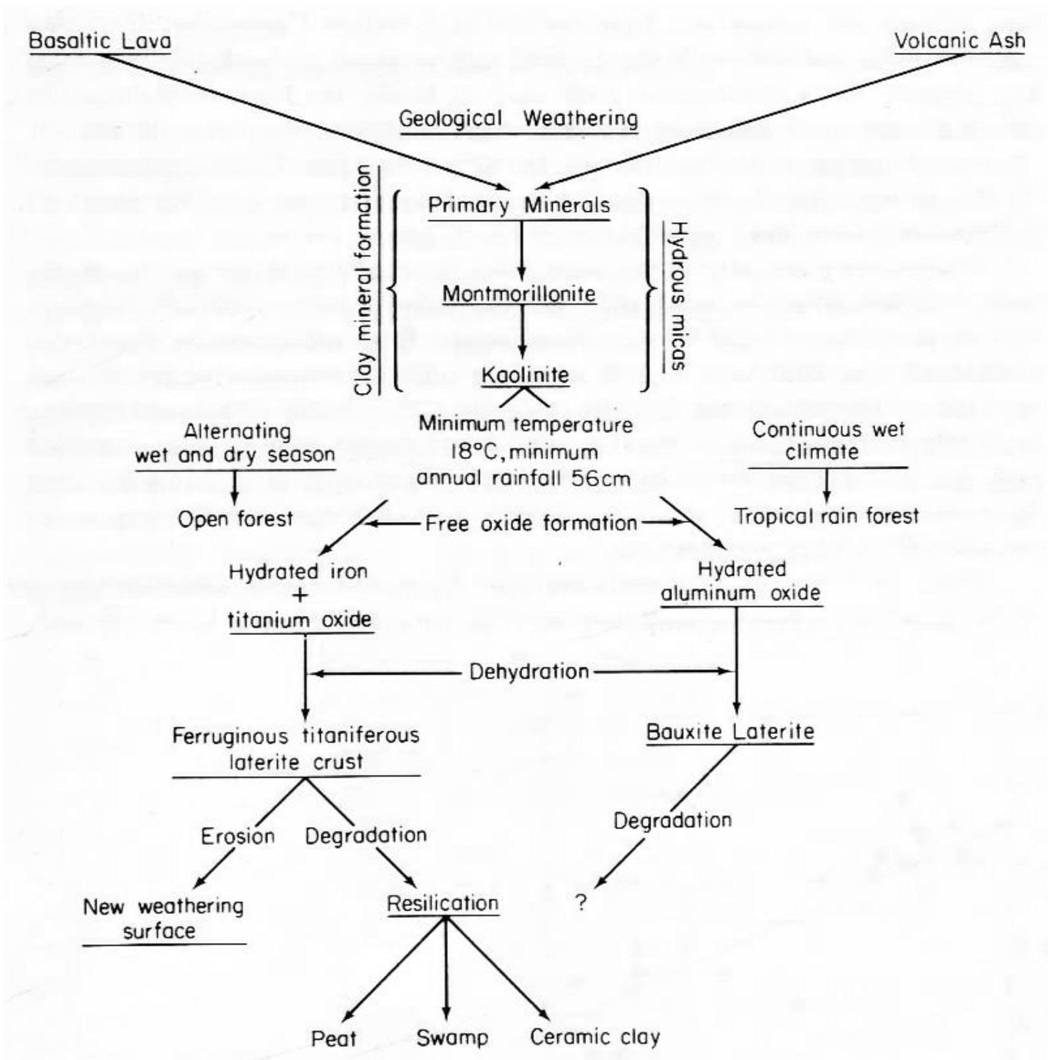


Figure 2. An example of a clay weathering process observed in the soils of the Hawai'ian Islands (G.D. Sherman 1952:157 in Blatt 1920:255)

The conditions which result in geological weathering, such as parent materials, topography, climate, organisms, time, and soil formation, ultimately cannot be considered independently, and different regions will generate clays and other weathered materials which are unique to those regions and their conditions (Protz et al. 1985:43). With this considered, it is likely – if not guaranteed – that the clays available in southern Ontario and the broader northeast region will demonstrate variability dependent upon their geologic materials and conditions, and this variability may be evident in the geochemical analysis of local pottery and clay deposits used to create the pottery.

2.2.3 How is clay collected and processed?

Due to the nature and scale of clay mineral particles, many deposits are created not at their point of creation – primary deposits – but rather in areas associated with slow-moving water, or secondary deposits. As with other silt particles, clay has a low settling velocity, meaning that it is unlikely to fall out of suspension in moving water as a result of the size and weight of the particles, which move primarily in continuous suspension, being transported to river mouths or deltas where they are deposited rapidly, or in quiet water environments such as wetlands and floodplains where they are deposited by flooding or fallout (Blatt 1980:108,116). Lacustrine and riverine deposits as a result of this, and floodplains, riverbeds, mudbeds, and wetlands are likely locations for clay collection.

Once a deposit is identified, the collection of clay depends on its form – dry clay may be easier to transport, being lighter than saturated clay material, but may require more intensive action in order to separate a desired amount from the deposit. Clay found within primary deposits are unlikely to be of preferential quality, often lacking plasticity when compared to those found within secondary deposits, which may have come in contact with impurities through their transport to their place of deposition (Levy et al. 2022:57). Clays can often be identified by their colour and texture, particularly when hydrated, but the quality of clay cannot be determined solely through visual assessment.

The processing of any collected clay is dependent upon the intentions of the processor. It is imperative to determine the plasticity of clay prior to intensive processing, which requires the hydration of a portion of the collected material and application of, at minimum, a “ribbon test.” The ribbon test involves rolling a portion of the hydrated material into a cylinder, then bending it – a non-plastic material will not bend, while plastic materials will bend to varying degrees of success depending on their quality (Levy et al. 2022:60). This test provides a baseline for determining whether or not the collected material may be considered plastic, and therefore clay.

Secondary deposits of clay wherein the particles have been sorted during hydrologic transportation may mean the collected material does not require manual sifting, but the inclusion of larger particles or rocks is neither impossible nor unlikely. The processor may also need to choose whether or not to remove any organic material within their sample – some types of organic inclusions may benefit the clay and any use in pottery, while others may be detrimental to the short- or long-term stability of any produced objects. Other contaminants, including salt and lime, may also cause issues during the transformation of clay into pottery due to their reactions to high temperatures and humidity (Levy et al. 2022:60-61).

Clay can be dry or wet sifted; pulverized dry clay materials can be passed through any sieve, though a graduated sieve may be the most effective. It may also be useful to soak larger pieces of dry clay material in order to more easily process them. With wet clay, it may be more effective to over-saturate the material in order to allow for ease of movement between its constituent particles and wet sifting. This wet clay will need to be dried, partially or fully, before it can be properly hydrated and used to create pottery, while the dry clay will similarly require adequate hydration prior to use.

2.3 What is Pottery?

Pottery is the result of manufacture and firing techniques applied to clay, and pottery may come in many forms. These forms are largely informed – and literally formed – by these techniques, including the forming techniques, adulteration and inclusions, and firing, all of which depend upon the region and cultures responsible for their individual pottery.

There are several methods of pottery manufacture, used both historically and in modern day. The simplest methods include coiling and slab manufacture: coiling requires a potter to roll the clay to create long cylinders, which are then "coiled" upon themselves before the inner and outer surfaces of the vessel are smoothed, while slab manufacture involves the creation of sheets of rolled clay, which are then cut to the required size and shape and attached to a base or other sections of slab-cut clay, with the seams adhered and smoothed (Rye 1981:67,74). Pinching is also a relatively simple and accessible method of pottery manufacture, wherein pressure is applied through the potter's fingers to spread and thin the clay, while shaping it into the desired form – often a bowl or pot (Rye 1981:70). Drawing is similar to pinching, where the clay is pulled and squeezed upward from a base to create the shape; this may also be combined with coiling, to provide the material base which the potter manipulates (Rye 1981:72). Throwing is a popular method of pottery manufacture in modernity, though the technique itself is not new; a potter draws from a base portion of clay deposited on a rotating surface, manipulating the clay through the application of manual pressure and tools as the clay spins. These rotating surfaces may be hand powered - spun like a lazy-Susan – or kick-powered, where the surface is attached to another wheel which may be propelled by the potter's foot while their hands remain free to shape the clay, or electrically powered, containing a motor which spins the surface and may be controlled through a dial or pedal (Rye 1981:74). Pottery may also be manufactured using a mold, either by being pressed into the shape, or with thinner, more watery clay "slip" being poured into a mold to dry before excess is poured out. Mold casting may allow for more consistent manufacture, and for detailed decoration which may be difficult to achieve through other manufacturing methods (Rye 1981:81). A potter may use any combination of these methods to create their vessels or objects, depending on what they may have been taught or what they have learned through their own experimentation and resources. The techniques involved in pottery manufacture leave evidence in the finished pieces which may, through several analytical techniques, allow for the determination of some of the choices of the potter (St. John and Ferris 2019).

Manufacturing methods are not the only, or necessarily the first, changes a potter may make to their clay material while creating a piece of pottery. One common change a potter may make to clay materials is the addition of *temper*, non-plastic, non-clay materials mixed into the clay prior to firing. These inclusions can increase durability before, during, and after firing, and can reduce the drying time of a finished but unfired clay object. Temper often consists of mineral materials, whether sand, gravel, or small stones, but can also include or consist of grog – small sherds of previously fired ceramic material – as well as organic materials such as shell, grasses, seeds, or bone (Alegretta et al. 2015). The type of temper used may depend on where an individual, a potter, is creating their wares and what materials they have available to them. Shell or sand tempers may be more likely to be used by potters near the ocean, being abundantly available, whereas potters with easier access to gravel or grass may use those materials.

The tempers used can also be affected by – or even influence the choice of – firing temperatures and conditions, with each type of temper reacting to the temperature and environmental conditions differently (Alegretta et al. 2015).

Once the clay has been appropriately hydrated and moulded to its desired form, the application of high temperatures will transform it, creating a hard, durable material known as pottery. The crystalline minerals in the clay material melt at high temperatures, and fill any small gaps or voids, bridging the spaces between other particles in the material (Orts et al. 1993). This is the basis for the solid, non-plastic material of pottery, though over thousands of years of human experimentation, this process has been altered to suit a variety of desired outcomes and functions. Firing results in the development of oxides, the transformation of the clay's elements after contact with oxygen at high temperatures; the oxides develop are dependent upon the original chemical composition of the clay, and the decomposition and crystalline reactions within the clay are heavily dependent upon the temperature and duration of firing (Toledo et al. 2004; Maritan et al. 2005).

2.4 Middle and Late Woodland Pottery in Ontario

The appearance of Vinette II pottery in the archaeological record is diagnostic of the transition to the Middle Woodland Period, also identified as Ontario Point Peninsula (Spence et al. 1990; Mortimer 2011). Ontario Point Peninsula pottery is typically grit tempered, and manufactured through the coil method, typically with dentate, pseudo-scallop, and cord-wrapped stick stamped or impressed decoration on the exterior surface.

The vessels tend to be cone-shaped, with elongate bodies and conoidal bases and slightly everted rims (Williamson 2013:49; Mortimer 2011:41; Wright 1999:633; Spence 1990). Three phases of pottery production though the Middle Woodland Period have been identified; Trent, Rice Lake, and Sandbanks, with Trent occurring the earliest (end of the Early Woodland Period to approximately 1 CE), then Rice Lake (1 CE to 800 CE), and finally Sandbanks (700 to 1000 CE, overlapping to some extent with the Early Late Woodland Period) (Given 2015:7). Many of the identifiable differences between the phases relate to decorative types and frequencies, though dentate, pseudo-scallop, and cord-wrapped stick decorations are still common (Given 2015; Curtis 2004; see Table 1).

Pottery of the Late Woodland Period also tends to be grit tempered, often with coarse, locally sourced materials, and is likely to have been manufactured through the paddle-and-anvil or modelling technique, with a large portion of clay being manipulated to the desired vessel form. This form tends to be rounder than that of the Middle Woodland, globular with round bases. Late Woodland vessels also demonstrate dentate and cord-wrapped stick stamped or impressed decoration, as well as linear stamped or incised decoration, push-pull decoration, and bossing or punctates (Braun 2015:115; Given 2015:11; Williamson 2013:49; Curtis 2004:230; Wright 2004; Fox 1990; Williamson 1990; Wilson 1977; see Table 1).

Period	Middle Woodland	Late Woodland
Construction	Grit temper Elongate bodies Conoidal or sub-conoidal bases Flat, round, or pointed lips Slightly everted rim Coil manufacture	Grit temper, often coarse Globular bodies Round bases Convex exterior rim Concave interior rim Paddle-and-anvil or Modelling manufacture
Decoration	Dentate stamping Pseudo-scallop stamping Cord-wrapped stick impressions Interior combed with a toothed tool Rocker stamping	Dentate stamping Linear stamping Cord wrapped stick impressions Incised linear decoration Bossing Push-pull

Table 1. Pottery Construction & Decoration techniques in the Middle and Late Woodland Periods.

2.5 Pottery Analysis in Ontario and the Northeast

As an inorganic and durable material, pottery often survives the conditions it encounters in its archaeological context – not necessarily wholly undamaged, but typically well enough to be identified, collected and analysed. Pottery lends itself well to the application of a variety of analytical methods; the techniques involved with manufacturing, finishing, and decorating the objects, and sourcing, collecting, and processing the clay and any materials used to adulterate it are numerous, and are often tied to cultural identity, technological developments, and regional resources. In Ontario and the broader northeast region, pottery is an invaluable archaeological resource, representing the breadth of technological and cultural development of the many Indigenous nations who have engaged with this landscape for thousands of years. Most archaeological pottery analysis throughout the 20th century focused on identifying cultural chronologies and their spatial distribution, in an effort to determine the ethnogenesis of Indigenous cultures encountered by Europeans throughout early colonial contact (Trigger et al. 1980:119-120).

There are many methods of analysis which may be applied to archaeological ceramics, given their complex existence, non-exhaustively summarized in Table 2Table 1 and described further, below.

Analysis	Methods	Result
Decorative	Visual (unaided OR microscopic)	Type, combination, and/or frequencies of surface alteration interpreted as intentional decoration of the vessel
Residue	Accelerator Mass Spectrometry (AMS)	Determining and interpreting use of vessels through the residues left behind on the surfaces of vessels, typically the interior surface
Absolute dating	Radiocarbon (C-14) dating	The carbon isotope C-14 is acquired by organisms and deposited in their cells; by comparing the remaining amount of C-14 in the material to atmospheric levels, the material can be dated to a particular period of time
Petrography	Microscopic analysis of thin-sections	Illuminated thin-sections of materials, typically pottery fabric, are viewed under a microscope to characterize and count the fabric and any inclusions, including temper
Geochemical	Neutron Activation Analysis (NAA), X-ray Fluorescence Spectrometry (XRF), Laser Ablation-Inductively Coupled Plasma-Mass Spectrometry (LA-ICP-MS)	Determining the chemical composition of an inorganic material, typically to compare between specimens or geological sources

Table 2. Methods of Pottery Analysis

The most apparent and accessible manner is that of decorative analysis – much of the pottery encountered in archaeological contexts demonstrates some amount of decoration or surface alteration which can be interpreted as having been made with purpose. The shapes, application techniques, frequencies, and combination of decorations may provide insight into the individual potter as well as their community, culture, and the evolution of preferred decorative techniques or styles over time.

As analytical methods and understanding of other sciences have expanded in the past century, further insights into the usage and creation of pottery have become available through the application of new technologies. Residue analysis in particular provides a unique window into the use of pottery, as the materials prepared, cooked, or stored in the vessels leave their mark on the ceramic surface, often through sooty or oily residues. When these residues are compared to modern samples and analysed for their chemical components, it may be determined what animal and vegetable matter may have been collected and consumed by those who utilized the archaeological specimens.

In a similar technological vein, radiocarbon, petrographic, and geochemical analysis of pottery have also become increasingly accessible to modern archaeologists. Radiocarbon analysis allows for the dating of organic materials through comparison of the material's carbon-14 (C-14) isotopic level to carbon levels in the atmosphere over time. Organisms take in C-14 throughout their lifetime, and cease to consume it after death. By considering the half-life of the C-14 isotope and how much C-14 remains in the material, one can estimate the period of time that the organism may have lived. Organic materials and residues can therefore be dated to their period of creation or use with more certainty than relative seriation. Petrography allows for the analysis of specimens at a microscopic level, providing insight into the composition, arrangement, and size of particles within a sherd of pottery. Thin slices of pottery sherds are removed and mounted on microscope slides before being analysed through microscopy to visualize inclusions – temper, larger clumps of unground clay, etc. – and account for their size and frequency in that portion of the sherd. Geochemical analysis, such as that performed for this thesis, analyses the materials at a chemical or elemental level, allowing for further insight into the changes experienced by the clay materials during firing, the elements common in clay used by potters, and the potential geologic origins of the materials used.

2.5.1 Decorative and Visual Analysis

One of the foundational texts concerning the analysis of pottery decoration in Ontario is Richard S. MacNeish's *Iroquois Pottery Types: A Technique for the Study of Iroquois Prehistory*, published in 1952 by the National Museum of Canada, now the Canadian Museums of Nature, Science and Technology, and History. In his book, MacNeish determined affiliations between sets of decorative techniques, vessel forms, geography, and cultural identities, translating these intersections into named typologies which could be used to identify sherds upon discovery.

Jerimy Cunningham applied decorative, form, and spatial analysis to pottery excavated from the Van Bree site in southern Ontario to investigate if pottery decoration could have been used as a cultural or ethnic identifier. Cunningham determined that it appeared unlikely that the decoration used was symbolic of the ethnicity of the potter, assuming that two ethnic groups may have cohabitated at Van Bree (Cunningham 2001).

A later instance of decorative analysis was presented in 2002, by Holly Martelle; Martelle's dissertation focused on a detailed analysis of Huron-Wendat pottery, particularly the dimensions, quality, and application of the decoration, as well as attributes that could be interpreted as informing or resulting from its function. It is possible through close examination to determine the handedness of a decorator. Her research demonstrated that there may be some correlation between decorative attributes and fabric attributes, and though decorative styles within Huron-Wendat pottery were not restricted to one form or function of vessel (Martelle 2002).

Amy St. John has also employed modern technology to better analyse the physical traits of pottery identified, beyond decoration and form. Pottery from the Arkona Cluster of sites, dating between the 12th and 13th centuries CE, in southwestern Ontario is typically identified as belonging to one of two cultural traditions: Ontario Late Woodland (OLW), previously Ontario Iroquoian Tradition, and Western Basin Tradition (WBT). OLW are considered to have become more sedentary earlier than WBT, establishing villages and relying on maize horticulture and fishing and hunting camps, while WBT has been typically considered to consist of more mobile, semi-sedentary Hunter Gatherers who relied on a broader spectrum of subsistence resources across the landscape. Later WBT bands may have become somewhat more sedentary, supplementing their traditional resources with agricultural resources. It has not necessarily been confirmed that these are two different groups who used different languages or considered themselves to have distinct cultural identities, however there are enough differences in the patterns expressed by the archaeological record to allow for comparison between the two (St. John 2020:19-22). Using pottery identified at sites associated with the two groups, St. John applied Micro-Computed Tomography (micro-CT) to the pottery to visualize inclusions, voids, and layers within the fabric of the sherds which otherwise would have been difficult or impossible to access. Micro-CT is a minimally invasive and minimally destructive analytical technique which generates a 3D image of the sherd, and provides more detailed information than the 2D images generated by traditional radiographic methods (St. John 2020:243). Having this 3D image enables the researcher to view and interpret the results of primary formation techniques, which are typically obscured by secondary formation and finishing techniques by merit of these latter two steps occurring later in the châine opératoire. Micro-CT analysis can also allow for the identification of formation techniques through the types and shapes of voids and layers created by those techniques – press moulding, coiling, and paddle & anvil are common throughout Ontario (St. John 2020:244).

