A Rocky Road:
Chert Characterization at ST 109, Keatley Creek Site, British Columbia

by

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Abstract

Globally, chert is the most common rock material found in archaeological contexts. Its prevalence on the Earth's surface in Quaternary deposits and relative abundance in archaeological contexts indicate that it was an important resource material for ancient populations and, as such, can provide information about toolstone exploitation in prehistory. The results of this research suggest a local origin for the chert artefacts recovered from ST 109 at the Keatley Creek site (EeRl-7) in the mid-Fraser region of south-central British Columbia, but also to a remote origin for the toolstone deposits found within the study area. Elemental characterization suggests that although the chert deposits in the study area are geographically separate, they are likely derived from a larger parent chert source, redeposited in the mid-Fraser region by glacial activity prior to human occupation of the area. This thesis also demonstrates through the application of the Keatley Creek Lithic Typology that the visible properties of colour and texture are not a reliable means for discerning the provenance of chert artefacts.

Keywords: chert; Keatley Creek; instrumental neutron activation analysis; lithic characterization studies, X-ray fluorescence; *St'át'imc*

This thesis is dedicated to the memory of my grandmother, Adriana Jane Howell, who is deeply loved and dearly missed.

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

AT	Artefact
B.P.	Years Before Present
CV	Coefficient of Variation
EMPA	Electron Microprobe Analysis
GS	Geological Sample
INAA	Instrumental Neutron Activation Analysis
Ma	Million Years Ago
MC	Maiden Creek Deposit
MAX	Maximum Value
MIN	Minimum Value
PCA	Principle Components Analysis
PPM	Parts per Million
pXRF	Portable X-Ray Florescence
SEM	Scanning Electron Microscopy
SFU	Simon Fraser University
ST	Structure
SD	Standard Deviation
UTM	Universal Transverse Mercator
WRGS	White River Group Silicates
XRF	X-Ray Fluorescence

Glossary

Chalcedony	A silica rich (silicon dioxide) variety of quartz that often contains Fe and Al[1]. It is typically identified by the presence of microscopic fibres (Chesterman 1979:504). Chalcedony has a high flakeability value due to its tendency to fracture conchoidally, producing a sharp cutting edge. It is generally opaque to translucent, and fibres are visible macroscopically when light is transmitted through the stone.
Chemical Sedimentary Rock	Chemical sedimentary rocks are formed from aqueous solutions and precipitation from a saline or freshwater solution (i.e., limestone and chert; Chesterman 1979:787).
Chert	A chemical sedimentary rock composed of the silica-oxygen tetrahedron. It commonly occurs in masses ranging in size from nodules to formations reaching thicknesses of 275 m (Chesterman 1979:723). Chert is found in various colours including grey (flint), white, red (jasper), and yellow. When struck by a hammerstone or billet, it produces a sharp cutting edge due to its tendency to fracture or cleave conchoidally.
Clastic Component	Formed as part of the depositional and postdepositional processes that form chert toolstone materials involve biogenic and chemical precipitation, and a clastic component (Bakewell 1995:5). This component consists of silicate minerals in clay, silt, and sand) within cherts. The minerals are stoichiometrically constructed, from major and minor elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, and P).
Flakeability	A quality that refers to the effectiveness in which a rock can be flaked—a rock that has a high flakeability produces flakes when struck at a specific angle. High quality chert materials are very flakeable; they flake predictably and produce a sharp cutting edge. In the mid-Fraser, dacite has also been observed by archaeologists to be highly flakeable, due to its small crystal size and cleavage.
Flint	Generally regarded as a chalcedony of homogenous composition, it is composed almost purely of silica (SiO_2) and water. Flints are commonly referred to as chalcedony in North America, and flint in Europe (Sieveking et al. 1972:151). It is fine-grained, amorphous and crystalline (cryptocrystalline).

[1] Throughout this thesis I refer to elements using standard abbreviations from the periodic table of elements (NRCAN 2013).

Geochemistry	Geochemistry is the study of how the various elements in rocks and minerals are distributed, and of the principles governing these distributions.
Geological Belts	A term used by geologists to identify discriminatory characteristics of bedrock within distinct geographic zones of British Columbia (Mathews and Monger 2010:2-4).
Geological Terranes	A group of rocks so similar in composition, it is likely that they formed and remained as a cohesive unit. Each terrane has a geologic record that is different from adjacent terranes (Mathews and Monger 2010:11).
Inclusions	A piece of one rock unit contained within another (Tarbuck and Lutgens 2002:655).
Instrumental Neutron Activation Analysis (INAA)	The same as Neutron Activation Analysis, but Instrumental Neutron Activation Analysis involves no chemical separations (Harbottle 1982:23).
Lithic/Toolstone Raw Materials	Accumulations of stone on the landscape deposited by glacial recession, fluvial action, or formed as bedrock. Refer also to source definition on page xvii.
Lithology	A description of the physical characteristics of a rock outcrop or sample.
Local Material	Near or associated with the production centre (Harbottle 1982:16). For the purposes of this study, deposits within 10 km from the Keatley Creek site are considered local. This is a manageable distance for procuring raw lithic materials by trade with nearby groups or manual procurement as part of seasonal rounds.
Neutron Activation Analysis (NAA)	A method in which the atomic nucleus provides the characteristic signature of the element to be analyzed (Harbottle 1982:22-23). This technique has been used for archaeometric studies since the 1960s.
Petrographic Studies	Petrographic studies of lithic material use microscopic analysis to identify similarities, some of which include colour, granularity, veins, opaqueness, and inclusions of diagnostic fossil types.
Pisolite	A pisolite is a sedimentary rock that is composed of pisoids (concretionary grains) that are composed primarily of calcium carbonate (Bakewell 1995: 49).

Provenance	In characterization studies this refers to a source, production centre, or origin (Pollard et al. 2007:15). This term is also used to refer to the process of discovering the source of raw materials (Rapp and Hill 1998:134). Provenance studies use elemental data (i.e., major, minor, trace, and rare earth elements) to correlate artefacts to their geologic location on the landscape. These studies use raw material characterization data to compare and correlate artefact samples to geologic samples through multivariate (i.e., principal component or discriminant function) statistical analysis.
Provenience	The observation of a systematic relationship between the chemical composition of an artefact (using trace elements) and the chemical characteristics of one or more of the raw materials involved in its manufacture (Pollard et al. 2007:5).
Toolstone Characterization	Identifying and quantifying elements within a single raw material or artefact sample using high precision instruments. Characterization can apply to both raw materials and artefacts, as long as the object contains a characteristic chemical signal which is unique to a particular material, or unique in terms of the materials context (Pollard et al. 2007:15)
Source	The natural deposit of a material. The location from where people procured raw materials (Harbottle et al. 1982:16; Pollard et al. 2007:15)

Chapter 1.

Chert Material Studies in Archaeology

Lithic materials are a major component of archaeological assemblages worldwide and constitute an important element in the archaeological record, illuminating past histories, lifeways, and technologies. Although much is known about stone tool technology, including manufacture and application, there is comparatively little known about the unmodified toolstone materials[2] used to make tools. The characterization of these materials is the first step in provenance studies, which, in turn, offer important insights into the geologic history and distribution of these materials; insights that are later used to interpret the nature of precontact societies (Hayden et al. 1996; Hayden and Schulting 1997; Malyk-Selivanova 1998). Essentially, characterizing toolstone materials involves identifying the elemental signatures of the rocks, making it possible to connect the physical deposit to lithics excavated from archaeological sites.

Throughout western North America the past use of particular toolstone materials by hunter-gatherer populations has long intrigued archaeologists. The abundance of one particular type of lithic material—chert—in archaeological contexts indicates its importance as a resource for ancestral populations and, as such, provides information on hunter-gatherer toolstone exploitation in prehistory. Specifically, the location of toolstone deposits and their proximity (or not) to settlements provides archaeologists with opportunities to infer the location of hunter-gatherer transportation routes, local and regional knowledge of resources, and exchange between communities (Malyk-Selivanova 1998; Malyk-Selivanova and Ashley 1998).

[2] Toolstone materials are defined as accumulations of flakeable stone on the landscape deposited by glaciers, rivers, or formed as bedrock

Questions about lithic material type, procurement strategies, and toolstone deposits can be addressed through geoarchaeological and archaeometric applications, including macroscopic, microscopic, and elemental analyses. For example, recent advances in geochemical technology have made it possible to connect geologic deposits of unmodified toolstone materials to lithics excavated from archaeological contexts (Shackley 2008). In particular, the development and availability of large-scale nuclear facilities allows for the quantification of selected elements (e.g., rare earth, alkali-earth) from geologic and archaeological samples (Neff and Glascock 1995), the results of which can then be compared using multivariate statistics to ascertain if there is a relationship between the deposits and the archaeological sites. Thus, archaeometric research and facilities make it possible for archaeologists to gain insight into the complexities of toolstone procurement and movement across space and, if archaeological contexts permit, time. Archaeometric studies have value beyond provenance studies as they allow archaeologists to explore the relationships between elemental composition and external appearance—providing a more accurate classification of material type than traditional lithic material analyses, which rely on visual properties to identify and classify lithic toolstone materials.

Research Goals

Lithic materials comprise the majority of archaeological assemblages found within British Columbia's Interior Plateau and constitute an important place within archaeological interpretations of hunter-gatherer history and technology in the region. Although much is known about the manufacture and use of stone tools in the mid-Fraser River region of British Columbia, there is comparatively little known about raw toolstone materials. Characterization of the chert toolstone materials within the mid-Fraser will provide baseline information that may be used in provenance studies to extrapolate on both the use of local toolstone deposits and the potential role toolstone played in the resource access and trade relationships described in the ethnographic record (e.g., Hill-Tout 1905).

My thesis offers an archaeometric case study that characterizes chert deposits in the mid-Fraser region using portable X-ray fluorescence (pXRF) and instrumental neutron activation analysis (INAA). For the purposes of this study, I use the term “chert” to refer to a chemical sedimentary rock that is composed of an oxygen-silicon tetrahedron with a significant clastic component[3].

The primary goal of my research was to characterize known chert toolstone deposits in the study area. A secondary goal was to test the efficacy of using the visual characteristics of colour and texture as a means of identifying chert material types and relating these to toolstone deposits. My final goal was to present a hypothesis for the geological origin of the chert toolstone deposits situated within my study area. These goals changed over the course of this research, along with the original scope of this thesis, which is discussed in more detail in chapter 2.

The south end of the mid-Fraser region is defined by the confluence of the Fraser and Thompson Rivers and the end of the Cascade Range of Mountains (marked by Mount Lytton), and bordered to the north and south by the Fraser and Thompson Plateaus, respectively. The study area is an arid to semi-arid environment with steep river valleys covered by sediments deposited by the Cordilleran ice sheet during the Fraser glaciation (Ryder et al. 1991). The Bridge and Fraser Rivers have carved out the valleys within the mid-Fraser area, creating large relatively flat terraces and benches bordering the two waterways. These landforms, abutting the rivers on one side and the mountains on the other, were ideal for human settlement, as they facilitated access to both water and land-based resources. Hunter-gatherer settlements in the mid-Fraser region were typically composed of a group of pithouses (i.e., timber-framed, semi-subterranean structures overlain with dirt and sod) of varying number, size, and arrangement (Prentiss et al. 2008). The archaeological remains of these structures are generally known as housepits (Hayden 1995). The focus of my study is the Keatley Creek (EeRl-7) site, a large multi-occupation (Plateau to late Kamloops Horizons) housepit village located on a river terrace approximately 25 km north of Lillooet, British Columbia on the east side of the Fraser River (Figure 1).

[3] In general, the term “silicate” typically refers to the most common group of minerals, which are built around the silicon oxygen tetrahedron. This large group includes olivine, pyroxene, amphibole, mica, feldspar, and quartz—all of which contribute to the structure of different types of sedimentary, metamorphic, and igneous rocks (Tarbuck and Lutgens 2002: 51). I use the term to refer only to sedimentary chemical rocks, such as chalcedony and chert.

Keatley Creek is one of the largest settlements within the mid-Fraser region, comprised of 122 housepits, as well as a large number of external storage and roasting pits. It is also one of the most intensively studied archaeological sites in the region[4], along with the Bridge River site (EeRl-4; Figure 1) located on the north side of the Bridge River approximately 10 km to the southwest (Austin 2007; Crossland and McKetta 2008; Prentiss et al. 2005; Prentiss et al. 2012). The longstanding excavations and survey work conducted at Keatley Creek produced a substantial and varied lithic catalogue, containing many different material types and lithic types (Bakewell 1995; Hayden 2000a, 2000b; Muir et al. 2008). Of particular interest to my research is the chert assemblage recovered from ST[5]109 during the 1998 and 2006 field seasons (Muir et al. 2008:26-27; Rousseau 2000).

[4] For additional information on intensively studied archaeological sites within the mid-Fraser region see Bakewell 1995, 2000; Hayden 2000a, 2000b, 2000c, 2004, 2005; Muir et al. 2008; Prentiss 2000; Prentiss et al. 2002; Prentiss et al. 2003; Prentiss et al. 2007; Prentiss et al. 2008; and Sanger 1964, 1966, 1968, and 1969.

[5] Throughout this thesis, I refer to housepit depressions as structures (abbreviated as ST), because, as noted by Morin (2006), the term “housepit” interprets these features as houses, which is not immediately apparent prior to, or even after archaeological investigation. Specifically, I refer to Structure 109 as ST 109.

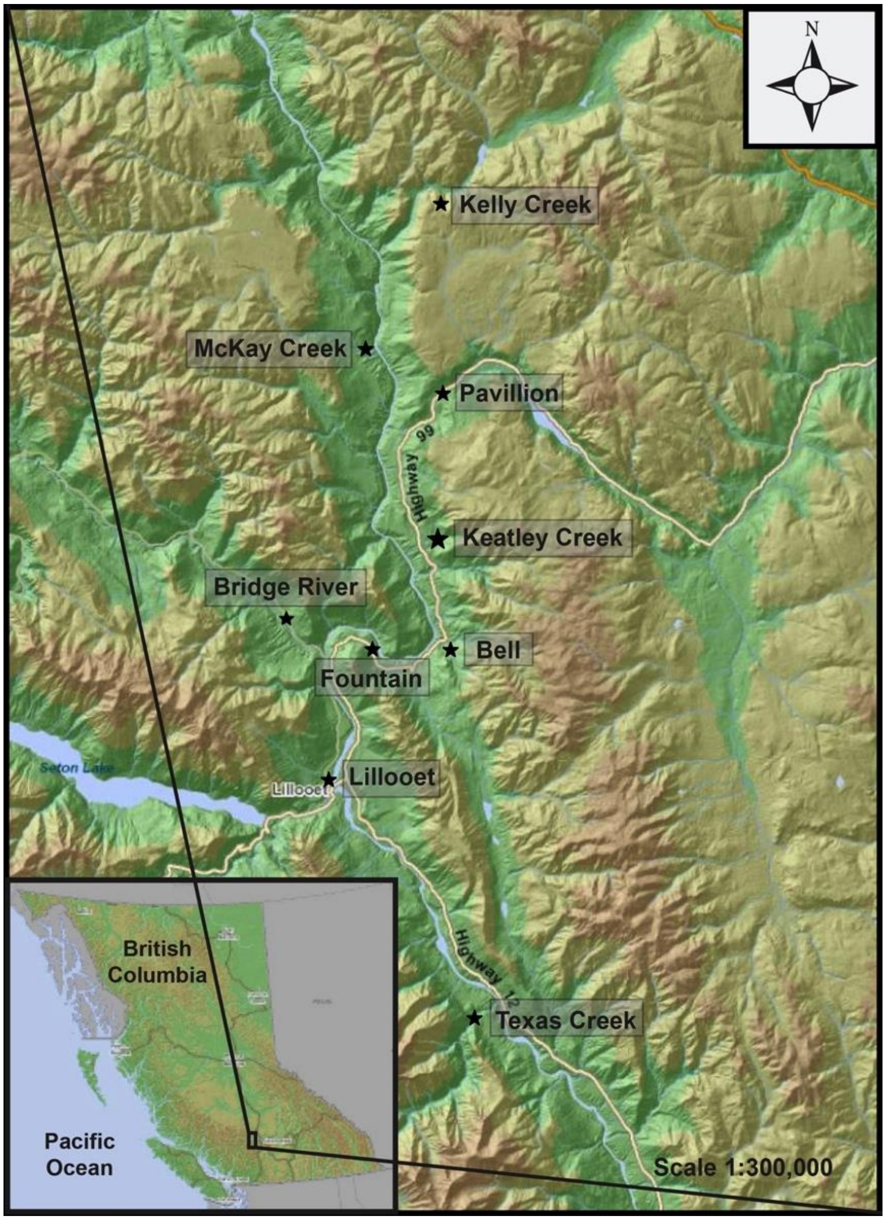

Figure 1. Study area: The location of Keatley Creek in relation to other large village sites. Map created by Chris Springer and used with permission.

Chert Studies in North America

Chert is a very hard, microcryptocrystalline sedimentary rock with morphological qualities that make it attractive for stone tool manufacture. These qualities include its colour, lustre, texture, and most importantly, its tendency to fracture predictably and conchoidally, thereby creating a sharp, durable cutting edge. Globally, chert is the most abundant lithic material found in archaeological assemblages (Malyk-Selivanova 1998:1;

Malyk-Selivanova and Ashley et al. 1998:673), likely due to the aforementioned characteristics.

The abundance of chert in the archaeological record prompted earlier geological and archaeological petrographic studies. In the early 1950s, Robert Folk and Charles Weaver (1952) published one of the first articles on the textures and compositions of chert. Using electron microprobe analysis (EMPA), they identified and defined two types of quartz (chalcedonic and microcrystalline) by measuring the refractive index of the quartz types. Folk's subsequent volume *The Petrology of Sedimentary Rocks* (1980) was a seminal review of critical topics in sedimentary rock identification and classification using grain size, morphology, mineral composition, petrology, and diagenesis.

One of the most significant contributions to geoarchaeological studies of chert and chert deposits is Barbara Luedtke's influential work *An Archaeologist's Guide to Chert and Flint* (1992). In it, she discussed both the archaeological significance of chert as a toolstone material and its mechanical, visual, and elemental properties. Her study also helped introduce and define provenance studies to archaeology, and highlighted their usefulness when analyzing chert materials found in archaeological contexts. Luedtke's research was based on earlier work (e.g., Folk 1980; Folk and Weaver 1952), and strongly influenced by the trace element analysis projects conducted by the University of Michigan's Museum of Anthropology in the 1960s (Neff and Glascock 1995). These projects were undertaken in response to the need for the development of protocols and standards for provenance studies that went beyond simply using the analysis of physical properties of stone tools to connect artefacts with raw material deposits—a problem particularly germane to chert characterization and provenance studies (Luedtke 1992).