2.5.2 Residue Analysis

In 2004, June Morton and Henry Schwarcz analysed residues found on pottery from both northern and southern Ontario, with the intent of exploring dietary changes through later portion of the Middle Woodland period, approximately 600 CE. Through the application of stable isotope analysis of the residues, Morton and Schwarcz demonstrated an increase in maize consumption from the end of the Middle Woodland period into the Late Woodland I period, between 600 and 1200 CE (Morton and Schwarcz 2004).

In 2019, Susan Kooiman and Heather Walder published *Reconsidering Chronology*, which analysed Iroquoian pottery from the Upper Great Lakes region, more specifically from Drummond Island in the Straits of Mackinac. Kooiman and Walder used accelerator mass spectrometry (AMS) to date the food residue discovered on interior vessel surfaces in order to more accurately determine the chronology of the pottery. Previous hypotheses asserted that a post-Contact period occupation of the site was earlier than the new research proposed, approximately 1630 CE, with a background of repeated late pre-Contact occupation after 1300 CE. The previous chronologies had been established through analysing decorative typologies, as well as the appearance of

European trade goods, indicating an earlier post-Contact occupation. The AMS analysis indicated that the post-Contact occupation of the site was indeed later, likely occurring between 1670 and 1700 CE, despite what the relative chronology had implied (Kooiman and Walder 2019).

2.5.3 Petrography and Geochemical Analysis

Trace-Element Analysis of Iroquoian Pottery, published in 1980, represents one of the early shifts from strictly physical and distributional analyses of pottery to the application of chemical analysis. It had been assumed that, due to their size, weight, and fragility, most pots were not typically transported from site to site, and therefore any pots or sherds of similar fabric or decoration found at separate sites were likely to have been made by local potters who had relocated. It is likely, though, that pottery was transported when communities moved between villages and were transported with travellers more often than was noted by post-Contact colonial observers (Trigger et al. 1980:131-132). The specimens analysed in this research were excavated at several sites between the St. Lawrence Valley in Québec and central southern Ontario, and were analysed using XRF to determine their chemical composition and compare patterns between the sites and regions. The results demonstrated eight chemical cohorts of Ontario Iroquoian (Ontario Late Woodland) pottery west of Kingson, which were primarily associated with individual sites, though some overlap between groups and sites were identified. The research determined that sherds found west of the Draper site in Pickering, Ontario, were unlikely to have been crafted in the St. Lawrence Valley or central southern Ontario. The Benson site, west of Balsam Lake in Ontario, may have acted as a sort of middle-man site between the St. Lawrence Valley and Ontario in terms of inter-community interaction (Trigger et al. 1980).

In 1984, Trigger and others applied XRF and neutron activation analysis (NAA) in order to compare pottery characteristic of Iroquoian potters and Parker Festooned (PFP) sherds to further comprehend the origins of the pottery excavated from the Lawson Site in southwestern Ontario. The analysis demonstrated three chemical cohorts: the Iroquoian pottery at the Lawson Site, the PFP at the Lawson Site, and the PFP from its namesake site, Parker, north of Lawson. With the three groups of pottery each demonstrating distinct chemical compositions, it can be inferred that the PFP sherds found at Lawson were not crafted using clay from the source Lawson potters exploited, and therefore that it was unlikely that Algonkian potters held at Lawson had crafted them. It is more likely that the pottery was brought from a different community to Lawson through indeterminate means (Trigger et al. 1984).

In 2001, Alicia Hawkins used Instrumental Neutron Activation Analysis (INAA) to analyse an "unusual pottery type" found at several OLW sites in southwestern Ontario and compare the pottery with other examples from New York. The results indicated that the two regions demonstrated chemical compositional differences, suggesting that the OLW pottery had not been transported from New York, but had potentially been crafted in a similar style by refugees who had relocated to Ontario (Hawkins 2001).

Using portable XRF (PXRF) technology, Hannah Devin analysed and compared pottery excavated from two Haudenosaunee sites in New York, south of Lake Ontario. The analysis determined that, despite a large and likely chemically consistent glacial clay deposit accessible from both sites, the pottery from each site formed its own cohort, indicating that the communities at each site likely accessed separate deposits. The chemical analysis also indicated that some variation in the composition may have been related to surface finishing, as PXRF, while non-destructive, tends to homogenize surface and inclusion compositions with clay fabric composition (Devlin 2016).

Gregory Braun published *Technological Choices: Ceramic Manufacture and Use at the Antrex Site (AjGv-38)* in 2010, presenting a comprehensive analysis of pottery collected from a site in what is now Mississauga. Braun initially applied methods of visual and microscopic analysis to the sherds to identify use alteration, before shifting to petrographic analysis to better identify unfired clay and untempered clay lumps in their fabric. The results of his analysis allowed him to identify cohorts of presumed use, based on fabrication and wear. The first, Juvenile vessels, demonstrated little evidence of use as cooking vessels, and were possibly symbolic or made and used by children. Small boiling vessels demonstrated carbonized residues on their interior and exterior surfaces, as well as damage to the interior neck and bottom surfaces implying the use of an implement inside the vessel while it was used to process foodstuffs over a fire. Medium-sized boiling pots demonstrate similar evidence of use, with interior and exterior carbonization and implement-related damage, while Hot-Stone cooking vessels present with alterations which imply they were likely heated with stones placed inside the vessels, and rotated while resting on the ground due to their size and weight – circular scratches on the exterior bottom surface, and patches of interior surface damage. These latter vessels were likely utilized to process materials which produced fats or oils, such as acorns (Braun 2010:87-90). Braun concluded that the raw materials the potters chose were selected purposefully for their traits throughout the chaîne opératoire, including firing and their use after manufacture (Braun 2010:93).

In 2021, Hawkins and others took a multi-faceted approach to analysing Huron-Wendat and St. Lawrence Iroquoian rim sherds. Of particular interest was furthering their understanding of the chaîne opératoire and communities of practice in these two cultural traditions. In order to accomplish this, they utilized micro-CT analysis to identify primary and secondary manufacture techniques, petrographic analysis to identify compositional patterning of raw materials and manufacture techniques, and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) to determine the chemical composition of the sherds. LA-ICP-MS was useful in this case for distinguishing between clay fabrics originating from different regions in the Lower Great Lakes and St. Lawrence Valley regions (Hawkins et al. 2021).

2.5.4 Clay Sourcing

There are very few Indigenous clay sourcing studies from Ontario or elsewhere in the northeast. Considering the complications of post-Contact urban and suburban development on the north shore of Lake Ontario, its impacts on natural soils, and archaeological analytical attention drawn to other facets of pottery, there are notable complications which may impact the success of clay sourcing projects.

One such project was completed in 2015, as part of the PhD dissertation of Gregory Braun. The dissertation analysed materials excavated from the Holly Site (BcGw-58), located west of Lake Simcoe near what is now the city of Barrie. Identified as an Iroquoian village, the site dates between 1290 and 1305 CE, and demonstrated a wealth of pottery materials (Braun 2015:32-33). Braun collected clay from deposits around Holly, then analysed and compared the collected samples to the pottery at the site through petrography (Braun 2015:176). The results showed the clay to be calcareous, or containing carbonate materials, while these carbonate compounds were largely absent in the excavated pottery. Much of the clay available in the area around the site are likely to be Glacial in origin, deposited as the glaciers of the last ice age melted. Glacial clays have higher carbonate contents, and cannot be fired at the same temperatures of other clays with lower carbonate contents as it often results in lime spalling and therefore a less durable finished vessel (Braun 2015: 177). A lack of carbonate content in the finished pottery, however, does not confirm that a clay was non-local, as the material may have been processed to remove the carbonate compounds (Braun 2015:178). It is also possible that, in the course of the research, non-calcareous clay sources simply weren't identified which the potters of Holly may have been aware of and exploiting (Braun 2015:179). If clay were being sourced elsewhere, beyond what could be considered a reasonable and economic distance, it appears likely that it was being brought in its raw form to Holly, as the pottery is consistent with the regional styles despite the difference in the chemical composition of the clays (Braun 2015: 177).

To my knowledge, no other clay sourcing research in Ontario has been published, and this research would represent the first of its kind in the province. With intense urban development and subsequent suburban sprawl spreading from the fertile north shore of Lake Ontario, many significant pre-Contact sites have been identified while their landscapes have been simultaneously destroyed, heavily altered, or rendered nigh-impossible to access. This minimizes our ability to analyse the sites and their artifacts in their original contexts, including any resources the people who occupied those sites would have exploited. These conditions complicate our ability to conduct clay sourcing research around important sites such as the Mantle (or Jean-Baptiste Lainé) Site in Stouffville, Ontario, which now rests under and within a landscape of a suburban subdivision development (ASI 2014). Some sites in these settings may have relatively undisturbed landscape towards the extents of the radii of potential exploitation, but their immediate surroundings likely no longer exist. The sites of concern in this research have also seem similar issues: the landscape around Chiminis-1 and Jacob Island have been intensely developed as cottages and leisure camps and, due to 19th century damming, water levels are much higher than they would have been when the sites were occupied pre-Contact and potentially resulting in the inundation of not only further archaeological sites, but also key resources communities in the area would have exploited. This pattern of disturbed modern landscape in conjunction with the trial-and-error of searching for adequate clay sources in any undisturbed areas results in a complex and potentially time-consuming project, though the results would still improve our understanding of landscape interactions.

2.6 Discussion

The previous sections by no means present an exhaustive overview of pottery analysis in Ontario, merely an overview of some of the work done in the past 80 years by archaeologists dedicated to utilizing ceramic remains to their fullest potential. With that said, however, it is clear that there are further opportunities for continued exploration and analysis of these varied and important artifacts, particularly with regard to chemical analysis. As technologies continue to improve and provide less destructive means with which to be able to determine the geological origins of clay fabric and temper, as well as the effects of finishing techniques and use-wear, both specimens that have been thoroughly investigated and those that have remained untouched can hold a wealth of information with which archaeologists can explore the choices and habits of individual potters, their communities, and their broader cultural settings.

The analysis of decorative motifs, their patterns, combinations, and frequencies, as well as their relationship with vessel form and size are the natural default for analysis; we can see and touch these aspects, take measurements and notes without causing harm to the sherds being analysed. They are deeply important to our understanding of the artistic and cultural expression of individuals and communities, but they are not necessarily the concrete, immutable examples of cultural identity that they may previously have been held to be. By applying methods and technologies outside of the traditional toolset of archaeologists, including micro-CT and other non-invasive techniques, we can see below the surface – literally. While logically, and experimentally, one may assume or demonstrate the steps that are taken during the châine opératoire of pottery production, such methods give us definitive examples of the choices potters made, perhaps through habit, muscle memory, or problem-solving skill. It allows us to see the individual amongst the group, while also providing further information in which we can identify patterns of behaviour.

The application of chemical analysis, of both residues and clay fabrics, allows us to see beyond the creation of the pottery in both directions; analysis of clay fabric and tempers in the past, choices and experimentation in pursuit of crafting the "best" vessel, and residues beyond its creation, the daily, weekly, seasonal use of the vessel as it served its community. Clay sourcing is a logical step in this process – exploring how these communities interacted with the landscape outside of a camp or village, exploiting naturally available, non-sustenance resources which might make certain tasks easier, or organic materials more stable. What patterns exist in these choices, and what difficulties impacted them? It is a very intriguing aspect of analysis that expands our consideration of archaeological materials beyond sites and deposits, into the environments that the people responsible for those sites would have inhabited in passing, temporarily such that little evidence beyond the materials they gathered still exists.

The regions surrounding Pigeon and Rice Lakes have been occupied by Indigenous communities for thousands of years, and their lives were not constrained to the sites we as archaeologists are able to define through the identification of features, artifacts, and villages. Whether seasonally mobile, or more settled in villages, the people who left the evidence that we find and interpret would have had connections and interactions with the landscapes and geological features that they encountered. As we move past rigid conceptualizations of space, it becomes increasingly necessary for us to interact with these same landscapes, changed as they may be, in order to deepen our understanding of the people who occupied them in the past. To the southwest of the sites in question, a partially fired "brick" of seemingly processed clay was excavated in the 1990s, representing an important part of the evidence we have regarding clay collection, processing, and pottery manufacture in the province (Fox and Beddard 2020:13-15). In Ontario, reanalysing the materials we have previously excavated beyond the typical designation of culture historical categories through decoration typologies and using information such as chemical analysis of pottery fabric to explore the catchment areas around sites, the choices and habits of potters, and potentially trade or travel presents an invaluable opportunity. This research intends to take part in that opportunity, and add to the knowledge of the practices of Middle and Late Woodland potters and their communities.

Chapter 3: Pottery Use Among Hunter-Gatherers

3.1 Introduction

There is an assumption that pottery only ever appears as a cultural innovation tied to increasing sedentarism, oftentimes in conjunction with the development of farming. The logical implication of this view is that that the spread of ceramic technology followed that of farming (Jordan and Zvelebil 2011:33). Mobile Hunter Gatherer (HG) cultures, by contrast, are generally assumed to lack ceramic technology as a practice, and perhaps only obtained pottery through contact with sedentary communities. However, there are several examples that contradict this assumption, both archaeologically and ethnographically. For example, evidence of Ertebølle-style ceramic production and use in early HG communities exists in neolithic Poland alongside early agriculturalists, and use of ceramics in mobile Kenyan Samburu pastoralist communities is essential to their continued existence (Nowak 2011:447-470, Grillo 2014:105-130). In Ontario, pottery first appears in the transition between the Late Archaic and Early Woodland periods, a millennium before the introduction of agriculturalism, with Vinette I pottery found in features at the Early Woodland Dawson Creek site dating to approximately 480 BCE (Jackson 1980:16). This assumption appears to be rooted in anthropology's long history of assuming agricultural sedentism was required for "civilized" technological innovations like pottery and metallurgy.

3.2 Neolithic Poland

A chapter by Marek Nowak in the book *Ceramics Before Farming* discusses at length the state of early pottery in what is now Poland (2011:449-470). Stratigraphic investigation in Poland tends to suffer somewhat for sandy conditions in many areas, however given a strong continuity of lithic technologies and techniques throughout the Mesolithic and into the early Neolithic period, the context of accompanying ceramics can be inferred (Nowak 2011:451-453,456,464). There are three ceramic traditions of concern in this instance: Linearbandkeramik (LBK), long associated with early agricultural traditions in the area, Ertebølle, associated with southern Scandinavian HG traditions, and Funnel Beaker Culture (FBC), a later ceramic tradition also associated with agriculturalism.

The LBK is associated with some of the earliest agriculturalists making their way into Europe, eventually disappearing and being replaced around 4800 BCE. The instances of these LBK sites in Poland, appear largely limited to fertile marshlands. There is some, very limited, evidence of possible transmission of some LBK technology to HG communities in the sandier, less agriculturally-suited areas in the form of coarse domestic cooking wares (Nowak 2011:451-452).

The Ertebølle tradition, which appears throughout the fifth millennium BCE, appears to be a separate tradition wholly uninfluenced by LBK traits. One such late fifth to early fourth millennium Ertebølle site in Poland, Dąbki, demonstrates a clear lithic tradition stemming from the preceding Maglemosian culture with some Ertebøllan traits. As the site's remains transition into the fourth millennium BCE, ceramics of clear Ertebøllan association appear, though with their own, novel features (Nowak 2011:454-455). This involvement of Ertebøllan traits implies some amount of contact and technological transmission between mobile HG communities in southern Scandinavia and Poland, rather than from neolithic agriculturalists to mobile HG communities (Nowak 2011:458). The concurrent development of individualized habits and styles at this point also undermines the assumption that only agriculturalists could and did develop ceramics; these are not habits and styles influenced by or adopted from agriculturalists, but rather created and developed by the HG communities that crafted them.

Finally, the appearance of Funnel Beaker Culture (FBC) is another strong indication of HG-originated ceramic technology. Believed to have been largely influenced by the ceramic traditions of HG groups throughout the late mesolithic and early neolithic, there is evidence that FBC ultimately informed the development of later Linin pottery – not to be confused with the earlier Linearbandkeramik pottery – associated solely with neolithic agriculturalists (Nowak 2011:463-464). It is intriguing that FBC, while largely associated with later neolithic agriculturalists, appears to be so heavily influenced by HG ceramics. The traditional assumed flow of information would typically contradict this direction of transmission – farmers give ceramic knowledge to foragers, thereby converting them to farmers and overriding the foraging lifestyle. However, in this instance, it appears that the farmers adopted technologies originating from HG practices, and adapted them to their own needs.

Continuous use of older lithic technology by HG groups in northern Poland concurrently with ceramics appears to imply that this ceramic technology originated with local foraging communities, rather than being transmitted from early agriculturalists. It does not appear to be a unidirectional uptake of ceramic technologies from the new agriculturalists moving into Poland to the existing HG communities. It is possible that these HG ceramic technologies were, in fact, influenced or introduced by contact with Scandinavian HG cultures. By contrast, there appears to be the eventual transmission of information from both sides in later cultural periods, with each applying new techniques and trends from the other to their own discrete practices before the eventual demise of European HG culture.

3.3 Samburu Pastoralists

Ethnoarchaeologist Katherine M. Grillo spent 2009 living in a Samburu community in the Kirisia Hills of central Kenya, with her research focus being on the use and perception of pottery (2014:105-130). The Samburu are a seasonally mobile pastoralist culture, raising cows, goats, sheep, and occasionally camels. Due to the environmental conditions in the arid lowlands, Samburu communities must move frequently throughout the dry season to allow their livestock consistent access to grass. Rain-fed irrigation is effectively impossible in the area, precluding sedentary agriculturalism and rendering pastoralism one of the only viable sustenance options for the local communities (Grillo 2014:109). The Samburu rely upon pots crafted by lower caste Ltorrobo potters to sustain their pastoralist practices (Grillo 2014:109-110). The livestock are raised for their milk, blood and meat, and the pots of varying sizes and functions allow for the processing and storage of these products throughout their movements. The Samburu's use of ceramics does not preclude their use of other materials; there are structural similarities between the construction of their ceramic pots and others crafted of wood and gourds. Indeed, milk is culturally prohibited from being stored or collected in ceramic pots, though dairy by-products are not similarly prohibited (Grillo 2014:107, 111, 119, 121). The ceramic pots allow for more thorough processing and more food-safe long-term storage of dairy by-products such as ghee that would otherwise be impossible if the Samburu were limited to vessels of wood and gourd.