The University of Michigan's trace element characterization study analyzed over 6,500 geological and archaeological chert samples between 1970 and 1974 utilizing the University of Missouri's INAA facilities. The Missouri University Research Reactor Center opened in 1966 (Missouri University Research Reactor 2014), and came under the direction of Hector Neff and Michael Glascock (1995) in the early 1970s; it has since grown to be one of the largest centres for archaeometric testing in the world. Using data generated at the Missouri University Research Reactor for the University of Michigan's Museum of Anthropology project, Luedtke (1978) was able to characterize chert deposits in Missouri, Michigan, Ohio, and Indiana.

In addition to her work on chert deposits in the eastern United States, Luedtke (1979) compared petrographic methods with trace element methods and concluded that only elemental analysis was replicable and accurate with the appropriate selection of elements. Luedtke (1979:756) also noted that while concentrations of numerous elements should be measured, only those identified as diagnostic should be included in the statistical analysis.

Due to the heterogeneous nature of chert materials, visual characteristics such as colour are not diagnostic of a single sample or deposit. This was demonstrated in Luedtke's study using INAA to characterize several geological deposits of chert in the Great Lakes region. Although the cherts were similar in appearance, geochemical analysis showed elemental variability within and between the deposits. Thus, visual identification without additional geochemical analysis was demonstrated to be an unreliable technique for connecting chert deposits with chert found in archaeological contexts. The provenance studies by Luedtke (1978, 1979) along with earlier work by Ward (1974), established the framework for standardized techniques and processes that would subsequently be followed and adapted by future researchers. Indeed, the delineation of deposit variation, characterization of each deposit, and comparison of artefacts with characterized deposits are now fundamental to lithic provenance studies in archaeology.

Archaeometrists conducting characterization and provenance studies began to address the problems and limitations inherent in this type of research and its instrumentation in the late 1970s and 1980s. As a consequence, guidelines and protocols were established for raw material collection and laboratory sampling (Luedtke 1992; Ward 1974). Importantly, some researchers began to caution against the growing belief that sourcing studies could provide definitive results with no margin of error (Harbottle 1982:14). Although characterization data are reliable when analyzing homogenous materials, when looking at heterogeneous materials like chert and other silicates, researchers must use a multi-analytical approach that includes petrographic and geochemical analyses. Although instrumental methods have been in use since the 1950s and their precision and accuracy have greatly improved, Harbottle's (1982:14) cautious statement still resonates:

> [W]ith very few exceptions, you cannot unequivocally source anything. What you can do is characterize the object, or better, groups of similar objects found in a site or archaeological zone by mineralogical, thermoluminescent, density, hardness, chemical, and other tests, and also characterize the equivalent source material, if they are available, and look for similarities to generate attributions.

In short, chemical characterization and provenance studies do not provide unequivocal results. However, when projected against an analytical and archaeological background, they provide data with which to test archaeological hypotheses. Also, archaeologists can use geochemical data to determine previously unknown connections between archaeological sites to develop new hypotheses (Harbottle 1982:17).

Many of the studies on the characterization of chert are done as part of larger provenance studies that seek to link archaeological sites to toolstone deposits. These research projects (described below) have largely focused on the study of ribbon or bedrock cherts, which are situated within a primary context[6] and have unique elemental signatures (e.g., the Onondaga chert outcrop in eastern Canada and the United States). Research that focuses solely on the characterization of toolstone deposits is not as common, but is noted in early studies on chert by Luedtke (1978 and 1979).

Following guidelines set out by Harbottle (1982), Luedtke (1978), and Ward (1974), archaeometrists in North America interested in archaeological provenance studies began to intensify their use of instrumental techniques (i.e., EMPA, INAA, and XRF) to collect geochemical data. These techniques provided replicable and precise data with which to characterize siliceous toolstone deposits and correlate siliceous artefacts to deposit areas. Using these techniques, studies were undertaken on the cherts of eastern North America, particularly in the Great Lakes region where chert lithic materials were excavated in abundance from archaeological contexts. The dominance of

[6] I refer to primary context as the location of materials that have remained in the place where they were originally formed.

chert lithic materials at these sites is likely due to their proximity to the Onondaga chert outcrop, one of the largest chert deposits in North America.

Western outcrops of the Onondaga chert formation are located on the Niagara Peninsula in Ontario, Canada, and extend as far south as western New York (Parkins 1977). Hugh Jarvis (1988) used INAA to characterize and correlate chert found in archaeological sites located along the Onondaga escarpment to the nearby Middle Devonian limestone formation of the larger Onondaga chert formation in Buffalo, New York. Using the SLOWPOKE reactor at the University of Toronto, Jarvis (1988) selected a series of major, minor, and trace elements for his analysis: U, Dy, Ba, Ti, Sr, I, Br, Mg, Si, V, K, Al, Mn, Cl, and Ca. He based his sampling and analysis strategies on Ward's (1974:41-42) phases, or steps of correlation. Through this study, artefacts from the French 3, Guenther, and Henry Long archaeological sites were successfully sourced to raw material samples from the Onondaga limestone formation (Jarvis 1988, 1990).

Many of the studies on eastern North American chert deposits were conducted using the SLOWPOKE Reactor at the University of Toronto[7] (see Hawkins et al. 2002; Jarvis 1990; Julig et al. 2002). For example, Julig et al. (1987, 1992, 2002) conducted provenance studies on the Onondaga chert formation and quartzites in the Great Lakes region. Using INAA and a range of elements (U, Dy, Ba, Ti, Sr, Br, Mg, Si, Na, V, K, Al, Mn, Cl, Ca), Julig et al. (1987) successfully correlated artefacts from the Cummins Paleoindian site near Thunder Bay, Ontario to deposits of Hudson's Bay Lowland chert along the Albany and Severn rivers, north of Lake Superior in Southern Ontario.

Rafferty et al. (2007) used energy dispersive X-ray fluorescence (EDXRF) to analyze chert deposits from eastern New York and compare them to chert artefacts from the Pethick site in the Schoharie Valley, New York. The chert toolstone deposits within this area are considered to be part of the Onondaga chert formation, and as part of this research the authors sought to determine the overall chemical heterogeneity of the deposit. Elements used in this study were Ti, Fe, Cu, Zn, Rb, Sr, Zr, Y, Sb, and Ba. The results strongly linked the artefacts to local chert deposits (Rafferty et al. 2007:183).

[7] The University of Toronto SLOWPOKE reactor was decommissioned in 1998.

Hoard et al. (1993) studied the White River Group silicates (WRGS), a large chert group in North Dakota at Sentinel Butte in the north-central United States. The authors hypothesized that ancestral Native American communities procured materials from the WRGS for the manufacture of chipped stone tools. This study distinguished deposits within the White River Group using INAA and discriminant function analysis. The authors successfully identified As, Ce, Co, Cr, Cs, Eu, Fe, La, Nd, Sb, Sm, U, Yb, and Zn as the elements that showed the greatest differences among the deposits within WRGS and sourced the artefacts from two Great Plains archaeological sites to these deposits (Hoard et al. 1993).

The WRGS materials were revisited in 2010 and compared with the lithic assemblage from the Clovis Beach archaeological site. Huckell et al. 2011 successfully sourced the siliceous materials within the lithic assemblage to the Sentinel Butte deposit of the WRGS using INAA. These studies of the WRGS show knowledge of toolstone deposits across the landscape by different groups of people. Long-term provenance projects, which may include the reconsideration and reanalysis of deposit areas, have the ability to link past hunter-gatherer communities to the landscape in a tangible way, and can also reveal previously unknown, ancient trade routes (Huckell et al. 2011).

Research in the western United States has focused on both bedrock and surficial deposits of chert materials. Mierendorf (1993) conducted a study of the Hozomeen chert in the Upper Skagit River Valley in Washington State to determine if local ancestral hunter-gatherers utilized the Desolation chert deposit. By excavating the rockshelter in which the chert deposit is located, he found extensive evidence of quarrying behaviour on the toolstone material. Areas adjacent to the rockshelter also yielded large accumulations of chert debitage. Mierendorf's study on the Hozomeen chert demonstrates how basic archaeological field techniques can be used to explain precontact use of toolstone deposits.

In recent years, other studies have combined petrographic and geochemical techniques to source chert artefacts to toolstone deposits. Petrographic studies of lithic material use microscopic analysis to identify similarities in colour, granularity, veins, opaqueness, and inclusion of diagnostic fossil types. Other examples of this type of analysis include the use of refractive light microscopes, scanning electron microscopy

(SEM), thin sectioning, and EMPA. Petrographic methods typically use visual attributes (especially colour) to identify similar qualities within and between samples. Malyk-Selivanova and Ashley (1998:676) adopted a geological-geochemical approach to chert artefact material correlative studies in northwestern Alaska. Based on this approach, the authors used petrographic (EMPA and X-ray diffraction) and geochemical (INAA) methods to identify signatures unique to the chert samples within their study area. As a result, they were able to determine that a chert artefact produced from material derived from a chert layer is unique/identical to that layer, and contains all its geochemical and petrological features (Malyk-Selivanova and Ashley 1998:677). This study used two main groups of geochemical signatures to discriminate chert deposits and chert artefacts: 1) elements that are indicative of the depositional environment, such as Ce, La, Eu, Sm; and 2) mobile elements that provide diagenetic-metamorphic signatures and signatures that are related to local geochemistry[8] and mineralogical variability (Malyk-Selivanova et al. 1998:680).

Geochemical Analyses of Chert Materials

The examples discussed above show that macroscopic, microscopic, and geochemical analyses of archaeological and geological chert materials have provided valuable insights into precontact hunter-gatherer resource areas and procurement strategies in North America. Identifying specific sites that would have been used by Indigenous peoples as collection areas for lithic materials allows archaeologists to obtain information about the accessibility of these sites, the quality, and size of the available material, and the intended use of the quarried material. These initial studies were primarily interested in chert artefacts and locating toolstone locations on the landscape. Today, archaeologists are using a variety of archaeometric techniques to geochemically characterize regional chert deposits and link these to archaeological sites.

Chert has a heterogeneous composition, meaning its internal and external compositions are inconsistent within and between individual samples. This heterogeneity

[8] Geochemistry is the study of how the various elements in rocks and minerals are distributed, and of the principles governing these distributions.

is a consequence of the clastic matrix[9] embedded within the surrounding silica, of which chert is primarily composed (Bakewell 1995). The clastic matrix is representative of the environment in which individual chert deposits were formed, and is unique to each deposit. For these reasons, geochemical (as opposed to petrographic) analyses for elemental characterization and correlation have a higher potential to connect chert artefacts to their geologic deposit.

Elemental characterization involves identification and quantification of elements within a single sample using high-precision instrumentation, such as XRF, INAA, near-infrared spectrometry, particle induced X-ray emission, and portable infrared mineral analyzers. Despite facilitating a high level of precision in analysis, all of these instruments are restricted by certain limitations (e.g., XRF is restricted by detection limits; high levels of precision for INAA are only possible by the use of powdered samples) and, as such offer varying levels of precision and accuracy that are inversely proportional. Regardless of instrumentation, all geochemical provenance studies use characterization data to compare and correlate artefact samples to geologic samples by applying multivariate statistics to define relationships within a given data set.

The results of elemental studies of chert show varied compositions, which are largely due to the formation processes that produced the rock. The chemical composition of chert is significantly affected by the environment in which it forms; consequently, it is often composed of a mixture of elements and compounds that are manifested in a variety of colours. Because chert rocks have a mixed and irregular internal composition, visual characterization methods typically distinguish one sample from the other using colour and in some instances, fossil inclusions[10]. Research has shown that cherts have high intra- and inter-chemical variation, and geochemical studies have proven that cherts of the same colour can have significantly different geochemistry (Bakewell 1995; Luedtke 1978, 1979, 1992). To address different levels of variation,

[9] The clastic matrix was defined by Bakewell (1995) and refers to the depositional and postdepositional processes that form chert toolstone materials that involve biogenic and chemical precipitation, and a clastic component (Bakewell 1995:5). This component consists of silicate minerals in clay, silt, and sand within cherts. The minerals are stoichiometrically constructed from major and minor elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, and P).

[10] Fossil inclusions refers to the microscopic identification of silica-secreting organisms that are present within cherts as fossils.

elemental characterization and correlative projects are built upon the provenance postulate (Malyk-Selivanova 1998; Neff and Glascock 1995; Pollard and Heron 2008). This postulate explicitly states that linking artefacts to deposits using compositional analysis depends on the supposition “that there exist differences in chemical composition between different natural sources that exceed, in some recognizable way, the differences observed within a given source” (Weigland and Harbottle 1977:24; see also Luedtke 1978:747). Thus, there must be sufficient intra- and inter-variation between and within deposits to both successfully differentiate geologic deposits in a given geographic region and to accurately connect artefacts to the geologic deposits.

The provenance postulate can be used to explain how archaeologists have been successful in characterizing and sourcing artefacts to specific outcrops within the large ribbon chert deposits in Eastern Canada and the United States. The Onondaga and WRGS deposits are large, continuous deposits of chert with exposures (outcrops) that exhibit enough inter-variation within the overall deposit to be distinguished from each other.

Thesis Outline

In this chapter, I have presented my research goals, introduced my study area, and provided a review of the history of North American studies of chert materials. Chapter 2 details the methods, sampling strategy, and the instrumentation used for this study (i.e., pXRF and INAA). In Chapter 3, I describe the physical and elemental properties of cherts, along with a detailed description of chert formation processes. Chapter 4 provides the archaeological and geological background information about the Keatley Creek site and the study area. The results of my elemental analysis (pXRF and INAA) are presented in Chapters 5 and 6, respectively. Finally, I summarize the findings and interpretations of my research in Chapter 7 and discuss the problems and limitations of elemental chert characterization and provenance studies within broader archaeological contexts.

Chapter 2.

Methods

A significant part of my research focused on characterizing the chert toolstone materials within the mid-Fraser region, and the chert artefacts excavated from ST 109, as stated in research goal one. To accomplish this, I used geochemical methods to characterize the chert materials by quantifying the elements that make up their internal composition. Elemental quantification was accomplished using two well-defined methods in archaeological provenance and characterization studies—pXRF and INAA. In this chapter, I describe the geochemical instrumentation, the application of the Keatley Creek Lithic Typology, my toolstone and artefact sampling strategy, and the statistical analyses used for this study. However, before outlining the above methods, I begin the chapter with a description about the changes in my research orientation, during the course of this study.

Changes in Research Orientation

The original intent of my research was to determine the geologic provenance of the chert artefacts excavated from Structure 109 (ST 109), at the Keatley Creek site (EeRl-7). Given several well-documented complications of chert characterization (i.e., Luedtke 1978, 1979 and 1994; Malyk-Selivanova 1998), I initially selected a sample of 51 chert and chalcedony artefacts and 22 toolstone samples for INAA testing (the chalcedony artefacts were included because many of the material types classified as chalcedony using the Keatley Creek Lithic Typology were later reassigned as chert [Bakewell 1995]).

The preliminary results of the INAA were inconclusive in terms of characterizing each chert toolstone deposit. The elemental data revealed that the sampled toolstone deposits do not have enough inter-elemental variation to characterize each deposit individually with a restricted number of samples. In light of these results, McMaster University Reactor staff provided additional elemental data but the results using these data were also inconclusive. Given the high cost of INAA, increasing the sample size for additional INAA testing was not possible. However, the preliminary study indicated that (1) the toolstone deposits have remarkably similar elemental composition and lack adequate elemental variation, which suggested that (2) these deposits were likely part of a much larger parent deposit.

Based on the inconclusive results, I revised the scope of my research to focus on characterizing the toolstone deposits and reduced focus on artefact provenance. I identified XRF technology as a supplement to INAA testing, as pXRF facilities became available at Simon Fraser University (SFU) soon after I received the preliminary INAA results from McMaster University Reactor. The availability and affordability of the pXRF to students at SFU also allowed me to increase the sample size of the toolstone deposit analysis. I analyzed 42 toolstone deposit samples and 19 artefact samples using pXRF. Although the focus is on geologic samples, my analysis of artefacts is included in this thesis to both illustrate the complexities of chert provenance studies and to highlight issues associated with the Keatley Creek Lithic Typology (Hayden 2004; see Appendix A for the typology); specifically, its use of colour and texture to identify relationships between archaeological and geological deposits of chert materials in the mid-Fraser region.

The Keatley Creek Lithic Typology

The Keatley Creek Lithic Typology was developed to address three specific problems using stone artefacts: 1) the relative age and contemporaneity of archaeological material excavated at Keatley Creek; 2) the relative wealth of the residents within different structures; and 3) the organization of activities and social groups within structures (Hayden and Spafford 2004:1).

In *The Ancient Past of Keatley Creek Volume III* (2004), Hayden and Spafford provide a detailed rationale for the functional categorization of lithic tools, but do not offer an equivalent explanation for the use of colour to define chert material types. Instead, the chert types listed by colour are directly associated with the petrographic textural categorizations defined by Bakewell (1995), which were incorporated into the Keatley Creek Lithic Typology. The typology lists nine chert material types, and 20 chalcedony types, based on the visual characteristics. My second research goal was to test the efficacy of this means of chert classification. To do this, I assigned the Keatley Creek Lithic Typology material types to all of the artefacts sent for geochemical analysis.

Sampling Strategies

Sampling for this research involved two components, field and laboratory sampling of both the toolstone deposits and the artefact assemblage excavated from the Kamloops Horizon deposits of ST 109. All of these samples were chosen for elemental analysis using pXRF and INAA. Samples were selected based on a number of criteria specific to the technique used for analysis, affordability, and access.

To be consistent with current archaeometric studies, my sampling strategy followed Shackley's protocols (2008:197-198), which are an expansion of earlier guidelines outlined by Luedtke (1992) and Ward (1974). These protocols divide the study into eight steps: 1) detecting a number of unknown sources from archaeological contexts; 2) consulting the geologic literature; 3) consulting with local residents, archaeologists, "rockhounds," and rockhound guides; 4) surveying deposits and surrounding terrain; 5) recording of the geologic setting; 6) determining which geochemical techniques are worth pursuing; 7) connecting the artefacts to the deposits; and 8) incorporating the precise locations of the deposits in the form of grid coordinates (UTM or latitude/longitude).

Field Sampling: Toolstone Deposits

The mid-Fraser region has significant Neogene and Quaternary chert deposits, which are found in secondary contexts. These deposits are situated on the east side of the Fraser River (a major travel corridor), within a single day's travel of the Keatley Creek archaeological site (Figure 2). I used geological samples collected from six deposits as a part of this case study: 1) Ashcroft Blue; 2) Glen Fraser; 3) Maiden Creek; 4) Hat Creek (Lower Medicine Creek and Hat Creek); 5) Rusty Creek Red; and 6) West Fountain deposits.