Grillo argues that Samburu communities have continued to be successful in their utilization of their pastoralist subsistence system because of their use of pottery, not in spite of it. The pottery enables cooking, processing, and storage of blood, milk, and meat products, as well as the production of herbal medicines. Their use in cooking and processing provides a more thorough and complete extraction of the nutrients they rely upon for survival and for improving the shelf-life of their products. It allows communities to function more efficiently and stably throughout the dry season, the period within which they are the most mobile and within which they can expect occasional but serious periods of drought which would otherwise put the communities and their herds in serious danger.

The pots also represent an important facet of Samburu cultural identity, being utilized in several cultural rituals, including the circumcision ritual wherein boys enter manhood. Grillo states, rather aptly, that:

> It seems clear that pottery use in the Sahara did not impede the development of increasingly mobile settlement strategies; in fact, pottery became increasingly abundant even as many hunting/gathering societies transitioned to herding and became more residentially mobile. [...] families own pots not despite the fact that they are mobile herders, but rather because those pots have, historically, enabled their lives as mobile herders (Grillo 2014:124,125).

Samburu pastoralists are a prime example of a mobile community which did not gain ceramic technology during its transition to agriculturalism, as such a transition never occurred. Indeed, they are able to function successfully and weather severe conditions as mobile pastoralists because of their use of and reliance upon pottery within their culture. Given the previously stated assumption that acquisition of pottery is solely associated with the development of sedentary agriculturalism, this appears to be quite a stark contradiction. The introduction of pottery did not come with complementary agriculturalist behaviours, nor did it mystify or prove to be detrimental to the functioning of Samburu pastoralism, rather demonstrably improving their ability to more safely and reliably operate as they had for centuries.

3.4 Early Pottery in Ontario and the Northeast

In southern Ontario, Late Archaic sites span a large chronological period, between 4500 and 2800 RCYBP, and in the Trent Valley are typically found along river confluences, lake shores and near wetland, and were likely occupied spring through fall by small micro-band communities which likely settled near lakes in the late spring and summer to fish, and away from the lakes too hunt as the weather became colder in the fall and winter (Ellis et al. 2009:812,821; Eastaugh et al. 2013). Though subsistence patterns appear largely unchanged from the Late Archaic, the adoption of pottery technology appears to have shifted the abilities of Early Woodland communities to extract and store nutrients that were otherwise difficult or impossible to access (Spence et al. 1990:131-134, Taché et al. 2017). Vinette I pottery is an accepted diagnostic artifact type which marks the shift in northeastern North America from this Late Archaic period to the subsequent Early Woodland period, approximately 4530-3150 years B.P. (Taché and Hart 2013:365). There is no one single date to which one can ascribe this shift, as each site demonstrates cultural change in its own time, presumably affected by delays in contact between communities due to geographic distance or other cultural factors, leading to large overlaps in many of the cultural periods archaeologists have established in Ontario and the broader northeast region.

This particular manifestation of ceramic technology typically takes the form of a small to medium, cone-shaped open-mouthed bowl, decorated using a cord-wrapped stick to make impressions, and presenting with no narrowing at the neck of the vessel (Taché et al. 2008:63, Spence et al. 1990:125). Steatite stone vessels predate and precede the use of clay in the northeast of North America (Tache and Hart 2013). It is also possible that this early pottery may have been preceded by organic storage vessels - pots found later in the American southwest are shaped similarly to the local squash varieties, and it has been proposed that during the Early Woodland period in the northeast, gourds may have been viewed as a more reliable storage vessel than the somewhat unrefined Vinette I pottery (Diehl & Waters 2006:82, Taché 2011:89). Taché and Craig (2015) conclude that, given the residue analysis, it is likely that pottery production in northeastern North America began as a tool to process fish and other aquatic resources available seasonally to many freshwater and marine-adjacent communities in the Early Woodland period. These fish oils, as well as nut oils, were items of prestige, being highly labour-intensive to collect, process, and produce - many of the nuts would otherwise have been inedible, and organic containers would not be capable of withstanding the extended periods of heat exposure required to render oils through boiling (Taché et al. 2017:228).

It is also possible that the staggered appearance of the transition to the Early Woodland period, and the scant appearance of pottery in the archaeological record across the northeast, may in part be explained by a small pool of existing vessels during the period of production and use. Not only would the seasonal movements of bands, with small and impermanent camp footprints, and the possible subsequent inundation of sites, due to natural and human factors, limit the potential for sherds to appear at any one site, it is also possible that the vessels would not have existed in abundance during their period of use. Taché and others (2017:226) posit that a large number of fish would be required to produce a small amount of oil – therefore, it would not be economic to produce a large volume of vessels if the associated product would not make use of those vessels. The existence of Vinette I does present itself as a net-benefit for the communities making use of this early pottery, however that benefit does have limits and those limitations may have impacted the appearance of pottery in the archaeological record in Ontario and the northeast.

3.5 Discussion

The creation of pottery has long been associated with the development of sedentarism and eventual urbanization. However, as archaeology progresses in its goal to further understand the past, it is becoming increasingly clear that, in many places around the globe, pottery may have been crafted and used by mobile communities. Ceramics, due to their longevity in the archaeological record, are one of the most integral features of ancient cultures archaeologists have consistent access to. While relative dating can be skewed by perception and biases, continued use of absolute dating can clarify some of these flaws, and make more accessible the patterns of mobile communities. We know that even the earliest global evidence of pottery, found in eastern Asia and dating between 20,000 and 12,000 CYBP, must – by merit of its dating – have been created by Hunter Gatherers (Craig et al. 2013:351). The use of pottery in pastoral Kenyan communities is essential for the continued maintenance of their way of life, and their continued survival throughout droughts and dry seasons. Ceramic use among mobile communities can be necessary to allow for the development of technologies and patterns of behaviour related to resource exploitation and consumption. Grillo also raises the intriguing point that HG and pastoralist sites are likely to be ephemeral in their remains, and unlikely to leave much trace of activity or their use of various technologies, including pottery (2014:106). The absence of pottery in the HG record, therefore, could be assumed to be attributed to careful transport of culturally and economically valuable ceramics and their essential contents, in conjunction with short periods of occupation at campsites rather than the total absence of pottery from that community's cultural and technological prowess. This seems particularly poignant when considered in the context of the potentially stratigraphically unstable sands of Poland. Is it possible that the inherently transient and impermanent nature of HG behaviours, in combination with the sensitive stratigraphic environment in areas uninhabited by agriculturalists, have resulted in a severely limited record of said HG behaviours, including ceramic traditions and technologies? Could the same be said in other similar contexts, influenced not only by natural ecological and geological processes, but also by modern human behaviour and development? Significant changes to waterways in Ontario and colonial development prior to the requirement of archaeological survey, combined with the previously considered limitations of availability and production of early pottery could skew the perception of technological capability and inclination of pre-contact indigenous communities based on what appears in the archaeological record. The tendency of western anthropologists and archaeologists to underestimate the capabilities and complexity of early cultures, particularly non-western European cultures, could also heavily contribute to the assumed lack of evidence for HG behaviours, including ceramics specifically. To continue to contradict the conflation of ceramics with sedentary agriculturalism, Dean Arnold, in an analysis of ceramics of the Ayacucho basin in Peru, discusses the likelihood of the expansion of resource exploitation by agricultural communities in less-than-ideal ecological environments (Arnold et al. 1975:194, 201). Assuming that a community, facing ecological conditions which do not adequately support crop growing, said community may also expand to exploit other natural resources in the area. Arnold concludes that this behaviour in response to marginalized agricultural conditions may have resulted in exploitation of clay and other resources associated with ceramic production. It seems logical that the same conclusion could be applied to HG communities. The adaption of ceramic technologies has sincere and complex benefits for mobile communities and their sustenance patterns, as demonstrated by the Samburu pastoralists. The evidence of HG ceramic across Europe, including ceramic technologies which appear to have originated solely from said HG groups, would imply that these benefits were apparent to those communities, as well.

Given the widespread evidence of HG ceramic, both independently developed and externally influenced, it seems necessary to reassess the potential for the presence of ceramic technologies in other pre-agricultural HG cultures. More specifically, there is a dearth of research from Ontario regarding the resource exploitation patterns of Middle and Late Woodland communities and, while this research may be hampered by intense development around significant waterways and the displacement of descendant communities, alteration and development around significant waterways, and the displacement of descendant communities, it may still be possible to uncover evidence of these behaviours through the application of interdisciplinary techniques to excavated material and other archaeological evidence.

Chapter 4: Methods and Sampling

4.1 Introduction

This chapter reviews the methods used to gather data for this project. It begins with a discussion of the theoretical framework used to identify clay sources in proximity to human activity. Subsequently, it reviews identified clay sources near archaeological sites along the Trent-Severn Waterway, and the methodology employed for clay identification at these sources. The chapter further examines the process of clay sample collection, followed by an overview of the processing procedures applied to these samples, encompassing pre-processing, firing, and the utilization of X-Ray fluorescence spectrometry (XRF) to ascertain the chemical composition of powdered samples. Finally, the chapter concludes with an explanation of the statistical methods used to analyse the XRF results.

4.2 Source Determination Model

Ontario Geological Survey data and GIS mapping formed the basis of initial investigation; each of the four sites were mapped and layered with quaternary geological data which identified areas with significant sand and clay deposits. I determined that all sites were close to at least one deposit, and should have historically had access to clay (OGSEarth 2023) (Figure 3).

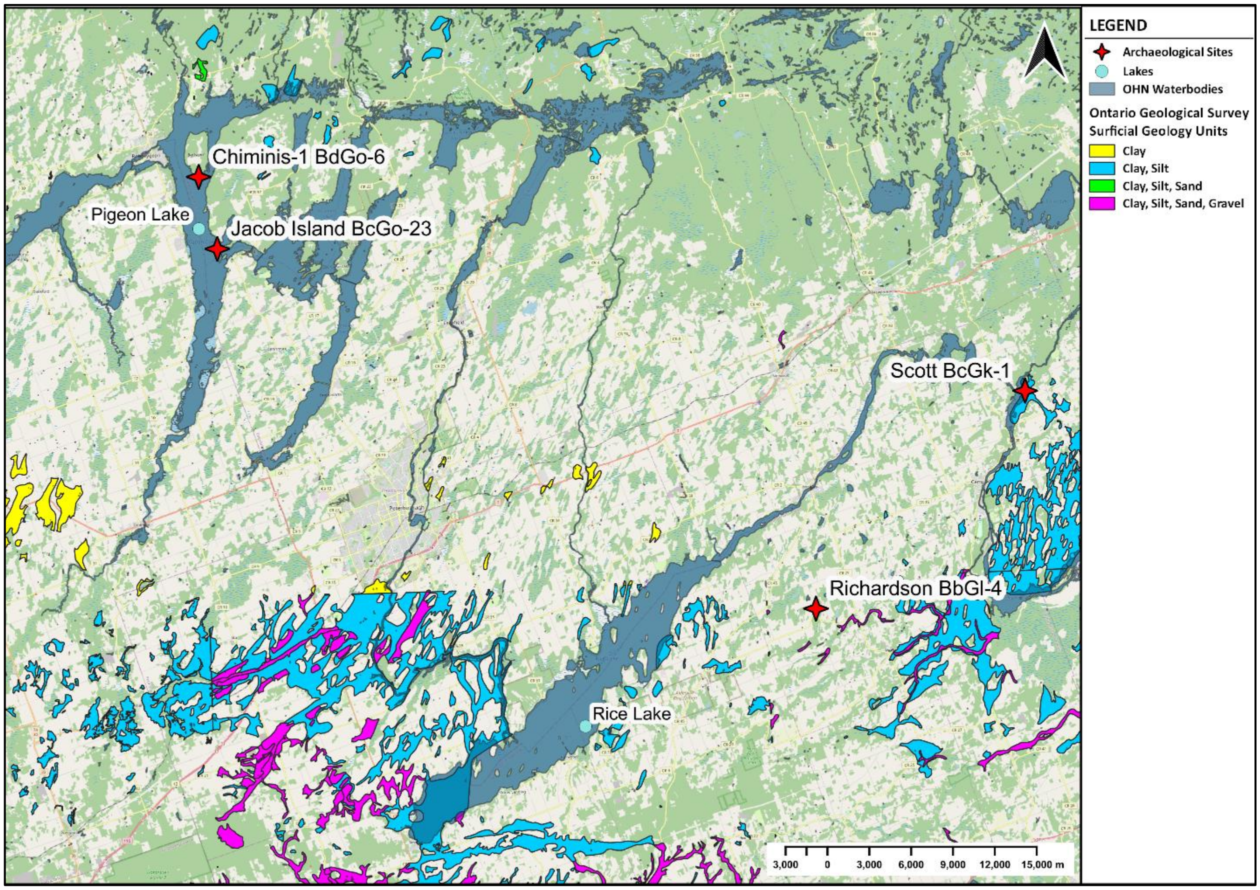


Figure 3. Map of archaeological sites and quaternary clay and sand deposits.

Clay deposits were considered to be within a site's catchment area based upon work compiled by Dean Arnold (1985). Based on several ethnographic studies and analysis by D.L. Browman (1976), Arnold proposed three spatial thresholds for resource exploitation, based upon their economic value to the community (Figure 3). While these thresholds were primarily determined through analysis of sedentary agricultural communities, there is some consideration given to mobile communities, and their potentially broader range of access to, and exploitation of, resources.

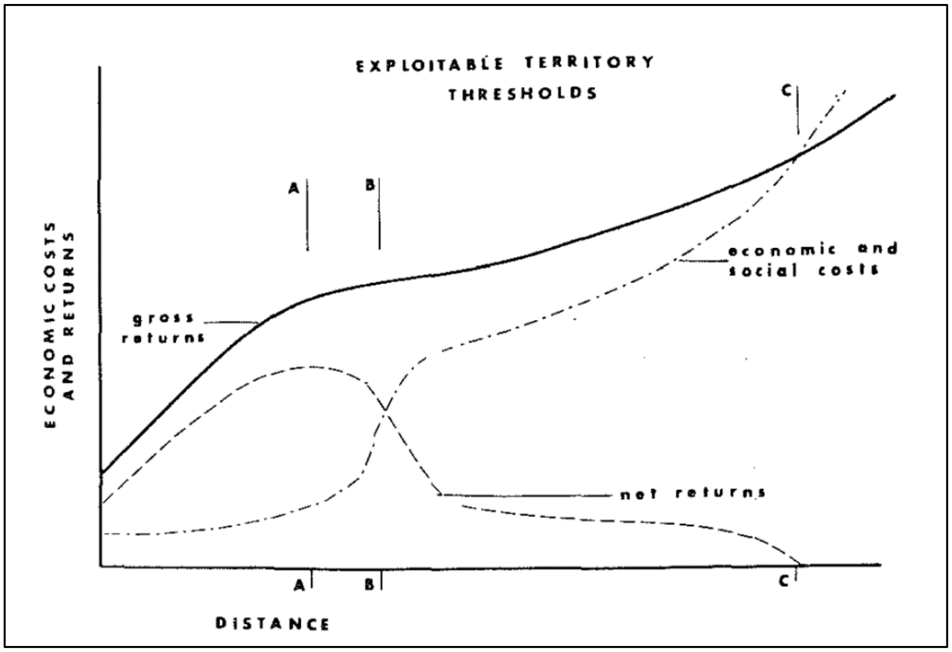


Figure 4. A model of exploitable territory thresholds, originally modelled by D.L. Browman (Arnold 1985:33).

Using Browman's initial work, Arnold determined that, for clay resource exploitation, threshold A represented a one kilometer journey for both clay and temper; this distance provides the most advantageous labour to returns ratio (Figure 4). Beyond threshold A, costs increase dramatically, though not to an insurmountable degree; seven kilometers is estimated for clay access, and six to nine kilometers for temper. Anything farther is unlikely to be accessed without modified methods of transportation, e.g. animal-drawn carts. However, there is also some ethnographic evidence that, upon depletion of a clay source or lack of access to a source, communities may travel beyond threshold B to access these resources for the continued benefit of the community (Arnold 1985:54-55). It is possible that the Middle and Late Woodland communities occupying the sites of concern may have travelled over water by canoe to access clay sources, and this may extend their threshold for clay exploitation. However, clay in varying qualities appears to be accessible to each site of interest within seven kilometers, per the boundary of threshold B.

4.3 Sample Location

With these thresholds presented by Arnold in mind, I hypothesized that a radius of ten kilometers around each site would be the farthest extent of any survey for clay, per threshold C. Sources five kilometers or closer would be preferred, as they may have been more economically viable, per threshold A. Given the likelihood of clay being deposited by running water, preference was given to creeks and creek beds in the vicinity of each site. Four likely locations were identified, as shown in Figure 5.

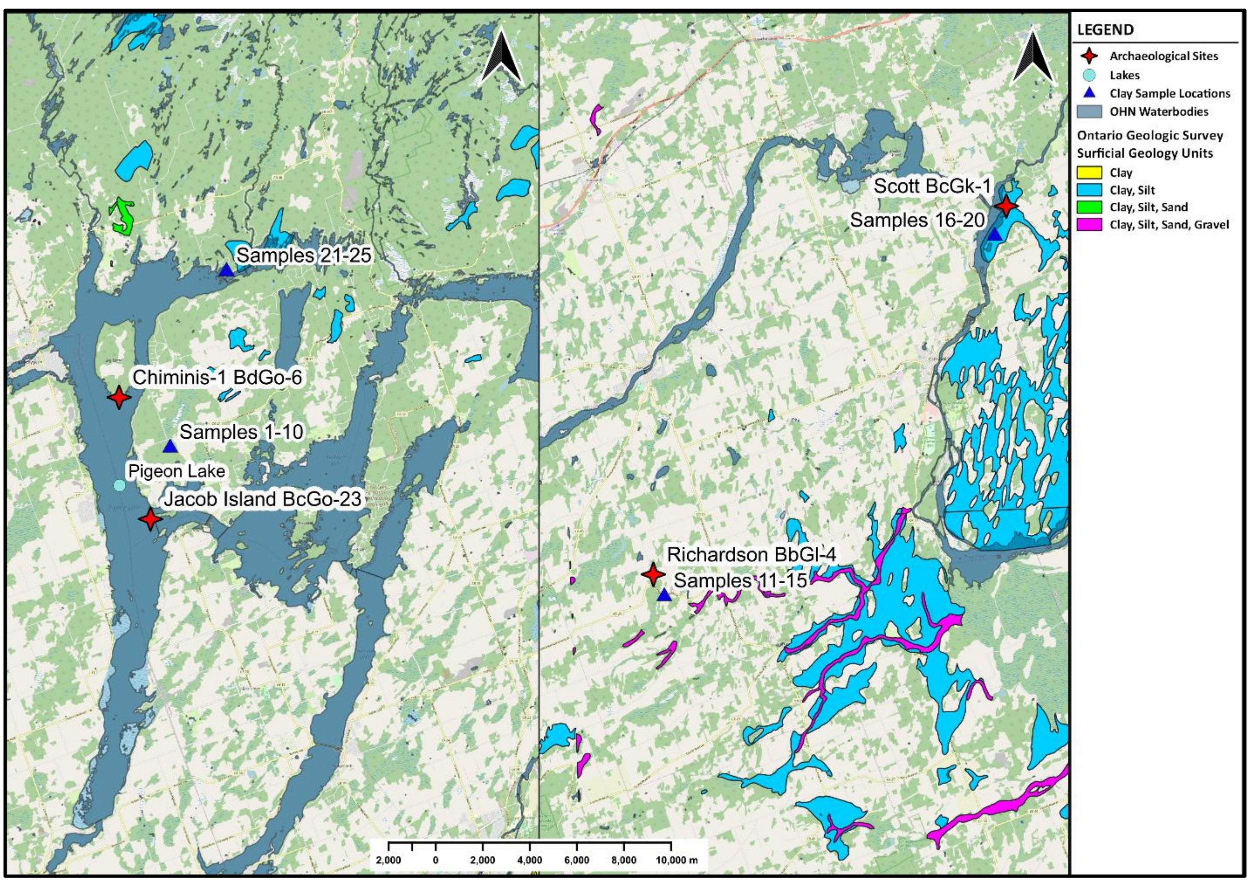


Figure 5. Identified clay sources and associated sites.

In order to locate and identify clay deposits, I visited each proposed location during the months of June-October 2023. At each likely location, I dug shovel test pits approximately 30 cm wide to varying depths. I took soil samples at approximately 15-20 cm from the surface and perform a field “ribbon test”, in which the soil is rolled between the hands to make a cylinder and bent to determine plasticity (Levy et al.2022:60, 64; Figure 6).

Figure 6. An example of the “ribbon test” from Levy et al., demonstrating plasticity of potential clay material (2022:60).

Under this framework, soil which does not roll into a cylinder should not be considered to have significant clay content, and the rolled material’s ability to bend without cracking demonstrates the plasticity, or quality, of the clay content. The Bear Creek and Crowe Bay samples were collected from the edge of wetland areas, below deposits high in organic material. The Percy Creek samples were collected from beside a culvert and were also below a very thick layer of organic material. The Point Pleasant samples were collected from a mostly dry creek bed in a forested area, and are mixed with denaturing sandstone material. Photographs of these sources are shown in Figure 7 to 15.

Figure 7. The view of Bear Creek, east of Pigeon Lake.

Figure 8. A test pit at Bear Creek.

Figure 9. The view from atop the culvert at Percy Creek, facing southwest.

Figure 10. A test pit at Percy Creek.

Figure 11. East of Crowe Bay, just north of Mud Lake.

Figure 12. A test pit at Crowe Bay, with grey clay material apparent.

Figure 13. The view of Point Pleasant, northeast of Pigeon Lake.

Figure 14. A test pit at Point Pleasant.

Figure 15. Denaturing sandstone in the soil at Point Pleasant.

Each source passed the initial roll test to varying degrees, however most were unsuccessful in the bend test, implying a range of clay content and quality. Ultimately, four clay sources were identified and a total of 25 clay samples obtained, as shown in **Table 3.** Clay source locations used in this study. (Figure 16 to 18):

Source	**Samples**	**Coordinates**	**Associated Site**	**Distance (km)**
Bear Creek	1-10	44°30'10.00"N 78°28'17.00"W	Chiminis-1	3.05
			Jacob Island-2	3.15
Percy Creek	11-15	44°13'19.00"N 77°57'2.00"W	Richardson	1.03
Crowe Bay	16-20	44°21'57.30"N 77°45'38.49"W	Scott	1.36
Point Pleasant	20-25	44°34'10.00"N 78°26'18.00"W	Chiminis-1	7.04

Table 3. Clay source locations used in this study.

The Point Pleasant source represents the extent of Browman's threshold B, chosen to provide a contrast to the Bear Creek source, being north and east of Pigeon Lake respectively.

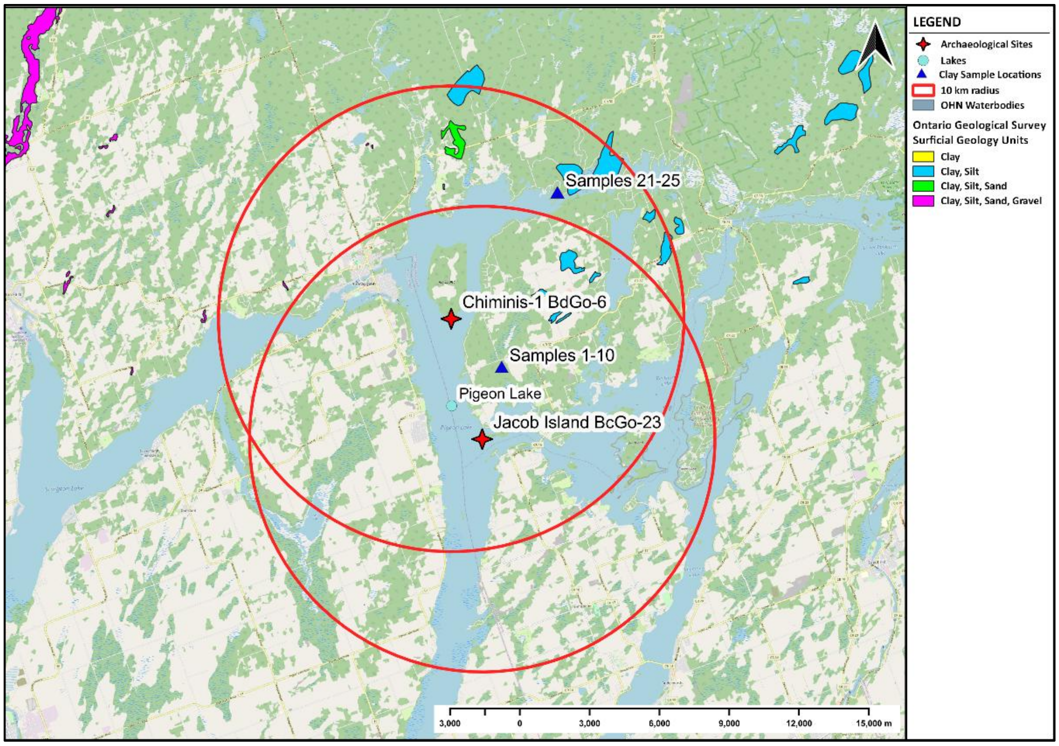


Figure 16. 10km radius around the Jacob Island and Chiminis-1 sites, with sources for Samples 1-10 and 21-25 noted.

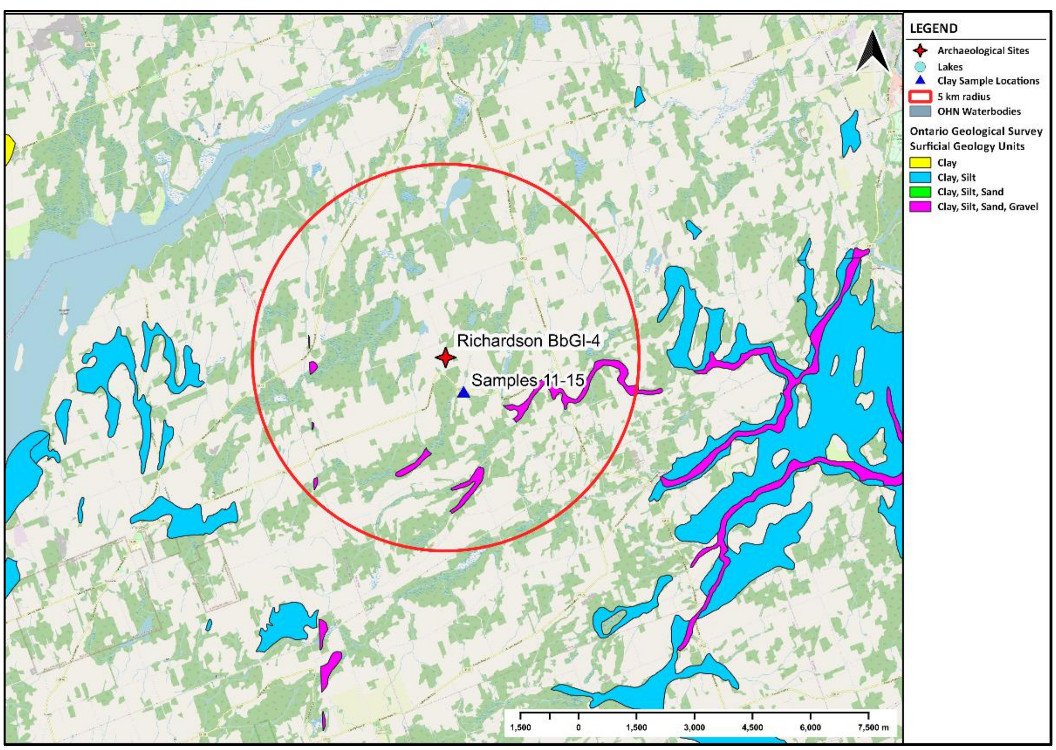


Figure 17. 5km radius around the Richardson site, with the source for Samples 11-15 noted.

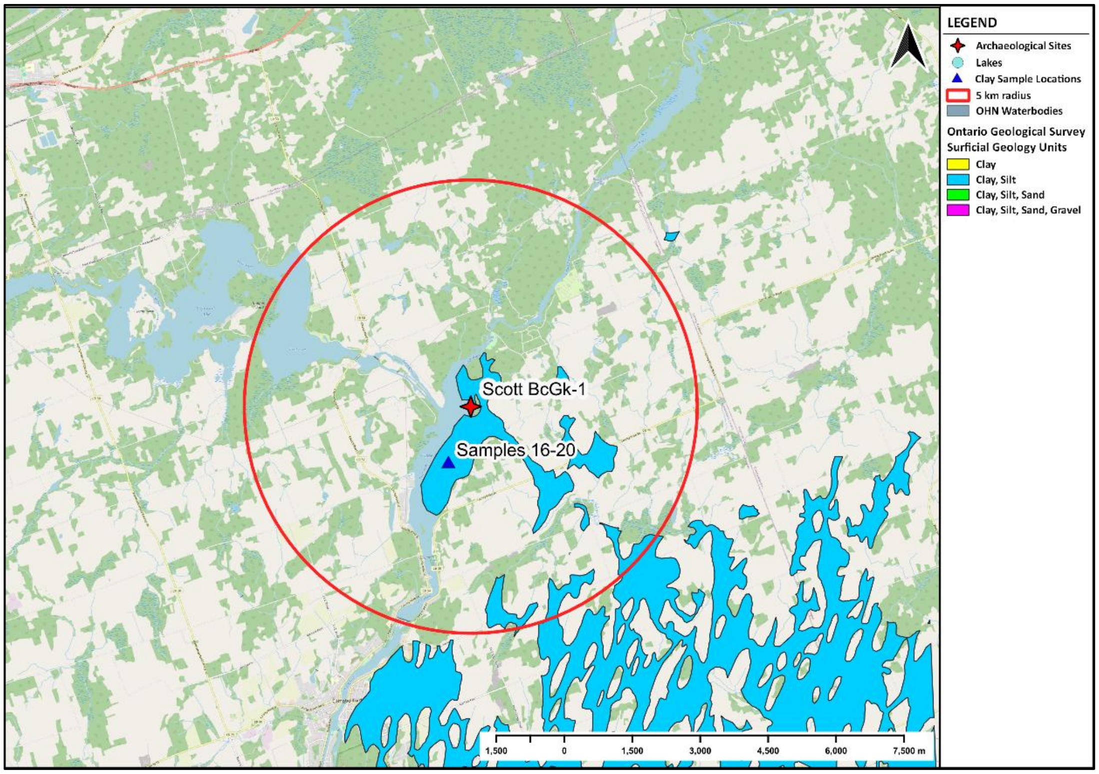


Figure 18. 5km radius around the Scott site, with the source for samples 16-20 noted.

4.4 Sample Collection

Collection was initially intended to consist of ten one-kilogram samples from each source, with the intention of investigating any potential variation of chemical composition between and within clay deposits. After the initial collection of samples from Bear Creek, I judged that sources were unlikely to be easily accessible across an area wide enough to allow for samples to be taken several metres apart. It also became apparent that, despite the collection weight being one kilogram, differing levels of water and organic content impeded the reliability of the collected sample weights and larger samples were preferred. Thereafter, I collected five samples of at least two kilograms in weight from each of the Percy Creek, Crowe Bay, and Point Pleasant sources. The samples are itemized in Table 4.

4.5 Sample Processing

Once collected, samples were wet processed; distilled water was added, and the material was manually agitated to break up any clumps and allow for it to be passed through a two millimetre sieve to remove larger organic material and rocks (Figure 19). This processing was done to more specifically isolate the clay body and reduce any potential "noise" or extraneous data that may skew the chemical composition.

Figure 19. Initial wet processing of material. Note the organic material floating in the water, and larger inorganic material in the sieve.

This material was then left to settle, and the used water siphoned off and discarded. The samples were left to dry at room temperature and then weighed before being broken up and again passed through the sieve (Figure 20 and 21; Table 4). Samples 1-5 were excluded from further analysis due to their low weight.

Figure 20. Drying samples.

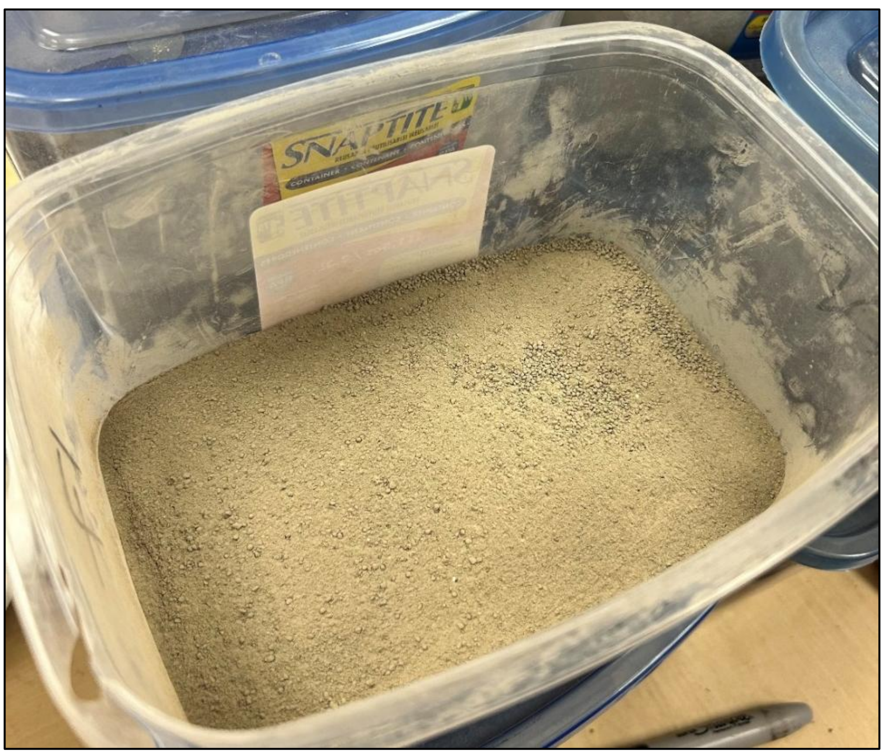


Figure 21. Sample 17 after drying and second sifting.

Sample #	Source	Collected Weight (kg)	Removed Organic and Inorganic >2mm (kg)	Final Dry Processed Weight (kg)	Processing Loss (kg)
1	*Bear Creek*	*1.090*	*0.300*	*0.620*	*0.170*
2	*Bear Creek*	*1.050*	*0.340*	*0.635*	*0.075*
3	*Bear Creek*	*1.030*	*0.275*	*0.550*	*0.205*
4	*Bear Creek*	*1.445*	*0.460*	*0.710*	*0.275*
5	*Bear Creek*	*1.215*	*0.430*	*0.685*	*0.100*
6	Bear Creek	2.395	0.705	1.210	0.480
7	Bear Creek	1.960	0.645	1.135	0.180
8	Bear Creek	2.325	0.735	1.345	0.245
9	Bear Creek	2.285	0.610	1.405	0.270
10	Bear Creek	2.340	0.805	1.010	0.525
11	Percy Creek	2.045	0.375	1.225	0.445
12	Percy Creek	2.455	0.250	1.325	0.880
13	Percy Creek	2.855	0.785	1.925	0.145
14	Percy Creek	4.740	1.055	2.880	0.805
15	Percy Creek	5.780	2.075	2.755	0.820
16	Crowe Bay	2.900	0.160	2.015	0.725
17	Crowe Bay	2.810	0.230	1.950	0.630
18	Crowe Bay	2.590	0.455	1.400	0.735
19	Crowe Bay	3.940	0.795	1.985	1.160
20	Crowe Bay	3.250	0.410	2.095	0.745
21	Point Pleasant	3.165	0.410	1.845	0.910
22	Point Pleasant	2.725	0.225	1.830	0.670
23	Point Pleasant	2.300	0.265	1.485	0.550
24	Point Pleasant	3.163	0.385	2.145	0.633
25	Point Pleasant	1.680	0.640	0.705	0.335

Table 4. Collected and processed sample weights. Italics indicate samples below weight threshold.

To examine changes in the clay after firing, a sample weighing 100 g was rehydrated with distilled water, and worked to incorporate. One additional sample from Bear Creek, *JS00*, was processed by Julia Reis Cordeiro through grinding with sandstone tools, as seen in Figure 22, and included its original organic and inorganic material.

Figure 22. Sandstone tools used to grind *JS00*.

Each sample was formed into a test tablet, approximately five centimetres wide, five centimetres long, and 1.4 centimetres deep, before being labelled for identification and marked to measure shrinkage during drying and firing (Levy et al.2022:64; Figure 23). Once dry, the test tablets were weighed and measured, then placed in a Cone Art BX 119D kiln and fired to cone 06 on a slow bisque profile, for approximately 13 hours and reaching a maximum temperature of 1060 degrees Celsius. Upon retrieval, the test tiles were measured for firing shrinkage and weighed for any loss of organic material. Samples 11-13 and 15 were not solid enough after firing to be measured for shrinkage. Photographs of the tiles are shown in Figure 24 and 25, and the test tile data is presented in Table 5.

Sample	Weight (g)	Water added (mL)	% Hydration	Wet tile (g)	Dry tile (g)	% drying loss	Fired tile (g)	Shrinkage line - Dry (mm)	% Shrinkage (dry)	Shrinkage line - Fired (mm)	% Shrinkage (fired)
BC 6	100	20	16.67	75.4	67.4	10.61	55.3	37.49	6.27	38	5.00
BC 7	100	20	16.67	80.4	64.5	19.78	53.5	37.64	5.90	35.83	10.43
BC 8	100	15	13.04	79.8	64.9	18.67	53.3	37.13	7.17	37.49	6.27
BC 9	100	15	13.04	75.2	60.2	19.95	48.4	37.23	6.93	38.18	4.55
BC 10	100	15	13.04	82.8	68.4	17.39	55.4	37.64	5.90	37.93	5.18
PC 11	100	20	16.67	65.4	43.8	33.03	34.7	35.26	11.85	*n/a*	*n/a*
PC12	100	40	28.57	67.6	46.8	30.77	32.9	36.27	9.32	*n/a*	*n/a*
PC 13	100	35	25.93	67.7	52.1	23.04	44.9	37.74	5.65	*n/a*	*n/a*
PC 14	100	25	20.00	74.0	57.2	22.70	50.2	34.82	12.95	35.06	12.35
PC 15	100	30	23.08	75.9	61.9	18.45	49.5	39.00	2.50	*n/a*	*n/a*
CB 16	100	30	23.08	81.1	63.6	21.58	59.9	37.86	5.35	38.15	4.63
CB 17	100	30	23.08	77.2	59.7	22.67	54.7	37.13	7.17	37.69	5.78
CB 18	100	45	31.03	72.3	50.7	29.88	42.3	36.76	8.10	36.68	8.30
CB 19	100	45	31.03	75.2	52.9	29.65	44.5	36.27	9.32	36.25	9.38
CB 20	100	35	25.93	76.8	56.2	26.82	50.9	35.94	10.15	35.83	10.43
PP 21	100	35	25.93	69.0	43.2	37.39	36.4	35.90	10.25	35.06	12.35
PP 22	100	30	23.08	70.1	46.2	34.09	41.8	35.17	12.08	34.99	12.53
PP 23	100	40	28.57	73.0	53.2	27.12	49.6	36.01	9.98	35.85	10.38
PP 24	100	30	23.08	76.0	56.3	25.92	52.7	35.96	10.10	36.29	9.28
PP 25	100	65	39.39	64.3	38.8	39.66	30.4	37.58	6.05	36.13	9.67
JS 00	100	25	20.00	87.7	70.9	19.16	55.7	37.57	6.08	37.54	6.15

Table 5. Hydration of clay and shrinkage of tiles.