Following Shackley's protocols, chert deposits were selected for sampling after reviewing the extensive work done by the Geological Survey of Canada (Duffel and McTaggart 1951; Monger and McMillan 1984), consulting archaeological literature (Austin 2007; Crossland and McKetta 2008; Rousseau 2000; Rousseau, pers. comm. 2009) and "rockhounds" (Hudson 2006), and conducting pedestrian survey and vehicle reconnaissance of the mid-Fraser region. At each deposit area, I collected samples in ten-meter intervals running north-south across the extent of the deposit. Each sample was placed in a labelled paper bag within a larger plastic Ziploc freezer bag. At each deposit, two to three GPS points were recorded using a Magellan Explorist 500 GPS unit at the deposit boundaries and one in the centre. Five to ten photographs were taken of each deposit with a Pentax digital camera. All aspects of my sampling protocol—sample collection, photography, provenience, and recording environmental and geologic context—were recorded on a form during in-field toolstone deposit sampling (see Appendix B).

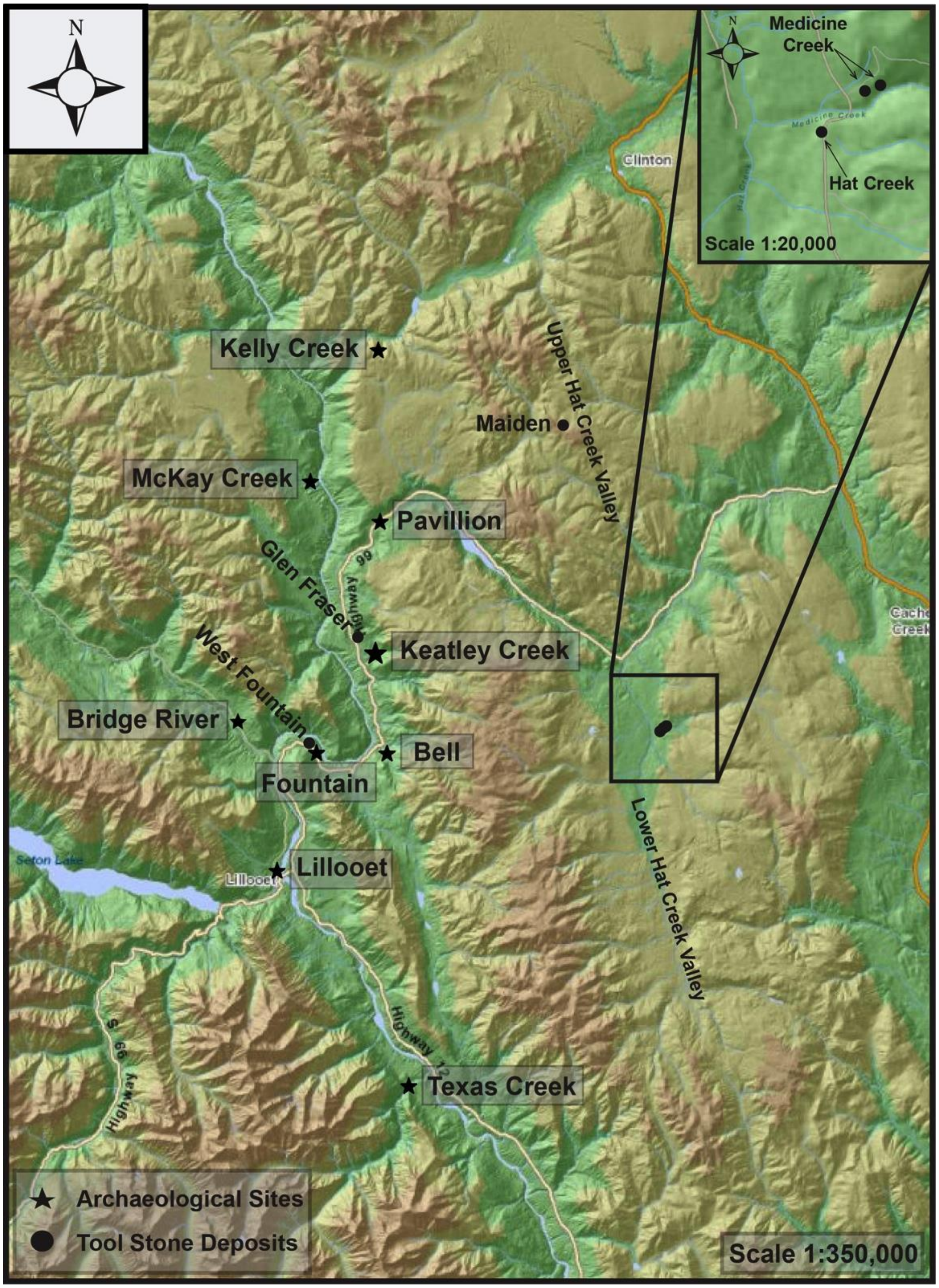

Figure 2. **Siliceous Toolstone Deposits of the mid-Fraser Region.** Map was created by Chris Springer using the location data (UTM coordinates) collected by the author. Map used with permission.

Field sampling of the Hat Creek Valley, Maiden Creek Valley, and Rusty Creek Red deposits was limited by the availability of the material present at the source locations. These deposits are well known to local rockhounds and collectors, and archaeologists have documented the exploitation of these deposits in the past (Pike 1975). To increase the variety of samples from these deposits, I used the collection of materials provided to SFU by Rousseau, and materials provided from Rousseau's private collection collected during the Fraser River Corporate Group Project.

Samples for INAA were largely dependent on the availability of the toolstone material at the given deposit. Once each sample was reduced to approximately 1g using an antler billet, they were placed in a Ziploc bag, labelled, and sent to McMaster University Reactor for analysis. In total, I sent 22 geological samples from six chert toolstone deposits for analysis. Geological samples for XRF were chosen based on their morphology and size. In total, I analysed 42 samples from six chert toolstone deposits (Table 1). As with the INAA samples, the XRF samples were reduced using an antler billet so that each prepared sample would both cover the X-ray window and fit within the lead-lined cap.

Geological samples were coded with the abbreviation GS, followed by an abbreviation for the deposit name (see Table 2). The final sequence of numbers delineated the sample's position in the sequence that it was tested; the lowercase letter at the end of the code indicates the run of the sample. The run is only present in pXRF samples because each sample was tested three to five times on different spots of the sample to test for intra-sample variation. The results of intra-sample testing are discussed in Chapter 5. INAA samples follow the same coding, with the exclusion of runs. All INAA samples were tested once; when a sample is irradiated it is no longer viable for future testing.

Table 1. Geologic Sample Coding for pXRF.

Deposit	Deposit Abbreviation	Sample number	Run
Ashcroft Blue	AB	01-06	a, b, or c
Glen Fraser	GF	01-10	a, b, or c
Hat Creek	HC	01-06	a, b, c, d, or e
Maiden Creek	MC	01-10	a, b, or c
Rusty Creek Red	RR	01-10	a, b, or c
West Fountain	WF	01-06	a, b, c, d, or e

Laboratory Sampling: Artefacts

I assessed 1,606 pieces of debitage excavated from ST 109 and selected 51 artefacts for INAA analysis based on weight, material type, and archaeological provenience (Table 2). Weight was measured in grams using a calibrated Ohaus Scout PRO portable scale, and was recorded to determine which samples exceeded 1g, making them viable for INAA testing. Of these artefacts, 778 were classified as chert, and 348 were classified as chalcedony; however, due to the 1g weight requirement for INAA, only 201 chert and chalcedony artefacts were suitable for INAA. Based on these counts my sample is equivalent to 25% of the viable chert and chalcedony artefacts.

Nineteen artefacts were selected for pXRF analysis. I chose these artefacts based on their morphology and archaeological context (focusing on the potential floor and construction fill strata with some consideration of the sub-floor and roof strata; see Table 2). The morphology of a given sample is important to consider when using pXRF, as the X-ray can only attenuate with the sample when it lies flat on the window. Similar to INAA, I found that many of the small debitage pieces were too small and thin for the XRF to produce reliable results. Samples that are too small and thin create backscatter from the X-rays rebounding off the instrumentation.

For the artefact analysis, I focused on sampling chert material types identified using Hayden's (2004) Keatley Creek Lithic Typology to determine if artefacts classified as jaspers (Chert 2) showed a confident relationship to the jasper deposits (e.g., the Hat Creek Valley and Maiden Creek Valley deposits). Finally, I selected chert material types that were not represented in the samples sent for INAA; in particular, I included

Chalcedony 17, Chert 5, and Chert 6 artefact samples. Selection of the samples was limited because the optimal artefact samples were previously sent to McMaster University Reactor for INAA.

Artefacts were coded with the abbreviation AT, followed by an abbreviation referring to the visual identification of raw material type—CH for chert and CA for chalcedony (Table 2). The final sequence of numbers delineated the artefact's number in the order it was initially catalogued and bagged. Table 2 shows the provenience and coding for all of the artefact samples (N=70) analyzed using INAA and pXRF. As shown, most of the artefacts sampled were excavated from the construction fill (N=31); with the remainder coming from undefined strata (N=6), and floor (N=12), rim (N=5), surface (N=7), feature (N=7), and roof (N=2) deposits.

The artefact samples for both INAA and pXRF testing represent a sub-sample of the 1,606 pieces of lithic debitage that I analyzed for material type and weight. Additional debitage analysis was done following the guidelines given by Andrefsky (2001, 2010). Refer to Appendix C, worksheet 1 for the complete lithic analysis catalogue.