Figure 23. Using a form to make test tile *PC11*.

Figure 24. Test tiles prior to firing. *JS00* is absent.

Figure 25. Test tiles after firing and sample collection. *PC11-PC15, top right, were pulverized after firing.*

Sample extraction protocol was based upon that established by Robinson and Conolly (2021); fabric samples consisting of one cubic centimeter were removed from each test tablet using a tungsten carbide drill bit which was cleaned with methanol between uses (Figure 26).

Figure 26. Powdered samples before analysis.

These extracted powder samples were sent to McMaster University's MAX Lab for x-ray fluorescence (XRF) analysis, where a Thermo Scientific ARL Quant'X energy-dispersive X-ray fluorescence spectrometer was used to identify and convert concentration estimates (ppm) of a relevant set of 14 elements and 7 oxides, per USGS standards (see Appendix A: McMaster MAX Lab XRF Analytical Protocols for full analysis protocols). This set of elements and oxides was determined by Robinson and Conolly, and is based on the results of regional ceramic research done by Hawkins (2001), Michelaki and others (2013, 2015), and Rieth and others (2007).

This data was then statistically analyzed using principal components analysis, following a portion of the protocols established by Robinson and Conolly (2021:12);

1. Observations were transformed to standard scores to reduce the influence of variables with high absolute ppm.
2. Uninformative variables were removed by using an iterative binomial regression to identify a small number of variables consisting of the most information about differences between clay sources.
3. The multivariate data was reduced using principal components analysis to identify the latent variables as expressed by the first three components.

The results of this protocol were then compared to those found by Robinson and Conolly to compare the composition of excavated ceramics to the nearby clay sources. All Robinson and Conolly (2021) data and R code available at https://github.com/jconolly/robinsonconolly.git, data and R code data for this paper available at https://doi.org/10.5683/SP3/NNCWRO. Four files pertaining to this research are provided: “raw_combined.tab” which contains the combined XRF data from this research and Robinson and Conolly (2021), scott_becca_thefinedetails_markdown.docx” which contains the Rmarkdown output of the Rcode used in this thesis, “scott_becca_the_fine_details_rcode.txt” which contains the Rcode used in this thesis, and “testtiles.tab”, which contains the test tile processing used in this thesis.

Chapter 5: Results

5.1 Introduction

This chapter discusses four facets of the results of this research. Firstly, the traits of the clay test tiles after firing, beginning with Bear Creek. Then the results are compared and explored with the intent of determining potential sources of variability in physical traits between clay sources. Third, a contextual overview of the excavated pottery samples analysed by Robinson and Conolly (2021) is provided. Lastly, this chapter will present the results of the X-Ray Fluorescence and Principal Component analyses, and compare the chemical compositions of the test tiles both between the clay sources and to the previously excavated and analysed archaeological materials.

5.2 Test Tile Firing Results

The Bear Creek samples resulted in a grey-buff fabric, which immediately after firing appeared sturdy and sufficient for use in a variety of ceramic applications. The surface was smooth, and survived firing without cracking, spalling or burning (Figure 27).

Figure 27. Bear Creek test tiles after firing and powdered sample removal.

Unfortunately, after a period of approximately two months of storage indoors, the tiles had disintegrated, potentially due to a high lime content drawing moisture out of the air. The resulting powder contained white, powdery masses that crumbled upon contact (Figure 28).

Figure 28. Remains of Bear Creek test tiles, demonstrating white efflorescent material.

The Point Pleasant samples survived firing, but were not of good quality. Two tiles fired yellow-buff, two beige or light brown, and one orange-red, but structurally were very fragile and had a sort of lightweight, styrofoam texture that crumbled upon handling (Figure 29).

Figure 29. Point Pleasant test tiles after firing and powdered sample removal.

The Percy Creek samples initially survived firing, but were not able to hold their shape when removed from the kiln. *PC12* disintegrated upon contact, while *PC11* and *PC13-15* disintegrated after removal and through the process of handling (Figure 30 and 31). These samples also had a very lightweight, foamy texture, and the resulting powdered material was coarser than the sample material prior to firing. The tiles fired to varying shades of brown, with the exception of *PC14*, which fired brown-red. The samples were placed in separate bags and pulverized after removal.

Figure 30. Percy Creek test tiles and *JS00* after firing, prior to removal.

Figure 31. *PC12* disintegrated upon attempted removal.

The Crowe Bay samples were the most successful of the test tiles, all firing brown-red or orange-red, with a very smooth and fine-textured surface (Figure 32). Upon removal from the kiln, *CB18* demonstrated a fine layer of white efflorescence across the exposed top surface, and *CB20* also demonstrated some efflorescence at the edges of its exposed top surface. After the removal of a powdered sample using a Dremel tool, *CB18* also had a noticeable mass toward the centre of the tile.

Figure 32. Crowe Bay test tiles after firing and powdered sample removal. Note the white cast on *CB18* and *CB20*, and white inclusion in the fabric of *CB18*.

After storage, the Crowe Bay samples also demonstrated some environmental alterations. The surface of *CB18* spalled and cracked, with a thin section of the top surface separating from the tile on the right side (Figure 33). The white mass noted after sample removal increased in size, clearly undergoing some amount of efflorescent alteration. *CB17* and *CB18* had each developed several small instances of efflorescence, and *CB19* had cracks across its top surface.

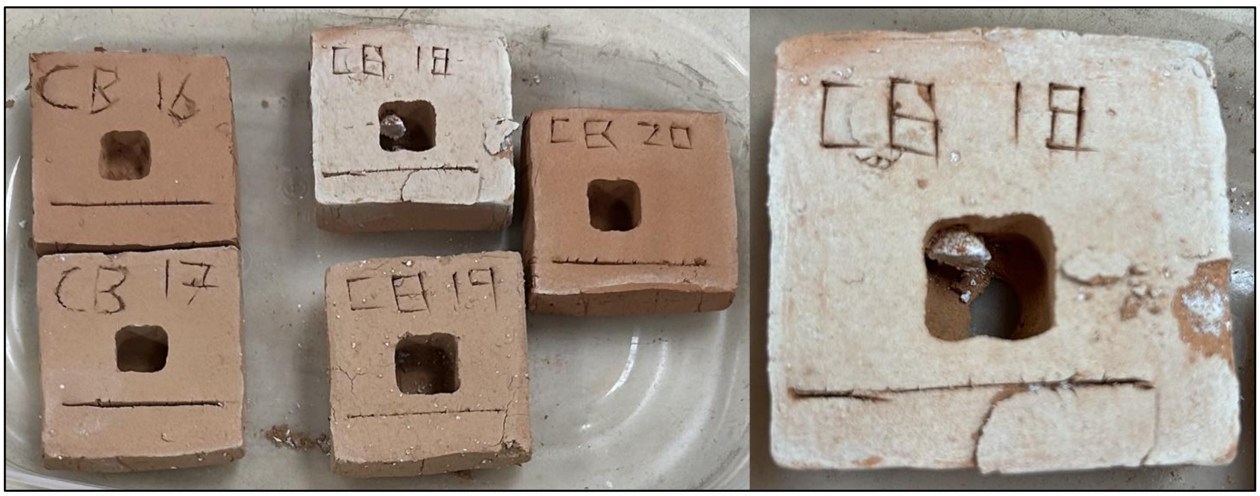


Figure 33. Crowe Bay samples after storage. Note the appearance of efflorescence on *CB17*, *CB18*, and *CB19*, as well as cracking and spalling on *CB18* and *CB19*.

5.3 Comparative Clay Results

Despite all demonstrating plasticity in the field, the material collected from each source clearly differed in terms of post-firing traits. These traits include the immediate stability of the fired material, colour, shrinkage, and the longevity of the material.

Percy Creek and Point Pleasant are arguably of the lowest quality of the four sources. The dry, unfired material from both sources is quite coarse in texture, and the wet material is plastic, but not exceedingly so. The dry material from Point Pleasant also presented alongside a denaturing inorganic material, likely sandstone, which added to its coarseness and made the unfired material glitter.

The unfired Percy Creek material is dark brown, and fires to a light orange or light red. These test tiles were immediately unstable, with one not surviving being removed from the kiln. The tiles were extremely delicate, and upon contact, collapsed into coarse red-orange dust; interestingly, the post-firing material was coarser than the unfired material, implying some amount of transformation of particle size due to firing.

The unfired Point Pleasant material is a dark beige, and fires to a light to medium yellow or medium orange, with speckles of a red oxide throughout the material possibly related to the denature sandstone. These test tiles were also immediately unstable and very lightweight upon being removed from the kiln, and did not withstand even gentle handling. The post-firing material from Point Pleasant also appears to be coarser than the unfired material, similar to Percy Creek.

Bear Creek is of moderate quality, with a grainy but decently fine texture when dry. The unfired material is a light beige, and fires to a yellow beige. The fired tiles were stable and tolerated handling well, however the passage of time illuminated a serious fault in the material: lime. After extended exposure to standard interior conditions, the material degraded into a coarse powder with chunks of white efflorescence, likely due to the lime content of the clay absorbing atmospheric humidity during storage. The effects of lime can be mitigated post-firing, however the lime content of the Bear Creek material was not identified prior to the tiles being stored.

The Crowe Bay material is of superior quality to the previous three sources. The dry, unfired material is a light yellow-beige or grey, very fine and almost powder-like in texture. After firing, the tiles were a light to medium orange and tolerated handling excellently. Of note was the appearance of efflorescence on the surface and throughout the fabric immediately after firing; after storage, the tiles also demonstrated some spalling of the surfaces. It can be inferred that the Crowe Bay material also contains a not-insignificant amount of lime, which also would need to be mitigated prior to its use as a functional vessel.

The materials collected at Percy Creek and Point Pleasant are effectively unusable in any practical application, barring significant adulteration with other, more stable clay materials. The wet, unfired material demonstrated limited plasticity, but the fired materials were immediately unstable and would not be useful for the creation of any practical vessel. It is possible that the post-firing profile of both sources could be a result of the firing temperatures or conditions, and that a lower temperature or shorter firing time could result in a more stable material, but this seems somewhat unlikely given the catastrophic structural failure of the fired materials. The materials collected at Bear Creek and Crowe Bay were of much higher quality, from the point of collection to immediately after firing. Of these two, Crowe Bay had a finer, more consistent texture, though the fired tiles from both sources were sturdy and had smooth-textured surfaces. The materials from both sources would ultimately reveal that they required some form of alteration or adulteration if used to form a vessel, presumably due to their lime content, but otherwise present as decent to excellent clay fabrics before and after firing.

Given these characteristics, I do not believe that an experienced artisan would choose to collect or work with the Percy Creek or Point Pleasant materials. They have few positive traits before and after firing besides their interesting colours, and would not be efficacious to collect or use in the manufacture of vessels. Bear Creek would be a decent choice, potentially improved by post-firing lime mitigation, mixing with other clay materials, or tempering for enhanced durability. Crowe Bay is the best of the four – it was the most similar upon initial collection to modern commercial clays, though it obviously demonstrates flaws similar to the Bear Creek material which would also require mitigation or alteration.

The data collected while processing the materials and creating the test tiles were tested for statistical significance in order to determine if those traits could illustrate the differences between sources, however none demonstrated any clear significance and were normally distributed (see Table 5 and 6, Figure 34).

Value	Shapiro-Wilk P-value	Fisher's Exact Test	Chi-Squared
Water added	0.0842	0.08452	0.06945
% Hydration	0.3601	0.08569	0.06945
Wet tile weight	0.91	1	0.3605
Dry tile weight	0.8017	1	0.3581
% Drying loss	0.7951	1	0.3581
Fired tile weight	0.1051	1	0.3581
Shrinkage line (dry)	0.3978	0.4727	0.2465
% Shrinkage (dry)	0.3968	0.4657	0.2465
Shrinkage line (fired)*	0.06667	1	0.5356
% Shrinkage (fired)*	0.06676	1	0.5356

Table 6. Statistical tests applied to processing data, and their results.

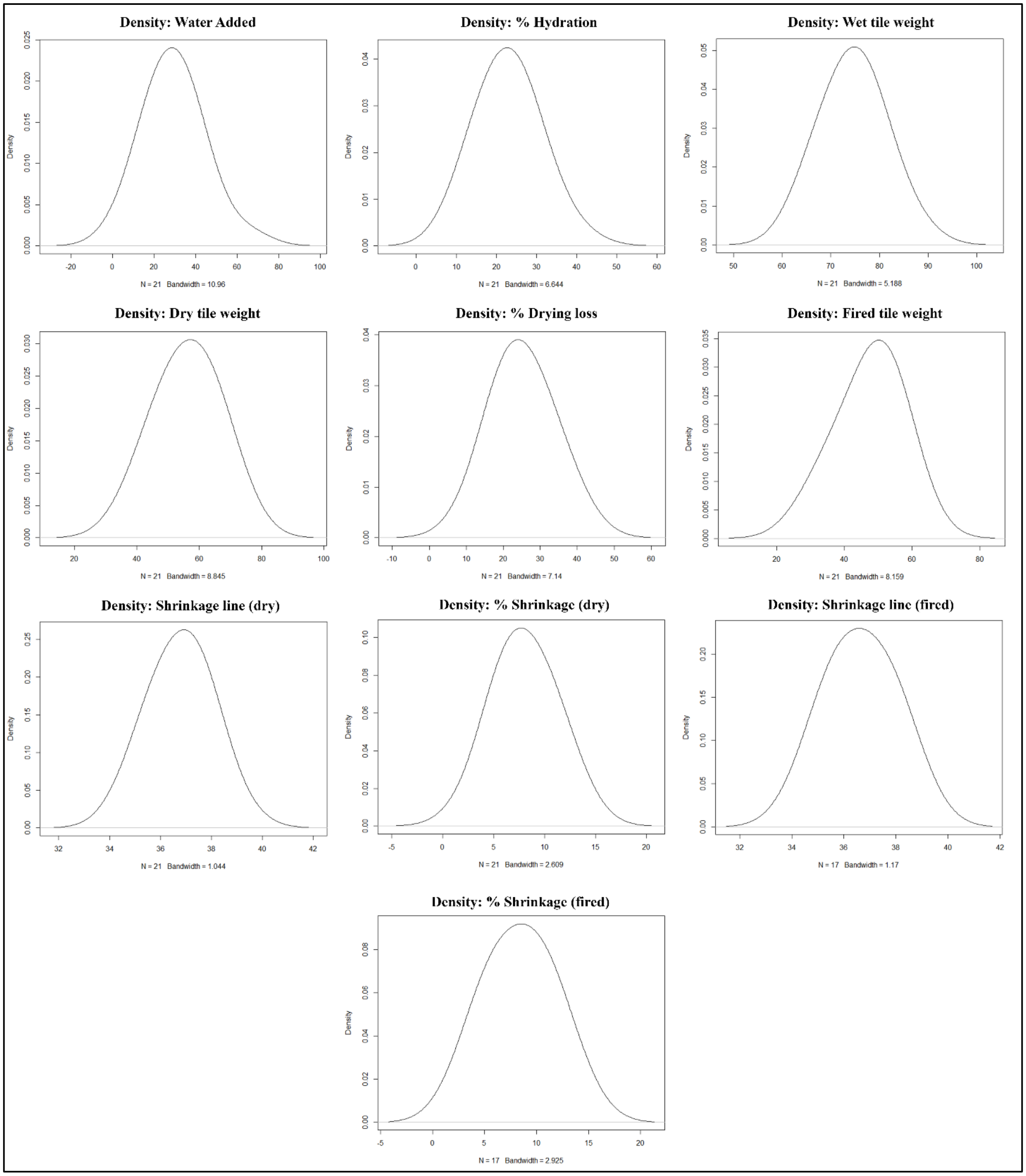


Figure 34. Plotted densities of processing data.

It seems likely that the differences between the quality and traits of the materials collected from each source are related to particle size, chemical composition, or some combination of both. More specific particle sorting, possibly through petrography or graduated sifting, could help to more definitively identify the particle sizes of the unfired material. The particle size of natural clays, as discussed in section 2.2.2 How is clay formed? is related to the weathering of the parent materials – both in terms of the method of weathering, and how long the material has been weathered. It may be possible to further reduce the particle size, possibly through grinding similar to reducing the size of temper grit, however there is no evidence to suggest that this was a practice employed by potters to alter or improve raw clay materials.

As demonstrated in the following section, each source is chemically distinct, with even the individual samples from each source demonstrating some level of uniqueness in their composition. It is possible that Crowe Bay and Bear Creek contain more of the phyllosilicate compounds that provide the typical plasticity, as well as other compounds which allow for more durable structure after firing. It is also likely, however, that the sources are of glacial origin similar to those identified by Braun (2015) near the Holly Site, and as calcareous clay materials, clearly demonstrate the same issues with regard to lime content after firing and the associated durability and reliability issues.

5.4 Overview of Archaeological Pottery Samples

As previously discussed (see Sections 1.2 Site Selection1.3 Previous Research 4.2 Source Determination Model and 4.3 Sample Location), the clay samples collected for the purposes of this research were intended to be compared to the results of prior analysis completed by Robinson and Conolly (2021). This prior analysis was completed by collecting powdered samples from seventy pottery sherds excavated from four archaeological sites; thirty sherds were associated with the Middle Woodland period, and forty with the Early Late Woodland period (see Table 7).

Site	Period	N=
Chiminis-1 (BdGo-6)	MW	20
Scott (BcGk-1)	MW	10
Jacob Island-1 (BcGo-23)	ELW	30
Richardson (BbGl-4)	ELW	10

Table 7. Pottery sample quantities per site, reproduced from Robinson and Conolly (2021:6).

The sherds selected for analysis were each identified as originating from a distinct vessel, for the purposes of controlling variation, and consisted of body or rim fragments to more accurately and consistently identify the period to which the sherds belonged (Robinson and Conolly 2021:8).

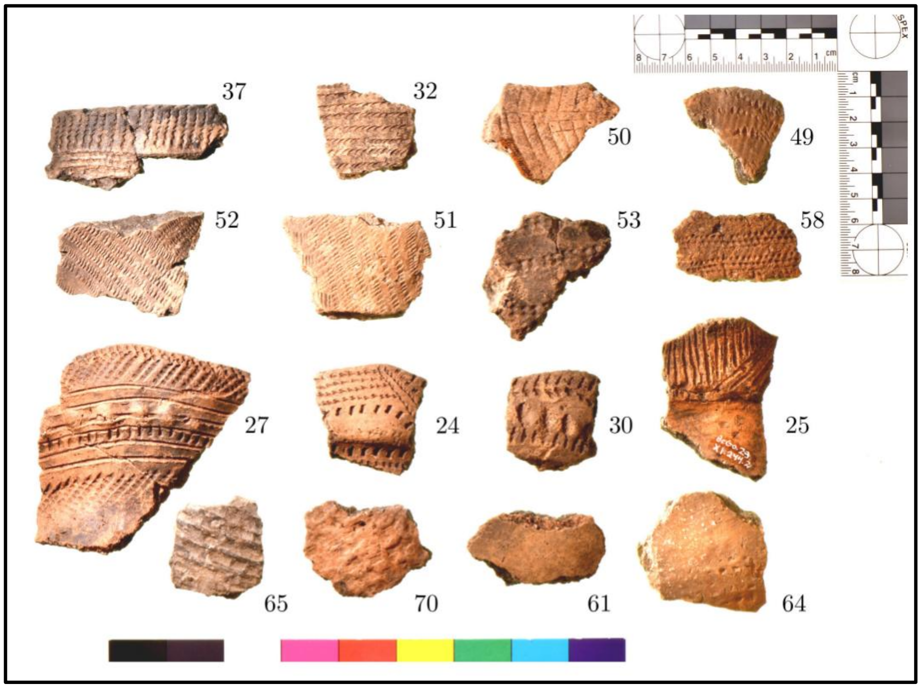


Figure 35. A portion of the sherds from which samples were taken. Reproduced from Robinson and Conolly (2018:9).

The samples were extracted from each sherd using a tungsten carbide drill bit, removing approximately one cubic centimetre of powdered material from each sherd for analysis. XRF analysis of the powdered materials was also completed by the McMaster MAXLab, with the same equipment and protocols to analyse this research’s materials.

5.5 X-Ray Fluorescence Analysis and Principal Component Analysis

The XRF results delivered from McMaster University were analysed using principal component analysis (PCA) in RStudio. The data was reduced to seven elements through covariance matrix analysis: tin, nickel, copper, strontium, niobium, barium, and lead, accounting for approximately 83% of the variation between samples.

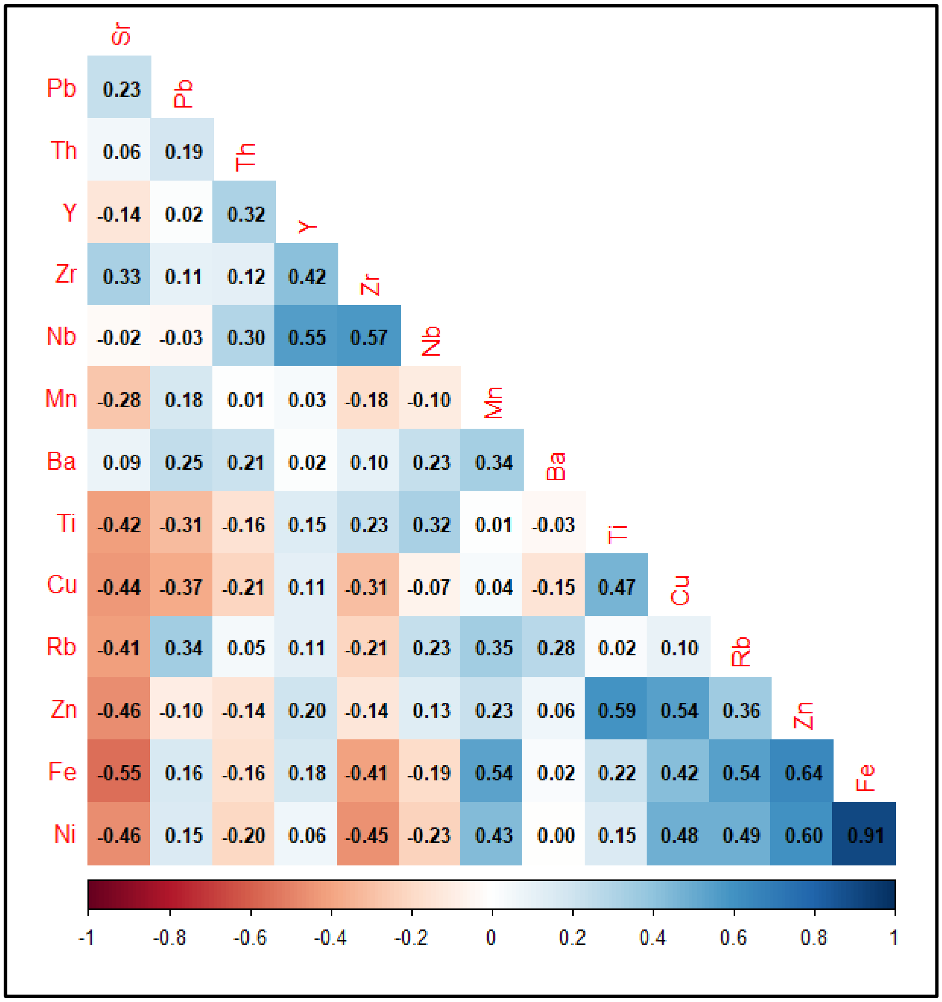


Figure 36. Covariance matrix of the combined XRF analysis data sets.

With the data reduced to the most relevant elements, the data was scaled to ensure high value data did not overwhelm lower value data using z-scores for the sake of simplicity and time (Greenacre 2018).

With PCA applied, each source is chemically distinct, and form their own individual cohorts when they are compared (Figure 37). There is no clear indication in trace element composition what may imply a proxy explanation for clay quality, though the higher-quality Crowe Bay sample cohort does appear distinct in its comparative nickel and barium content.

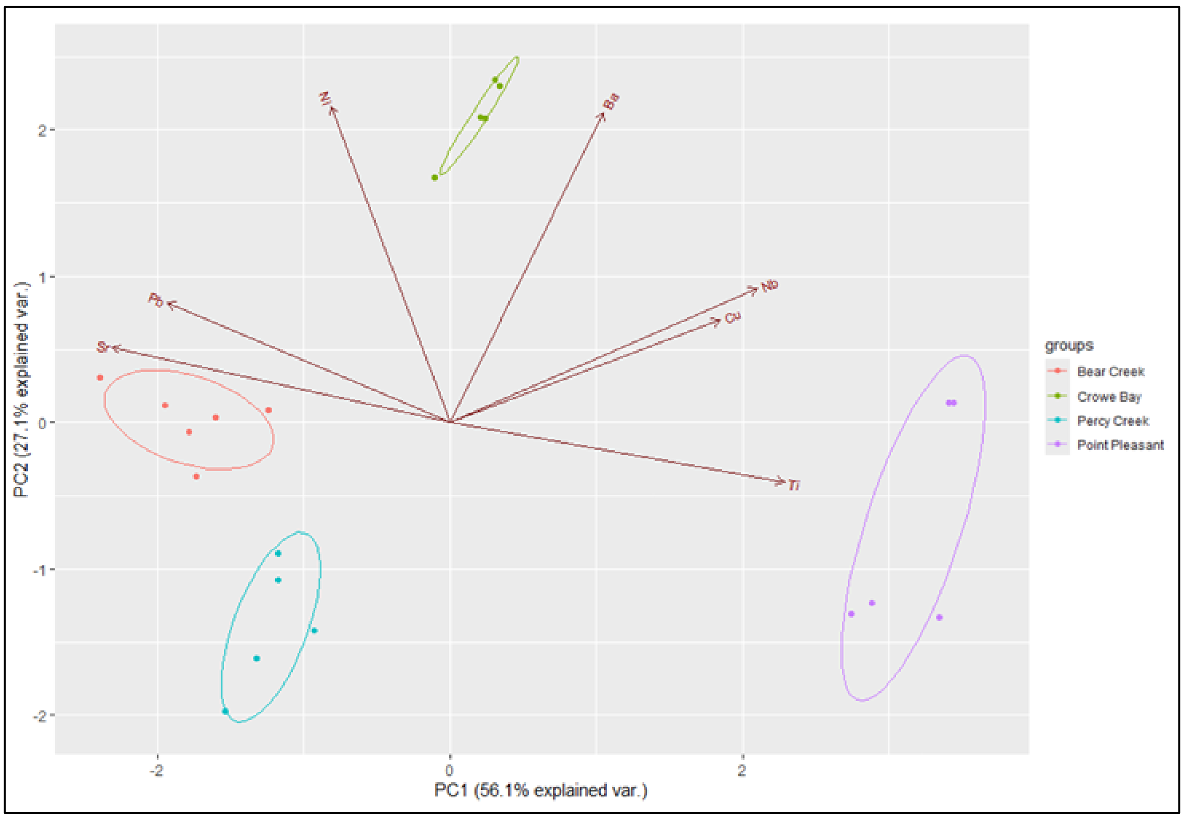


Figure 37. PCA of sources.

When scaled and analysed with the experimental clay, pottery from all four archaeological sites demonstrate significant overlap, though only one source correlates with some of the pottery (Figure 38).

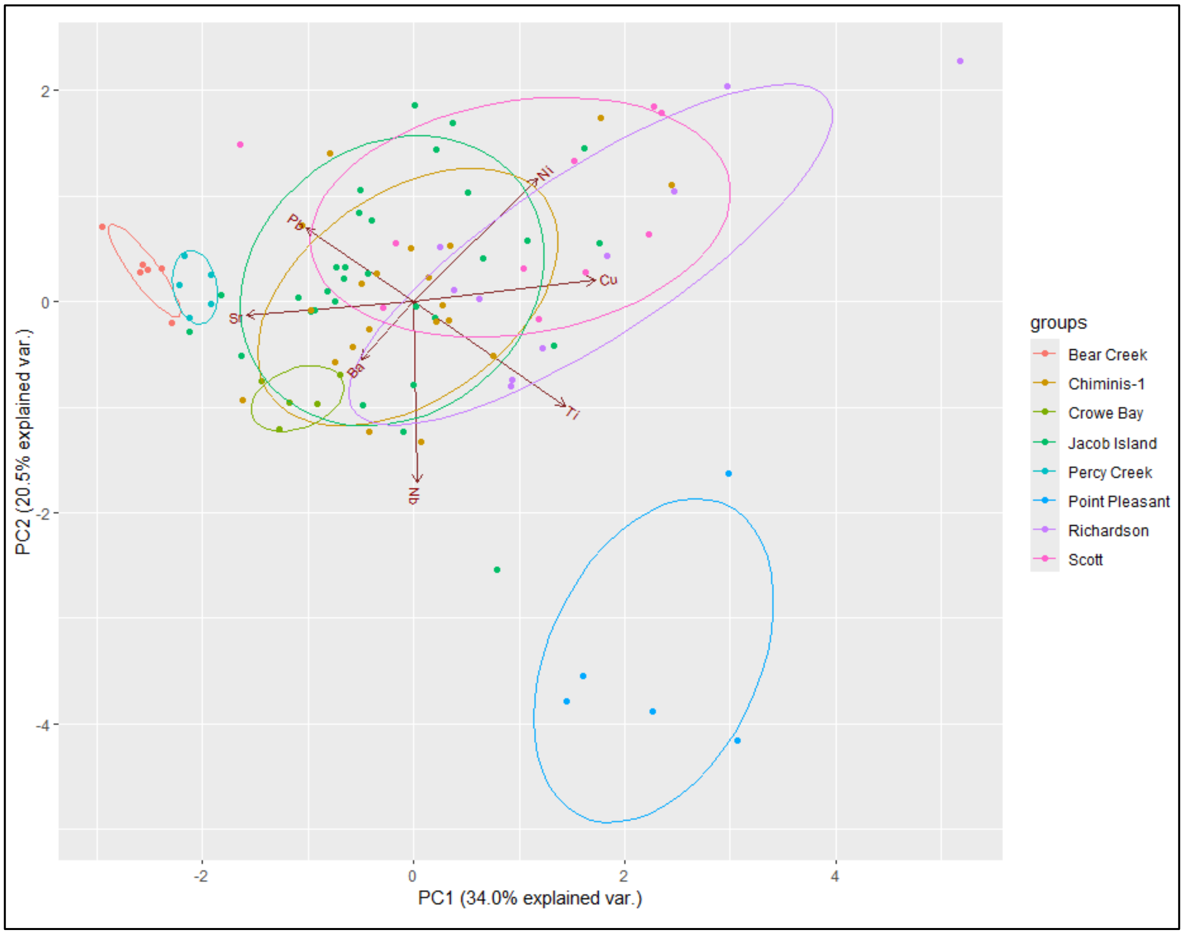


Figure 38. PCA of collected clay and excavated pottery.

The Crowe Bay clay source correlates most closely with some of the excavated pottery from Chiminis-1 and Jacob Island. However, this source is not local to those sites as it lies approximately sixty kilometres from both (Figure 39).

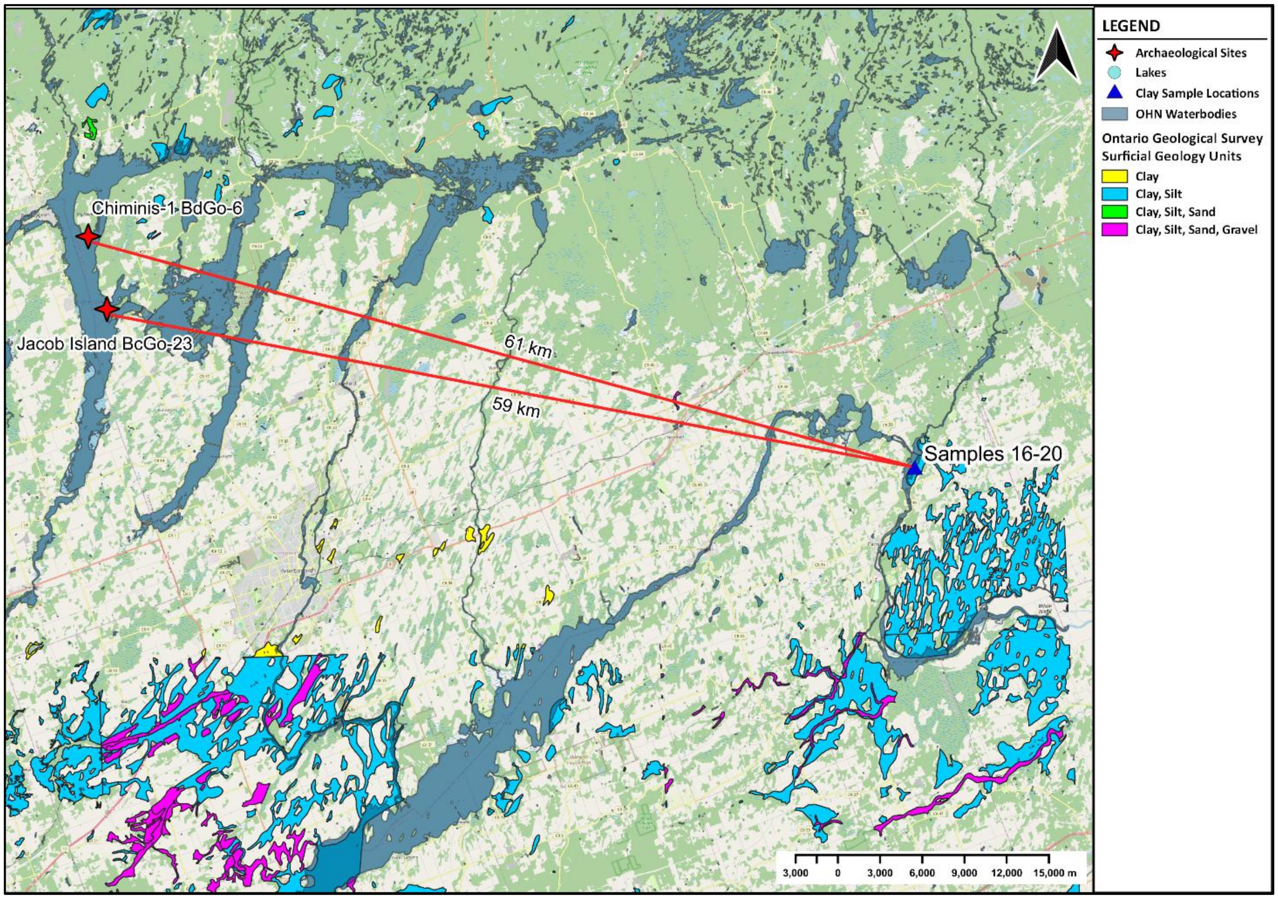


Figure 39. Map showing distance between the Crowe Bay source and Jacob Island & Chiminis-1.

The other three clay sources do not demonstrate any overlap with the excavated samples, though some outliers approach similarity with sources.

One of the Bear Creek samples, *JS00*, was processed using sandstone tools as discussed in the previous chapter. When compared with the other samples from Bear Creek, there does appear to be some difference in the chemical composition of *JS00* - the clay processed with sandstone demonstrates higher levels of nickel, strontium and niobium than the five other samples (Figure 40). The other samples also demonstrate some differences in composition, particularly in regard to their lead and tin levels, but are all still distinct from *JS00*. Approximately 75% of the variation between the Bear Creek samples can be accounted for with the aforementioned elements.

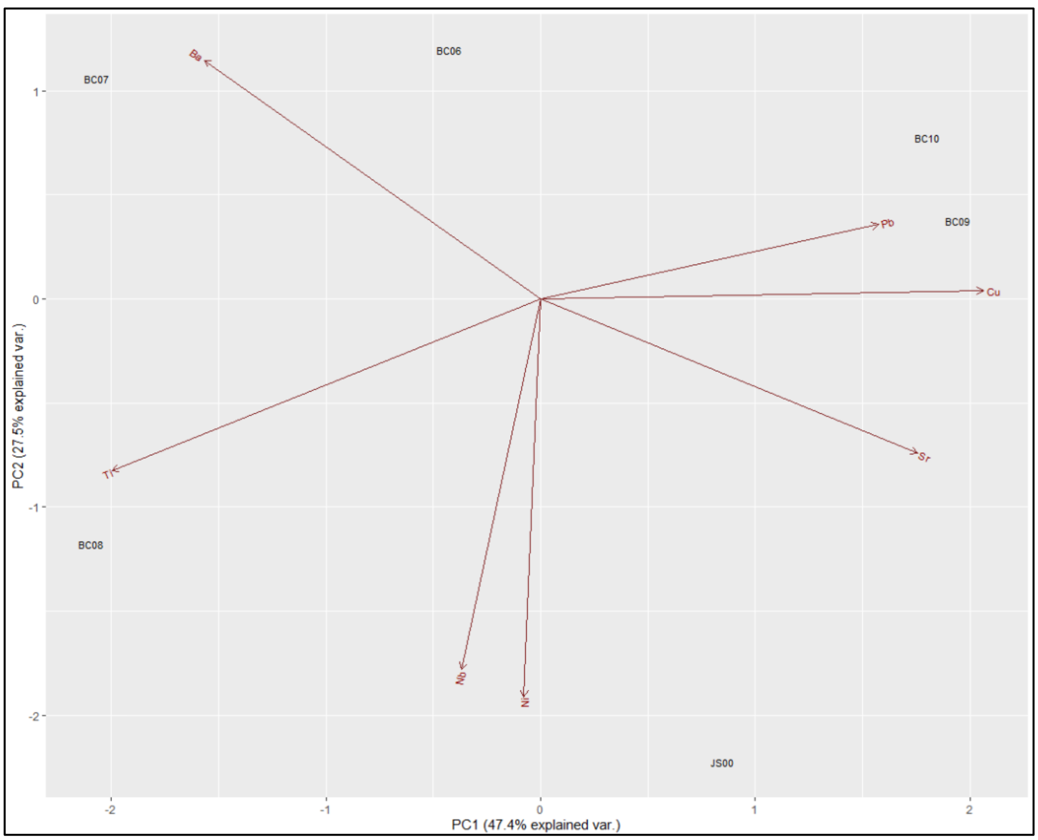


Figure 40. PCA of samples collected from Bear Creek.