Table 2. Provenience of Artefacts Selected for Geochemical Analysis.

Sample	Bag Number	Provenience					Analysis Used
		Square	Subsquare	Level	Stratum	Stratum Type	
AT01		B	6	1	IV	Construction fill	XRF
AT02		B	8	1	IV	Construction fill	XRF
AT03		B	12	1	IV	Construction fill	XRF
AT04		B	11	2	IV	Construction fill	XRF
AT05		B	3	4	IV	Construction fill	XRF
AT06		A	8	1	XIV	Possible floor	XRF
AT07		A	8	1	XIV	Possible floor	XRF
AT08		A	8	1	XIV	Possible floor	XRF
AT09		B	3	1	IV	Construction fill	XRF
AT10		B	8	1	IV	Construction fill	XRF
AT11		B	8	1	IV	Construction fill	XRF
AT12		B	8	1	IV	Construction fill	XRF
AT13		K	9	2	II	Roof surface	XRF
AT14		E	9	3	IV	Construction fill	XRF
AT15		B	6	2	III	Sub floor	XRF

Sample	Bag Number	Provenience					Analysis Used
		Square	Subsquare	Level	Stratum	Stratum Type	
AT16		B	6	2	III	Sub floor	XRF
AT17		B	4	4	F.U.1	Pit fill	XRF
AT18		E	13	5	IV	Construction fill	XRF
AT19		O	12	1	III	Floor	XRF
ATCA602	478	A	16	3	II	Undefined	INAA
ATCH606	477	A	16	2	II	Undefined	INAA
ATCA606	941	E	5	3	IV	Construction fill	INAA
ATCA707	711	A	2	1	IV	Construction fill	INAA
ATCA1708	711	A	2	1	IV	Construction fill	INAA
ATCA210	316	A	12	1	III	Floor	INAA
ATCA2111	300	G	2	2	III	Floor	INAA
ATCA713	758	A	3	1	FU1	F98-3 hearth	INAA
ATCA616	779	A	2	2	IV	Construction fill	INAA
ATCH219	733	A	3	3	IV	Construction fill	INAA
ATCH1008	353	A	12 +16	?	II	Undefined	INAA
ATCA1103	55	F	1	1	XII	Rim	INAA
ATCA1704	566	A	4	3	V	Construction fill	INAA
ATCA305	938	A	7	1	IV	Construction fill	INAA
ATCA2114	758	A	3	1	FU1	F98-3 hearth	INAA
ATCH205	604	K	13	1	I	Surface	INAA
ATCH624	437	A	6	2	III	Surface	INAA
ATCH232	713	A	2	1	IV	Construction fill	INAA
ATCH1025	578	G	11	1	II	Roof	INAA
ATCH1028	778	A	2	3	IV	Construction fill	INAA
ATCH207	353	A	12 +16	1	II	Undefined	INAA
ATCH213	418	C	14	FU2	F98-4	FU2	INAA
ATCA1015	892	A	6	1	IV	Construction fill	INAA
ATCH201	479	G	14	1	I	Surface	INAA
ATCH211	25	F	9	1	XI	Rim	INAA
ATCH514	933	A	4	6	IV	Construction fill	INAA
ATCH215	1010	E	13	2	IV	Construction fill	INAA
ATCH616	1010	E	13	2	IV	Construction fill	INAA
ATCH217	566	A	4	3	IV	Construction fill	INAA
ATCH202	706	C	6	3	I	Surface	INAA
ATCH903	286	A	10	1	I	Surface	INAA

Sample	Bag Number	Provenience					Analysis Used
		Square	Subsquare	Level	Stratum	Stratum Type	
ATCH229	778	A	2	3	IV	Construction fill	INAA
ATCA619	713	A	2	1	IV	Construction fill	INAA
ATCH227	892	A	6	1	IV	Construction fill	INAA
ATCH1409	478	A	16	3	II	Undefined	INAA
ATCH212	417A	C	14	FU2	F98-4	FU2	INAA
ATCA1709					III	Floor	INAA
ATCA1001	101	C	16	1	I	Surface	INAA
ATCH210	909	L	14		XIII	rim	INAA
ATCH218	566	A	4	3	V	Construction fill	INAA
ATCH220	627	A	7	1	III	Floor	INAA
ATCH204	286	A	10	1	I	Surface	INAA
ATCH221	623	A	4	2	III	floor	INAA
ATCH223	788	C	6	2	II	roof/rim slump	INAA
ATCH226	299	C	15	FU2	PIT	F98-4	INAA
ATCH230	786	C	6	3	II	roof/rim slump	INAA
ATCH634	713	A	2	1	IV	Construction fill	INAA
ATCH233	1010	E	13	2	IV	Construction fill	INAA
ATCA2112	758	A	3	1	FU1	F98-3 hearth	INAA
ATCH231	353	A	12 +16	1	EHPE-06-1	undefined	INAA
ATCH522	529	A	8	1	III	Floor	INAA

Archaeological, Geological, and Archaeometric Analysis

In this section, I describe in detail the techniques employed in the analysis of both the artefact and toolstone samples used for this characterization case study of chert artefacts from ST 109 and chert toolstone deposits within the mid-Fraser region.

Artefact Laboratory Analysis

I analyzed the lithic material excavated from ST 109 looking for traits used in previous studies conducted by Hayden (2000a) and Bakewell (1995, 2000), including material type and weight. Details of the lithic analysis are provided in Appendix C: worksheet 1. I classified material type using the Keatley Creek Lithic Typology to compare the colour-based identifications with the results of the elemental analysis. If the colour-based identifications show a relationship to the artefacts elemental composition, the artefacts of similar colour or type should cluster together. Table 3 shows the artefact samples and their assigned material type using the Keatley Creek Typology.

All of the chert artefacts that I analyzed exhibited characteristics indicative of annealing[11], including small surficial cracks (crazing), potlidding, and a bright, matte lustre. It is important to recognize the use of annealing on raw material, as the effect of this process/treatment on the internal composition of cherts remains unknown. In addition to the evidence for annealing, many of the specimens showed lipping on the platform, tapered ends, and were small-sized, traits typically derived from pressure or billet flaking.

Table 3. Artefacts Sample Visual Material Type Identifications

Sample Number	Hayden Material Type	Bakewell Material Types
AT01	Chalcedony 7 (white translucent)	Chalcedony
AT02	Chalcedony 7 (white translucent)	Chalcedony
AT03	Chalcedony 3 (mustard yellow)	Jasper
AT04	Unknown material type – not included in typology	Unknown
AT05	Chalcedony 7 (white translucent)	Vitric Tuff
AT06	Chalcedony 1 (light grey)	Vitric Tuff
AT07	Chert 5 (medium brown)	Jasper
AT08	Chalcedony 17 (mottled red and yellow)	Jasper
AT09	Chalcedony 1 (light grey)	Vitric Tuff
AT10	Chert 2 (reddish-brown)	Jasper
AT11	Chert 2 (reddish-brown)	Jasper
AT12	Chert 6 (medium yellow)	Jasper
AT13	Chert 5 (medium-brown)	Jasper
AT14	Chert 2 (reddish-brown)	Jasper
AT15	Chert 2 (reddish-brown)	Jasper
AT16	Chalcedony 17 (mottled red and yellow)	Jasper
AT17	Unknown material type – not included in typology	Unknown
AT18	Chert 2 (reddish-brown)	Jasper
AT19	Unknown material type – not included in typology	Unknown
ATCA602	Chalcedony 6 (light pink)	Pisolite
ATCH606	Chert 2 (reddish-brown)	Jasper

[11] The term annealing refers to the process of heating toolstone materials in a fire to improve their quality for flintknapping (Domanski et al. 2009).

Sample Number	Hayden Material Type	Bakewell Material Types
ATCA606	Chalcedony 6 (light pink)	Pisolite
ATCA707	Chalcedony 7 (white translucent)	Chalcedony
ATCA1708	Chalcedony 17 (mottled red and yellow)	Jasper
ATCA210	Chalcedony 2 (white opaque)	Vitric Tuff
ATCA2111	Chalcedony 2 (white opaque)	Vitric Tuff
ATCA713	Chalcedony 7 (white translucent)	Chalcedony
ATCA616	Chalcedony 6 (light pink)	Pisolite
ATCH219	Chert 2 (reddish-brown)	Jasper
ATCH1008	Unknown material type – not included in typology	Unknown
ATCA1103	Chalcedony 11 (light yellow and gray)	Pisolite
ATCA1704	Chalcedony 17 (mottled red and yellow)	Jasper
ATCA305	Chalcedony 3 (mustard yellow)	Jasper
ATCA2114	Unknown material type – not included in typology	Unknown
ATCH205	Chert 2 (reddish-brown)	Jasper
ATCH624	Chert 6 (medium yellow)	Jasper
ATCH232	Chert 2 (reddish-brown)	Jasper
ATCH1025	Unknown material type – not included in typology	Jasper
ATCH1028	Unknown material type – not included in typology	Jasper
ATCH207	Chert 2 (reddish-brown)	Jasper
ATCH213	Chert 2 (reddish-brown)	Jasper
ATCA1015	Chalcedony 10	Unknown
ATCH201	Chert 2 (reddish-brown)	Jasper
ATCH211	Chert 2 (reddish-brown)	Jasper
ATCH514	Chert 5 (medium-brown)	Jasper
ATCH215	Chert 2 (reddish-brown)	Jasper
ATCH616	Chert 6 (medium yellow)	Jasper
ATCH217	Chert 2 (reddish-brown)	Jasper
ATCH202	Chert 2 (reddish-brown)	Jasper
ATCH903	Chert 2 (reddish-brown)	Jasper
ATCH229	Chert 2 (reddish-brown)	Jasper
ATCA619	Chalcedony 6 (light pink)	Pisolite
ATCH227	Chert 2 (reddish-brown)	Jasper
ATCH1409	Unknown material type – not included in typology	Unknown
ATCH212	Chert 2 (reddish-brown)	Jasper
ATCA1709	Chalcedony 17 (mottled red and yellow)	Jasper
ATCA1001	Chalcedony 10 (white translucent)	Unknown

Sample Number	Hayden Material Type	Bakewell Material Types
ATCH210	Chert 2 (reddish-brown)	Jasper
ATCH218	Chert 2 (reddish-brown)	Jasper
ATCH220	Chert 2 (reddish-brown)	Jasper
ATCH204	Chert 2 (reddish-brown)	Jasper
ATCH221	Chert 2 (reddish-brown)	Jasper
ATCH223	Chert 2 (reddish-brown)	Jasper
ATCH226	Chert 2 (reddish-brown)	Jasper
ATCH230	Chert 2 (reddish-brown)	Jasper
ATCH634	Chert 6 (medium yellow)	Jasper
ATCH233	Chert 2 (reddish-brown)	Jasper
ATCA2112	Unknown material type – not included in typology	Unknown
ATCH231	Chert 2 (reddish-brown)	Jasper
ATCH522	Chert 5 (medium brown)	Jasper

Elemental Analysis

Two types of instrumentation were used for elemental analysis: 1) pXRF; and 2) INAA. Both of these methods were chosen for their precision, availability, and well-documented use in previous characterization and provenance studies (see Huckell et al. 2011; Jarvis 1988; Malyk-Selivanova 1998; Shackley 2011). These techniques are used by archaeometrists to charaterize lithic materials and to link the artefacts to sources through their elemental signatures. Both have been highly successful for determining prehistoric trade routes, especially for obsidian, as obsidian sources are relatively easily differentiated from one another through their chemical compositions (e.g., Braswell et al. 2000; Glascock 2004). With respect to chert, quantifying trace elements helps to determine the original sources of the sediments that make-up chert toolstone deposits, the environmental conditions in which chert occurs, and any post-depositional influences that may have affected the rock. The proportions in which elements are found are specific to each formation or part of a formation, but some degree of intra-formational variation should be expected because the formation or depositional processes may have changed over time. The following sections explain how pXRF and INAA work and their application to my study.

X-Ray Fluorescence (XRF)

As discussed, XRF is a technique used to quantify elements present within a single sample using X-rays. It has been used successfully in many studies involving volcanic rocks, particularly basaltic and obsidian materials. X-ray fluorescence technology has not been as widely used for chert materials, as it cannot detect rare-earth elements, which are considered necessary for chert characterization; however, XRF can detect a number of trace, major, and minor elements which are useful indicators of environmental conditions (Malyk-Selvanova 1998).

Simply put, XRF quantifies elemental composition by targeting electrons with X-rays. Basically, all atoms possess five electron shells: K (the innermost), L, M, N, and O, with the closest having stronger bonds. When an X-ray contacts an electron and its energy is sufficient to destabilize it, the innermost electron is dislodged and is then replaced by an outer shell electron. These phenomena cause a measurable release of energy, known as the photoelectric effect (Shackley 2011:17). Since the energy level of each element is known and permanent, the amount of fluorescence is equivalent to an element's composition within a sample. In XRF, this known reaction informs the instrument operator what energy settings are required to knock shell electrons out of their respective orbits to accurately quantify elemental compositions.

In spite of its ability to detect a number of trace, major, and minor elements, XRF has limitations, including physical sample size and detection limits. For optimum results, samples should be greater than 10 mm in smallest dimension, and greater than 2 mm thick (Shackley 2011:9). In terms of detection limits, XRF is limited to a subset of the mid-*Z*[12] X-ray region of elements (atomic numbers 13–92), and often cannot provide compositions for most rare earth elements (Shackley 2011:10). These detection limits significantly affect the ability of XRF to characterize heterogeneous toolstone materials. Especially since rare-earth elements such as Sm, Eu, Ce, and U are considered to be indicative of environmental conditions (Malyk-Selivanova 1998:680).

[12] In XRF studies, mid-*z* elements range from atomic number (*z*) 19 to atomic number 41 (Shackley 2011:24).

For my analysis, I used a Bruker Tracer III-V+ pXRF at the SFU Department of Archaeology for elemental data acquisition. Each of the geological samples analyzed was tested on three sides to aid in the determination of intra-sample variation. All samples were subjected to X-rays for three minutes at 40 KeV and 1.4 micro amps. The instrument was also equipped with a vacuum system without a filter in order to facilitate the broadest range of elemental data. I identified the following elements as useful for my analysis: Si, S, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Rb, Sr, Y, Zr, and La. The morphology of the samples was also considered during analysis; where possible flat sections of each sample were placed on the instrument window as flat surfaces facilitate the reliable attenuation of the X-rays.

The data generated by the pXRF analysis, transferred from the acquisition program S1PXRF, were converted into a text file readable by the data analysis program ARTAX. ARTAX is used to select peaks and then measure raw photon counts within each element per sample. Cumulative results, exported to Microsoft Excel, are provided in Appendix C: worksheets 2 and 3.

Instrumental Neutron Activation Analysis

Instrumental neutron activation analysis is an analytical method for determining elemental concentrations with high accuracy and precision, and a great degree of sensitivity in a wide range of materials (Pollard et al. 2007). A sample analyzed using INAA is subject to irradiation by slow[13] (thermal) neutrons (Rapp 2000). The target nucleus is bombarded with neutrons resulting in a non-elastic collision forming a compound nucleus[14]. This process can produce both short- and long-lived counts. In short-lived counts, the compound nucleus de-excites almost instantaneously and releases gamma rays. In other words, the elements that react instantly to the activation process have relatively short half-lives. Long-lived counts are quantified four to eight weeks after irradiation to identify long-lived isotopes. These isotopes decay over a more extensive period of time because they have longer half-lives than those isotopes

[13] A thermal neutron is a slow moving neutron that has low kinetic energy.

[14] A compound nucleus is defined as an intermediate state of a nuclear reaction in which the incident particle combines with the target nucleus and its energy is shared with all of the nucleons of the system.

included in short-lived counts. The compound nucleus can also form a radioactive element that will have its own characteristic gamma ray decay. These emitted gamma rays are detected and counted and the number of gamma rays emitted is used to determine element concentrations (Figure 3). Thus, very specific and detailed compositional information can be derived using INAA, which can reveal specific types of chert.

Numerous chemical elements can be detected at the low parts per million (ppm) level and many can be detected well into the parts per billion (ppb) range (Rapp 2000). Furthermore, there are no associated extraction techniques, only a small sample (1g) is required, and a wide range of elements (major, minor, rare earth, and trace elements) can be measured simultaneously (Glascock and Neff 2003; Neff and Glascock 1995:280).

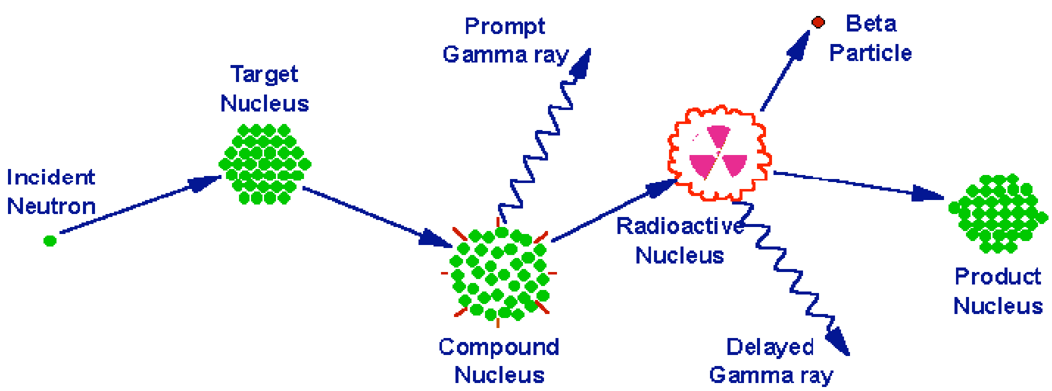

Figure 3. Process of Neutron Capture by a Target Nucleus Following the Emission of Gamma Rays (from Glascock 2004).

Despite these advantages, INAA has several limitations. For archaeologists, the disadvantages include limited availability and its destructive quality. There are very few INAA facilities currently in operation within North America, and only two in Canada: 1) the McMaster University Reactor in Hamilton Ontario; and 2) the SLOWPOKE Nuclear Reactor Facility at the University of Alberta. Finally, unlike other methods, the process of INAA involves the irradiation of a powdered sample. This means that the artefact or a portion of the artefact must be ground down into a powder. In most cases, damaging artefacts is not a viable option. However, analysis of debitage from the same contexts as fully formed artefacts is generally an acceptable alternative for use in destructive analyses.