Point Pleasant demonstrates an intriguing distribution, which accounts for approximately 83% of the chemical variation (Figure 41). *PP25*, which fired to a noticeable different colour, is far removed from the other four samples, appearing to have much more lead and copper content. *PP21* is equally distinct in its high barium content, but has similar levels of niobium, strontium, nickel, and titanium to those of *PP22-24*.

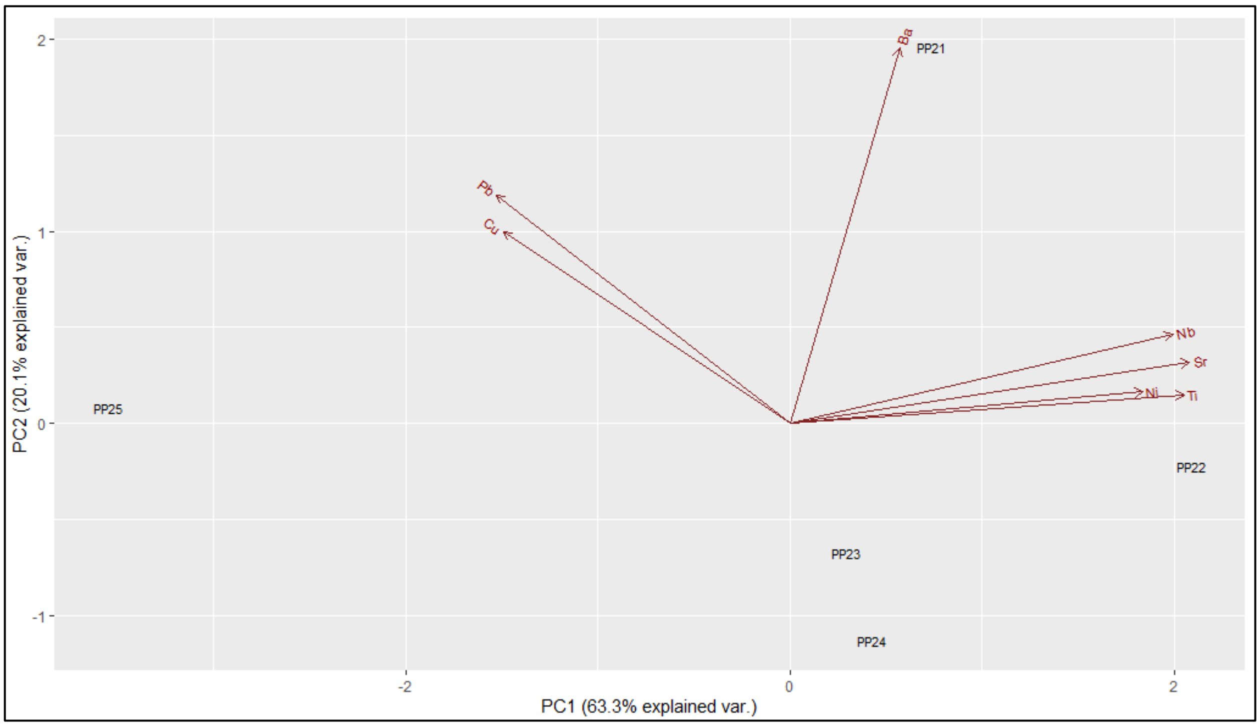


Figure 41. PCA of samples collected from Point Pleasant.

Percy Creek is more widely distributed, with little to no clustering of the samples. The PCA accounts for approximately 82% of the variation (Figure 42). *PC14* appears unique due to its tin and nickel content, while *PC15* appears unique due to its lower level of niobium and barium.

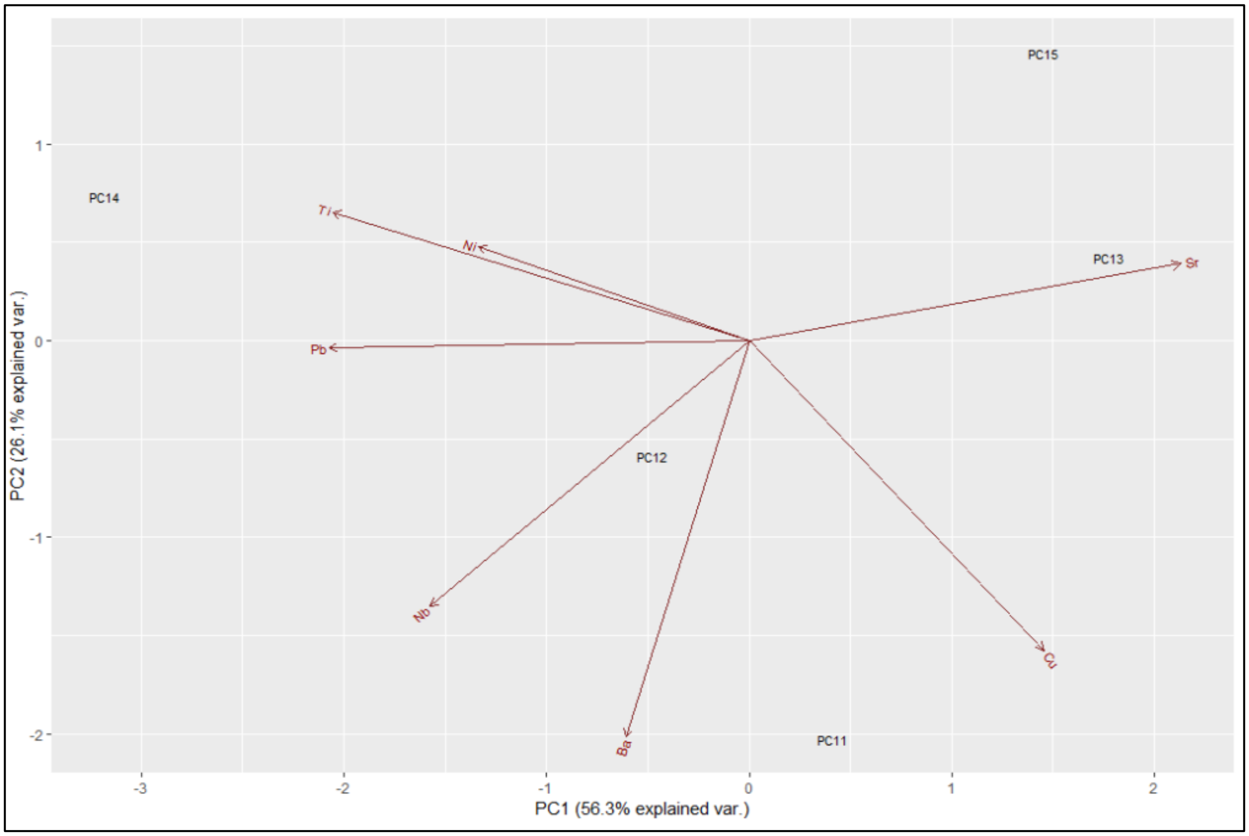


Figure 42. PCA of samples collected from Percy Creek.

Crowe Bay similarly demonstrates a wide distribution, with the analysis accounting for approximately 79% of the variation between samples (Figure 43). *CB18*, which had noticeable efflorescence on the top surface after firing, appears to have higher levels of titanium, and less copper and lead. *CB19* also developed efflorescence during storage, but demonstrates an inverse composition to *CB16*, with higher levels of copper and lead, and less titanium.

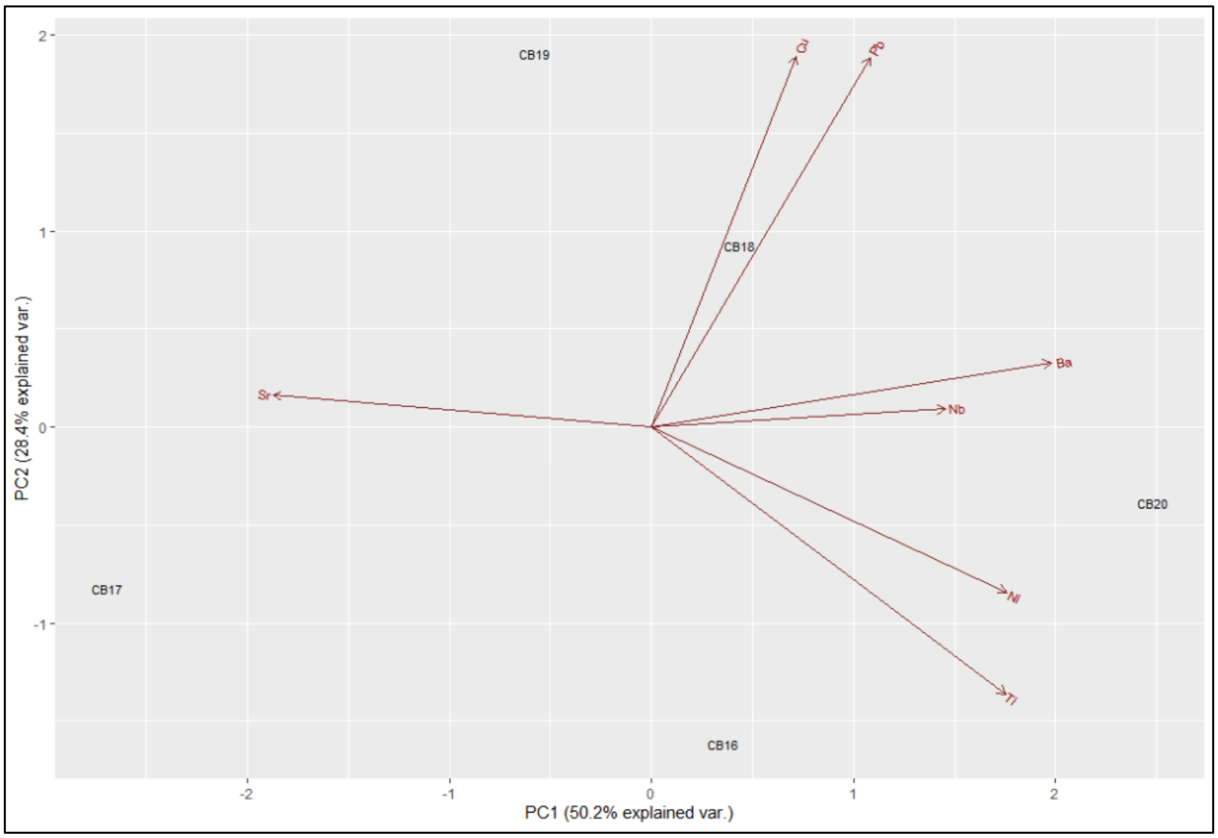


Figure 43. PCA of samples collected from Crowe Bay.

Chapter 6: Discussion

6.1 Introduction

The following chapter discusses the research questions presented in Chapter 1 in the context of the results of the research. It then closes with the conclusion of the thesis and research.

6.2 Answering the Research Questions

6.2.1 Can the sources of archaeological ceramic material be identified?

Hypothetically, yes, the sources could be identified. However, centering the sites from which the materials have been excavated as an origin point assumes an integral relationship between the production of the ceramic and its point of deposition, and applies an assumed cultural framework to this relationship. That is not to say that there is *no* relationship, rather that assuming the bounds of this relationship and relying upon those assumptions may be misleading. There is clearly some kind of relationship between the ceramics excavated from Chiminis-1 and Jacob Island and the source identified at Crowe Bay. This relationship does not correlate with Dean Arnold's (1985) thresholds of resource exploitation, though. I believe this can be tied to an overextension of observed patterns – much of Arnold's work concerned observations of *sedentary* agriculturalists and their resource exploitation. This was not necessarily the incorrect place to begin within the context of the decreased mobility often attributed to Late Woodland communities, however it clearly is not the best framework for future clay and ceramic associated resource exploitation in southern Ontario throughout the Woodland Period.

There are several factors that must be taken into account for any future research framework in this context: firstly, the type of site a deposition may be excavated from. Jacob Island and Chiminis-1 are both situated within a multicomponent and multifunctional landscape which is not guaranteed to have involved ceramic production. There are many burials in the Pigeon Lake area, implying the site may have been of ceremonial significance to those who interacted with the landscape (Conolly 2021:9,10). There are also other occupational components to both sites, implying some period of day-to-day activities and resource exploitation which may not be related to the nearby burials (Conolly 2021:61). These two patterns of behaviour cannot necessarily be disassociated but are also not necessarily inherently associated. That ceramic was excavated from the two sites, and others nearby, does not guarantee that they were produced in that area. It cannot be assumed that the resources associated with archaeological material are inherently associated with their place of deposition. Middle Woodland culture, and particularly those living in and around Pigeon and Rice Lakes, were part of an especially complex mortuary tradition tied to the landscape that existed around the lakes (Walker 2019:133). This tradition likely involved seasonal macroband gatherings for the purpose of burying individuals who had died throughout the previous seasons; given the material behaviours associated with this tradition, it is possible that some of the ceramics excavated from Jacob Island and Chiminis-1 could have been deposited by a microband or community who travelled from Rice Lake to bury their dead (Walker 2019:134, Spence, Pihl, and Murphy 1990:167). This would account for the connection between the Jacob Island and Chiminis-1 pottery and the Crowe Bay clay: that is, indeed, where the clay was sourced from because it was sourced by a community who spent part of the year on or near Rice Lake.

Secondly, post-contact alterations to the environment of southern Ontario are known for having intense ramifications on pre-contact Indigenous archaeology. The construction and continued use of the Trent-Severn Waterway has permanently altered water levels and water courses through damming and the creation of locks and canals, much more than the typical changes to water courses that may be expected through the natural processes associated with waterways. Particularly in the context of Pigeon and Rice Lakes, there are multiple known sites which have been inundated as a result of this process, as well as other sites which have been inundated in the post-glacial period (Conolly and Obie 2021). These changes to the landscape around archaeological sites must be taken into account when considering any resource exploitation that may have relied upon the composition of said landscape; in this context, clay sources and the access to these sources may be altered or rendered inaccessible. The scope of this research did not lend itself to underwater clay collection, which could also be hampered by an unknown amount of silt which could be assumed to have been deposited after inundation of any previously exposed sources.

Thirdly, Arnold's framework relies upon the assumption that each community would source its own materials to produce pottery within the community. This is problematic for two reasons; in part, it assumes that the resources available locally would be exploited by default, and that any flaws or failures presented by these resources would be overlooked for the sake of their proximity. It also assumes that all communities would have produced their own pottery. By the Late Woodland period, it should be safe to assume that most, if not all, communities used pottery and, when travelling, were likely to have transported this pottery with them (source). The existence of pottery within a community, however, does not automatically entail community production of said pottery. Extensive trade networks existed across Turtle Island in both the pre- and post-contact periods, and are known to have transported prestige materials across great distances, from their point of collection to their eventual point of deposition (Stewart 2013:30, Ellis 2013:42, Ferris 2013:107, Ferris 1999:22, Lattanzi 2007:127). One such material is Ramah chert; found in Labrador, the far northeast reaches of what is now Canada, Ramah chert has been found across Ontario, from the Early Woodland period and beyond, and more specifically exists as part of the Late Archaic component at Jacob Island (Brose, Fox and Julig 2021:28, Thor 2021:330, Elaschuk 2015:171). It is possible that the ceramics excavated from the Chiminis-1 and Jacob Island sites were obtained through one of these trade networks, particularly if the clay near the two sites were of low quality and there is no clear evidence of ceramic production at the sites. The material sourced for this research from Point Pleasant was of especially low quality, and though the material sourced from Bear Creek seemed of decent quality, it ultimately carried serious flaws which may have been uneconomical to manage when other materials – raw or finished – may have been available through a local trade network. The clay that was most similar to the pottery excavated at Jacob Island and Chiminis-1 was that collected from Crowe Bay, which was of noticeably higher quality as soon as it was uncovered. After firing, it appeared more similar to archaeological examples in colour and texture, and was more robust than the material collected from the three other sources. If a community relied upon its pottery for food storage, transportation, and production, poor quality clay would be a liability, allowing for the loss or spoiling of food resources and increasing the economic burden associated with those resources. It seems logical, then, to seek higher quality materials, even if these materials may present a higher initial economic burden in the form of trade costs or any output associated with travel. So while Arnold's thresholds are not necessarily inaccurate, they do not adequately account for the agency involved with material quality and the availability and influence of intercommunity contact.

Finally, with regard for clay quality: it is also equally possible that the similarities between the chemical profiles of the ceramics from Jacob Island and Chiminis-1 and the clay sourced near Crowe Bay are owed to the choices made regarding quality. Again, assuming communities only exploit resources within the boundaries of certain thresholds ignores the agency involved with choosing quality materials despite any initial economic burden. It is possible that the similarities in composition found here exist because there was a *type* of clay that was preferred, whose favoured qualities exist because of their chemical composition and that may have existed in more than one deposit across the area of concern. These qualities may have been more practical, such as a clay that was more likely to survive firing, or one that results in a more robust fabric after firing, but they may also have had some more superficial qualities that were preferred, such as colour or texture after firing, or ease of decoration or burnishing. In terms of the clays sourced, the Crowe Bay clay was certainly the best quality; while working, it was very plastic and had a fine-grained texture which made it pleasant and effective to work with. The material sourced from Bear Creek, while it initially seemed to be of moderate quality, had a fatal flaw that I was unprepared for: the fired ceramic material contained something hydrophilic, probably lime, and when left exposed and undisturbed, disintegrated due to its absorption of humidity from its storage environment (Levy 2022:60). Even when mixed with the Crowe Bay clay and being soaked after firing, the resulting fabric was exceedingly delicate, and a small bowl made with the mixed material broke during regular handling. The Point Pleasant and Percy Creek materials, despite demonstrating some plasticity in the field, were of very low quality and the Point Pleasant material did not fire to what one might consider a "typical" ceramic fabric, rather a powdery, Styrofoam-like texture that did not tolerate handling, while the Percy Creek material fired to an even more fragile and less tolerant fabric. These latter two materials, despite their proximity to sites, were wholly impractical and unusable as a ceramic material. The Crowe Bay and Bear Creek materials, however, present an intriguing contrast to each other: both initially promising materials in the field and after firing, the Bear Creek material demonstrated delayed flaws which would have compromised its ability to be effectively used by the community which sourced it. The economic resources expended to source the Bear Creek material would ultimately have been waster due to its flaws, while the resources expended in order to source the Crowe Bay clay, though initially more costly, would have allowed for access to a more reliable and durable material that would expand a community's ability to exploit and store other resources.

6.2.2 Is there variation within clay sources which could affect source identification?

No, I do not believe there is likely to be enough variation within a clay deposit to affect source identification. While there does appear to be *some* variation within the clay sources identified through this research, each source still demonstrated a close relationship with its sample cohort. While the excavated materials demonstrate two fairly broad ranging cohorts with noticeable outliers, the sampled materials appear to be consistent in their compositions, and any potential outliers are still relatively similar to the rest of the samples from that source. It is possible, though, that one may encounter the boundary between two surficial deposits without necessarily recognizing the boundary, and this may influence the results of any chemical analysis. However, assuming a researcher is collecting and recording samples across a large area, it should be apparent in the results that there was a shift between collection points which would indicate this change in deposits.

6.2.3 Do these sources have implications for the cultural patterns of the people who exploited them?

Yes, it does appear that the results of this chemical analysis may have implications for the cultural patterns of Middle and Late Woodland communities in the Pigeon Lake area, however I cannot comfortably extend that to a settled conclusion. A similarity shared between two sites and one source does not a pattern make, and much more extensive research will have to be completed in order to properly assess the extent of clay sourcing in southern Ontario pre-contact cultures. It is possible that the people who occupied Jacob Island and Chiminis-1 sourced their clay from Crowe Bay, a deposit of similar chemical composition to that of Crowe Bay, or that the ceramic deposited at the two sites was collected and manufactured by a community near Crowe Bay, being acquired by another community through trade or deposited at the sites by a Crowe Bay community. With this ambiguity and abundance of options in mind, I do believe that resource exploitation is intrinsically and reciprocally related to the broader cultural patterns of a community, but determining these patterns will not be straightforward. The complicating factors of seasonal mobility and the millennia-old continental trade networks that Woodland communities in what is now Ontario would have had access to mean that we as modern researchers cannot draw one easy line between deposition and exploitation, and that we cannot equate possession to production.

6.2.4 Can cultural patterns be explored through the exploitation of ceramic resources?

Yes, they can. This has been demonstrated across many different cultures and periods, but more specifically, the research completed by Robinson and Conolly (2021) demonstrated a change in composition between the Middle and Late Woodland periods. Through the research done by Robinson and Conolly, it does appear that the shift in the mobility of communities from Middle Woodland seasonal mobility to Late Woodland sedentarism had some effect on the composition of the clay material being sourced by these communities. This could be due to a shift from accessing clay sources near seasonal campsites to accessing sources near more permanent settlement sites, as was assumed as the basis of this paper's research. However, the results of this research did not correspond to the findings of Robinson and Conolly; there was no distinct connection between the sources I identified near the sites and the Late Woodland pottery excavated from them. The two best matches for the Crowe Bay clay, Chimins-1 and Jacob Island, were of Middle and Late Woodland origins, respectively. It is possible that this is not true for every site in southern Ontario, that there are many Late Woodland sites whose occupants only exploited a nearby clay source, and who did not travel or trade for their materials or items. It is also possible that seasonally occupied campsites may demonstrate pottery materials which were obtained from nearby clay sources, and deposited shortly after fabrication at the same campsite, or deposited in subsequent occupations of the same campsite by the same group of people. However, this is not what this research demonstrated and it is necessary or further research to be done in order to explore these patterns, with the understanding that there is unlikely to be one single, simple explanation for which clay resources were exploited, and how and why these resources were exploited by each community.

6.3 Conclusions

As previously stated, this research was concerned with investigating and analysing potential clay sources in the vicinity of four archaeological sites, with the intention of furthering understanding of landscape interactions and resource exploitation in the Middle and Late Woodland Periods.

No previous chemically analysed clay sourcing research has been done in Ontario, though pre-Contact pottery material has long been a focus of archaeological research in the province and throughout northeastern North America. My research has helped to fill this gap, and hopefully establish that clay sourcing is a valuable path of archaeological research in this region. Further chemical analysis and comparison of pottery fabrics and clay sources can help to expand our understanding of the interactions of not only communities within their landscapes, but also potentially the interactions between communities.

This research could be improved by more extensive sample collection and the identification of more potential clay sources, as well as continued chemical analysis of pottery from a breadth of sites throughout southern Ontario. By characterizing the chemical composition of pottery and identifying geographic cohorts, we could explore the behavioural boundaries that may exist around sites and broader cultural areas. This may allow for more intensive clay sourcing, if any potential preferences or common characteristics of the materials is identified through the pottery characterization.

Hopefully this research marks the beginning of continued clay sourcing works in Ontario, especially where the landscapes around identified sites are relatively undisturbed and can be analysed in the most accurate context available.

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Appendix A: McMaster MAX Lab XRF Analytical Protocols

The 21 powdered ceramic samples were run under two analytical protocols at the McMaster Archaeological XRF Lab [MAX Lab] by a Thermo Scientific *ARL Quant'X* EDXRF spectrometer. The spectrometer is equipped with an end window Bremsstrahlung, air cooled, Rh target, 50 watt, X-ray tube with a ≤7.6 µm (0.3 mil) beryllium (Be) window, an X-ray generator that operates from 4 to 50 kV in 1 kV increments (current range, 0-1.98 mA in 0.02 mA increments), and an Edwards RV8 vacuum pump for the analysis of elements below titanium (Ti). Data is acquired with a pulse processor and analogue to digital converter.

The analytical protocols and methods follow those devised by M.S. Shackley (2005, appendix; Poupeau et al., 2010: 2711). In this study, the samples were first run under two analytical conditions. First using a Mid Zb analysis condition with the X-ray tube operated at 30 kV using a 0.05 mm (medium) Pd filter in an air path for 200 seconds livetime to generate X-ray intensity Kα-line data for elements titanium (Ti), manganese (Mn), iron (Fe), nickel (Ni), copper (Cu), zinc (Zn), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), niobium (Nb), lead (Pb) and thorium (Th); as well as a High Zb analysis condition with the X-ray tube operated at 50 kV using a 0.63 mm (thick) Cu filter in an air path to detect the element barium (Ba). This protocol was used to distinguish the major sources in question, however, the samples were then run under a second protocol to obtain the major oxides present in each sample.

This was achieved by analyzing each sample under three analytical conditions. Firstly, under a Low Za analysis with the X-ray tube operated at 4 kV using no filter in a vacuum path for 182 seconds livetime. The second under a Low Zb condition with the X-ray tube operated at 8 kV using a cellulose filter in a vacuum path for 180 seconds. And lastly, under a Low Zc analysis condition with the X-ray tube operated at 12 kV using an aluminum filter in a vacuum path for 180 seconds. These three conditions were used to measure the total weight percentage for the oxides Na_2O, Al_2O_3, K_2O, CaO, TiO_2, MnO_2, and Fe_2O_3 in each sample. This analytical protocol was devised by K. Campeau in the MAX Lab (Carter et al., in press).

Trace element intensities were converted to concentration estimates by employing a least-squares calibration line ratioed to the Compton scatter established for each element from the analysis of international rock standards from the US Geological Service [USGS]. The USGS standard RGM-2 is analyzed during each sample run to check machine calibration and accuracy, with a maximum of 19 samples, plus standard per analysis. Once in Excel form, data is normalized to the standard reference sample, RGM-2, before its interrogation and plotting. This process consists of determining the relative error in the standard measurement and applying this difference to the individual samples analyzed for each tray processed by the instrument. This process ensures that the sample data results are consistently based on the reference, thus providing a more accurate match between chemical fingerprints.

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Appendix B: Analysis Raw Data

Analyse n°1

Sample n°	Ti (ppm)	Mn (ppm)	Fe (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Ba (ppm)	Pb (ppm)	Th (ppm)
0	2389.986	677.726	25775.101	17.151	10.236	43.809	48.560	464.007	33.481	222.142	6.743	656.706	17.113	1.976
6	2374.556	643.634	23922.310	13.387	9.256	41.974	52.618	452.523	28.454	262.125	5.916	726.303	16.403	3.597
7	2445.987	796.237	23100.114	15.312	8.998	45.530	54.926	430.540	29.795	245.107	5.762	779.111	15.892	2.140
8	2515.131	651.990	20188.725	15.551	9.294	39.400	54.897	445.169	30.707	215.062	7.458	767.982	13.883	2.714
9	2240.074	535.950	18533.405	14.834	11.408	49.204	57.871	451.887	26.314	208.510	6.449	705.030	23.544	4.328
10	2161.577	587.525	19597.059	14.565	11.628	42.232	53.558	465.900	25.223	236.387	6.041	733.015	16.615	1.714
11	2687.305	492.519	24336.794	8.854	8.973	40.221	39.876	401.047	22.182	237.505	6.247	702.361	13.298	1.076
12	2691.648	545.069	24519.186	13.470	7.714	50.569	40.977	382.477	20.251	227.272	5.079	700.346	12.817	1.287
13	2495.828	511.710	25908.470	10.686	7.470	36.173	35.195	436.366	19.749	233.295	4.735	635.376	11.035	0.685
14	3652.376	657.210	30840.349	12.462	5.955	53.023	50.245	363.548	26.588	259.487	6.311	642.424	15.479	0.000
15	2751.910	481.396	21334.737	9.853	7.622	42.773	34.425	420.987	25.043	224.183	3.853	574.471	12.566	1.364
RGM-2	1335.577	276.099	10893.284	2.446	10.246	24.445	144.326	104.448	24.721	225.211	9.876	857.551	19.862	13.575

Average	2478.496	571.422	22412.461	12.381	9.067	42.446	55.623	401.575	26.042	233.024	6.206	706.723	15.709	2.871
1-Sigma	524.549	130.813	4928.803	3.986	1.68	7.465	29.07	98.896	4.143	16.345	1.498	75.134	3.454	3.58
% RSD	21.16	22.89	21.99	32.2	18.53	17.59	52.26	24.63	15.91	7.01	24.13	10.63	21.99	124.67
Minimum	1335.577	276.099	10893.284	2.446	5.955	24.445	34.425	104.448	19.749	208.51	3.853	574.471	11.035	0
Maximum	3652.376	796.237	30840.349	17.151	11.628	53.023	144.326	465.9	33.481	262.125	9.876	857.551	23.544	13.575

Analyse n°2

Sample n°	Ti (ppm)	Mn (ppm)	Fe (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Ba (ppm)	Pb (ppm)	Th (ppm)
16	4215.08	564.488	42660.46	22.036	17.639	66.402	82.529	395.353	42.276	283.339	11.408	1111.52	14.048	2.479
17	3726.159	528.47	31717.5	20.497	17.502	64.571	74.279	402.169	40.708	307.101	9.477	1091.287	14.092	3.616
18	3860.03	515.01	30704.36	22.472	29.345	80.715	78.873	378.47	47.234	273.931	10.235	1104.577	15.485	4.338
19	3652.625	477.456	27780.51	19.862	25.834	77.112	73.492	404.07	45.723	331.075	11.162	1113.048	16.064	6.171
20	4336.584	571.969	41007.87	22.929	22.365	81.28	83.42	365.595	43.289	260.8	11.032	1121.554	15.699	1.757
21	15146.675	450.803	23008.61	12.182	31.852	114.6	47.063	260.31	43.978	365.272	14.899	981.215	10.135	3.627
22	18226.696	674.215	41611.7	18.463	29.393	201.245	49.864	269.373	36.752	367.761	14.027	856.066	6.322	0
23	14731.346	386.022	19721.98	8.94	16.001	86.363	48.335	253.278	34.58	331.023	14.025	813.468	9.398	3
24	13632.508	572.587	28764.07	11.012	14.398	127.228	51.603	224.928	35.16	325.11	13.002	846.49	6.203	1
25	10343.941	495.566	49059.45	6.302	51.543	115.122	46.753	149.751	48.843	266.594	8.828	835.943	11.156	0
RGM-2	1360.928	275.72	11371.81	2.831	10.342	25.719	145.954	105.212	23.222	224.783	10.504	875.596	20.557	13.69
Average	8475.689	501.119	31582.57	15.23	24.201	94.578	71.106	291.683	40.16	303.344	11.691	977.342	12.651	3.624
1-Sigma	6015.228	105.934	11240.25	7.196	11.441	45.216	29.123	105.314	7.35	45.393	2.008	132.452	4.43	3.823
% RSD	70.97	21.14	35.59	47.25	47.27	47.81	40.96	36.11	18.3	14.96	17.18	13.55	35.02	105.49
Minimum	1360.928	275.72	11371.81	2.831	10.342	25.719	46.753	105.212	23.222	224.783	8.828	813.468	6.203	0
Maximum	18226.696	674.215	49059.45	22.929	51.543	201.245	145.954	404.07	48.843	367.761	14.899	1121.554	20.557	13.69

Appendix C: Normalized XRF Sample Data

Analyse n°1

Sample n°	Ti (ppm)	Mn (ppm)	Fe (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Ba (ppm)	Pb (ppm)	Th (ppm)
0	2660.954166	670.1190443	30783.56022	28.04742437	9.990240094	59.14080589	49.45969541	479.7866498	32.50451034	218.974757	6.144896719	644.7971631	17.23190011	2.183425414
6	2643.774767	636.4097009	28570.74626	21.89206868	9.033769276	56.66361219	53.59288001	467.9121094	27.62412524	258.3876898	5.391251519	713.1320773	16.51696707	3.974585635
7	2723.304361	787.299849	27588.78619	25.04006541	8.781963693	61.46410309	55.94364148	445.1815257	28.92601432	241.612328	5.2509113	764.9824465	16.00241668	2.364640884
8	2800.287664	644.6719112	24111.67397	25.4309076	9.07085692	53.18879116	55.91410418	460.3080193	29.8114154	211.9957018	6.796476306	754.055262	13.97945826	2.998895028
9	2494.045673	529.9343714	22134.70236	24.25838103	11.13410111	66.42389037	58.94320497	467.2544807	25.54653938	205.5371185	5.876974484	692.2448461	23.70758232	4.782320442
10	2406.648961	580.9304815	23405.03907	23.81847915	11.34881905	57.01190427	54.55029586	481.7440257	24.48735893	233.0166555	5.505164034	719.7223605	16.73044004	1.893922652
11	2991.982143	486.9908511	29065.77024	14.47914963	8.757563927	54.29711597	40.6148026	414.6855469	21.53505117	234.1187153	5.692891859	689.6242463	13.39039372	1.188950276
12	2996.817537	538.9510176	29283.60354	22.02780049	7.528791724	68.26659849	41.73620138	395.4840303	19.66036973	224.0316148	4.628493317	687.6457867	12.90605176	1.422099448
13	2778.796158	505.9664468	30942.84466	17.47506132	7.29065001	48.83244017	35.84707537	451.2056526	19.1730108	229.9687404	4.315006075	623.8539655	11.11167053	0.756906077
14	4066.469482	649.8333207	36833.05608	20.37939493	5.812024205	71.57942319	51.17591425	375.9113051	25.81254804	255.7873017	5.751215067	630.7741557	15.58654718	0
15	3063.91183	475.9926983	25480.37198	16.11283729	7.439000586	57.74223768	35.0628092	435.3036535	24.31260871	220.986657	3.511239368	564.0534289	12.65330782	1.50718232
RGM-2	1487	273	13010	4	10	33	147	108	24	222	9	842	20	15

Analyse n°2

Sample n°	Ti (ppm)	Mn (ppm)	Fe (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Ba (ppm)	Pb (ppm)	Th (ppm)
16	4605.551477	558.9192804	48806.00427	31.13528788	17.05569522	85.20027995	83.12045576	405.8294111	43.69236069	279.8310281	9.774562072	1068.871763	13.66736391	2.716216216
17	4071.338405	523.2566009	36286.62862	28.96079124	16.92322568	82.85092733	74.81133097	412.8260274	42.07182844	303.2988349	8.120049505	1049.415089	13.71017172	3.96201607
18	4217.610785	509.9293849	35127.5408	31.75132462	28.37458905	103.565263	79.43825452	388.4990305	48.81646714	270.539507	8.769516375	1062.195161	15.06542783	4.753104456
19	3990.992451	472.7458581	31782.488	28.06358177	24.97969445	98.94226059	74.01869082	414.7774018	47.25484454	326.9760169	9.563785225	1070.341134	15.6287396	6.761504748
20	4738.311217	566.3264798	46915.34449	32.39703285	21.62541095	104.2902135	84.01784124	375.2828575	44.73929894	257.5710797	9.452399086	1078.520765	15.27362942	1.925127831
21	16549.81434	446.3557921	26323.16029	17.21229248	30.79868497	147.0430421	47.40028365	267.2079231	45.45138231	360.7496296	12.7657083	943.5664736	9.860388189	3.974068663
22	19915.15859	667.5638147	47606.16169	26.08689509	28.42100174	258.2170769	50.22135741	276.5110824	37.98329171	363.2078138	12.01856436	823.2193523	6.150702924	0
23	16096.01059	382.2138619	22563.06985	12.63157895	15.47186231	110.8122011	48.68139962	259.9895829	35.73852381	326.9246607	12.01685072	782.2558075	9.143357494	3.396639883
24	14895.37977	566.9383831	32907.74605	15.55916637	13.92187198	163.2460049	51.9728202	230.8883397	36.33795539	321.0848685	11.14032749	814.0107767	6.034927275	1.184441198
25	11302.17048	490.6772015	56126.82173	8.904274108	49.83852253	147.7128193	47.08806199	153.7192335	50.47937301	263.2933451	7.563975628	803.8684576	10.85372379	0
RGM-2	1487	273	13010	4	10	33	147	108	24	222	9	842	20	15

Appendix D: Normalization RGM-2

Analyse n°1

Tracking	N°	Ti (ppm)	Mn (ppm)	Fe (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Ba (ppm)	Pb (ppm)	Th (ppm)
Standard Analysed	RGM-2	1335.6	276.1	10893.3	2.4	10.2	24.4	144.3	104.4	24.7	225.2	9.9	857.6	19.9	13.6
Standard value.	RGM-2	1487.0	273.0	13010.0	4.0	10.0	33.0	147.0	108.0	24.0	222.0	9.0	842.0	20.0	15.0
	Normalize	1.113	0.989	1.194	1.635	0.976	1.350	1.019	1.034	0.971	0.986	0.911	0.982	1.007	1.105
Verification		1487	273	13010	4	10	33	147	108	24	222	9	842	20	15

Analyse n°2

Tracking	N°	Ti (ppm)	Mn (ppm)	Fe (ppm)	Ni (ppm)	Cu (ppm)	Zn (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Ba (ppm)	Pb (ppm)	Th (ppm)
Standard Analysed	RGM-2	1360.9	275.7	11371.8	2.8	10.3	25.7	146.0	105.2	23.2	224.8	10.5	875.6	20.6	13.7
Standard value.	RGM-2	1487.0	273.0	13010.0	4.0	10.0	33.0	147.0	108.0	24.0	222.0	9.0	842.0	20.0	15.0
	Normalize	1.093	0.990	1.144	1.413	0.967	1.283	1.007	1.026	1.034	0.988	0.857	0.962	0.973	1.096
Verification		1487	273	13010	4	10	33	147	108	24	222	9	842	20	15