I selected samples for INAA based on weight, material type, and their archaeological or geological provenience. I focused on the Kamloops strata as it contained the majority of the chert excavated from ST 109; only two pieces of chert material were excavated from the earlier Plateau strata (Muir et al. 2008:26-27). Samples were sent for INAA to the McMaster University Nuclear Reactor Lab, and were processed by laboratory technician Brandi Lee MacDonald. Elements tested for included Al, As, Au, Ba, Br, Ca, Ce, Cl, Co, Cr, Cs, Dy, Eu, Fe, Hf, K, La, Lu, Mg, Mn, Na, Nd, Rb, Sb, Sc, Sm, Sr, Ta, Tb, Ti, U, V, Yb, and Zn. This suite of elements was chosen specifically to include rare earth elements (Sm, U, Eu, and Dy) and elements that have been noted as useful in discriminating geologic chert deposits in previous chert studies (Sr, Ca, Zn, and Na). Additional elements were added to the analysis at the discretion of McMaster University Reactor technicians to provide further clarity when original results were inconclusive. The ppm data are provided in Appendix C: worksheets 4 and 5.

At McMaster University Reactor, two irradiations were performed on samples to acquire data on elements that produce short- and long-lived isotopes. In total, data on 34 different elements were obtained for each sample. Six standard reference materials (SRMs) and control samples were run with each bundle of samples. Standard reference materials (SRM) used for this analysis include SRM 1632c Coal (x2), SRM 1633b Fly Ash (x2), SRM 688 Basalt (x1), and SRM 278 Obsidian Rock (x1); all were issued by the National Institute of Standards and Technology.

Two samples (designated as HKCP 3-15/GSLMC101 and HKCP 2-14/CA210) yielded significantly high concentrations of Al and/or Mn that can cause interferences for the accurate detection of other elemental concentrations. At the suggestion of MacDonald (2009), these samples were excluded from the study. The results of the INAA process are presented in Chapter 5. Details regarding the long and short irradiations required during the testing process are outlined in a report that was provided to me upon completion of the INAA testing (see Appendix D).

Statistical Analysis

To assess how much variation existed within the data set, I entered the pXRF and INAA elemental compositional data for the toolstone material samples into the JMP 10 statistical program to conduct various summary and multivariate statistical analyses. Using this program, I calculated the mean (average) for each deposit for each element. Using these averages, I then calculated the standard deviation[15] for each geologic deposit for each element. Standard deviation measures the amount of variation or dispersal from the mean (Drennan 2010:30-31). I also calculated the coefficient of variation[16] (CV), which expresses the variation as a percentage of the mean. To view the variation between deposits, I plotted the variables using box and whisker plots (boxplots). Boxplots show the range of variation from the mean. Furthermore, plotting the toolstone deposit areas on the same chart serves to highlight the outliers.

Based on the results of the boxplots, I identified elements that showed potential for discriminating toolstone deposits from one another. I plotted these using bivariate plots, which are presented in the Chapters 5 and 6. To determine if the variation that existed between the deposits was visually evident, I ran 20 principal component analyses (PCA) on the respective pXRF and INAA elemental data for the geologic deposits. Principal component analysis was chosen as the multivariate method for this research because it has advantages over the commonly used cluster analysis. First, it shows variation in group shape, which is preserved in the PCA plots. Second, information on the chemical basis of the represented structure is maintained and may be represented by plotting the variable coordinates on plots (Neff and Glascock 1995:282). However, PCA is dependent on the selection of data included in the analysis, which should be initially determined using a discriminating analytical test such as boxplots, stem and leaf plots, or error bars.

The final step in my statistical analysis was to plot the artefact elemental data with the principal component results to show different artefact-material correlations. To

[15] Standard deviation reveals how much variation or dispersion from the mean exists in a dataset (Drennan 2010: 29).

[16] The coefficient of variation is a normalized measure of dispersion of a probability distribution or frequency distribution

complete this last step, I applied the component loading values used for the PCA of the geological samples on artefact sample variables (elemental data) to make them comparable to the principal component results for the geologic sample. The standardized variables for the artefacts were then plotted with the geologic source using PCA to show the relationship between the artefacts and toolstone materials. The results of the statistical analyses are presented in Chapters 5 and 6.

Summary

My research characterized both the chert toolstone deposits and chert artefact debitage excavated from ST 109 using pXRF and INAA. I systematically sampled from six toolstone deposits within my study area: the Ashcroft Blue; Glen Fraser; Hat Creek Valley; Maiden Creek Valley; Rusty Creek Red; and West Fountain deposits. I also supplemented my sample with specimens held at SFU for deposits that have been exhausted by a combination of past use and more recent rockhound collection. Artefacts were chosen for pXRF and INAA testing based on the criteria of weight, size, morphology, archaeological provenience, and available material. Sampling was somewhat restricted by the high cost of INAA, as well as the weight and size of the debitage; however, I was able to analyze 25% using INAA and 9% using pXRF of the testable material excavated from ST 109.

Toolstone deposits in the mid-Fraser region have been linked with the lithic material excavated from ST 109 based on the assumption that visual characteristics (i.e., colour and texture) are a reliable means of correlating archaeological and geological materials. This case study was, in part, designed to address whether visual characteristics are related to elemental composition, but the primary focus was to determine whether the chert toolstone deposits could be characterized using pXRF and INAA in combination with multivariate statistical analyses. The chert archaeological samples were included to highlight the complexities of chert's elemental composition, and to evaluate the reliability with which the artefacts from ST 109 could be connected to one or some combination of the local deposits.

Chapter 3.

Properties of Chert

Chert is a chemical sedimentary rock that is formed by the precipitation and replacement of molecules within its clastic component. This continual change and alteration makes cherts internally reflective of their natural environment, since the elements that affect these internal changes are found in the surrounding environment. It is this formation process that aids in the understanding and characterization of chert types by the identification of diagnostic elements unique to specific environments. However, this constant state of reformation and restructuring can also complicate characterization, as the each stage of formation replaces the last. As such, understanding the expected types of impurities inherent within the fabric or matrix of the structure of cherts will allow archaeologists to identify different types of chert toolstone materials used for the production of stone tools.

In this chapter, I outline the elemental and physical properties of cherts. I begin with a discussion on chert geochemistry, which includes its internal chemistry, chemical structure, and inter- and intra-variation. This is followed by a summary of the physical characteristics of cherts such as strength, hardness, elasticity, homogeneity and isotropy, and thermal properties. I conclude with an examination of cherts in sedimentary environments and how they are affected by their context.

Elemental and Physical Properties of Cherts

This section addresses the general elemental and physical attributes of chert. First, I discuss the chemical compounds that form chert deposits, and how these affect their physical properties. I then summarize the overall physical properties of cherts and use these to define different chert types.

Elemental Properties

Chert is classified as a chemically precipitated, dense sedimentary rock that is mono-mineralic—composed primarily of microcrystalline and/or chalcedonic quartz with minor amounts of impurities (Folk 1980:79-80). These impurities are referred to as the clastic component/matrix and are unique to individual chert deposits (Bakewell 1995; Hayden et al. 1996:349). This matrix provides the variability that makes cherts chemically unpredictable, but also provides the necessary elemental quantifications to identify unique compounds within deposits. If present, these diagnostic characteristics, when compared to archaeological samples, can link chert deposits to archaeological contexts using various geochemical analyses. By using techniques such as XRF and INAA, geochemical analyses produce reliable data from which unique variables can be obtained to facilitate distinguishing deposits in the same geographic area. However, to better understand the compositional data produced by these kinds of analyses, the internal and chemical structure of the stone material must be considered.

Structure

Cherts are predominantly composed of SiO_2, and are a member of the silicate family that includes a number of minerals each composed of different combinations of silicon and oxygen, referred to as the silicon-oxygen tetrahedron. There are four oxygen ions for a smaller silicon ion (Tarbuck and Lutgens 2002:47). Additional minerals and components become imbedded within and around this tetrahedron, forming the clastic matrix, or component. It is this matrix that provides the elemental compositions that will vary between chert deposits. However, silicon remains a useful element to measure because it can help to distinguish chalcedony from chert deposits—the former being almost pure silica (Bakewell 1995:6).

Characterizing chert deposits requires knowledge of the mineral and elemental compositions of the material. Although cherts are composed primarily of silicon and oxygen, all cherts contain impurities because they form in close association with other rocks, sediments, and organic remains. It is by examining these impurities that chert deposits may be distinguished from one another.

Impurities in cherts are primarily clays, carbonates, iron oxides, and organic materials (Luedtke 1992:36). The source of these impurities is generally from the elements that precipitated from solution and became incorporated into the chert as it formed. Some minerals form early in chert diagenesis, while others precipitate later in the formation process into pores, cracks, and cavities present within the material.

Intra- and Inter-Variability

Cherts typically have high levels of intra- and inter-variation because they are heterogeneous composites made up of elements and compounds taken from their environment. The variation among chert types is largely due to the differences in their formation processes. For example, cherts that form in environments suitable for carbonate-secreting organisms are likely to be high in carbonate-related elements. Knowledge of the environmental conditions of cherts is crucial when attempting to characterize different deposits. There are four different types of cherts distinguished by different formation processes: 1) jasper; 2) agate and chalcedony; 3) silicified wood; and 4) magadi cherts[17] (Luedtke 1992:48-49).

The variations in formation processes cause the majority of the intra- and inter-variation in cherts due to the impurities present in each environment. For instance, jaspers are expected to contain the rare earth elements U and Ba, to be low in the clay forming elements Ce, Rb, Cr, Hf, Th, and Br, and high in Fe, Co, Ni, and Cu (Lovering 1972); especially Fe (Hatch and Miller 1985; Luedtke 1992:48; Prothero 1983:345-454). To effectively characterize chert deposits, archaeologists must have knowledge of these impurities and how they form different chert types, and the elemental differences that exist between them. Impurities include clays, iron minerals, carbonates, and organic materials.

[17] Magadi type cherts contain finely disseminated calcite, zeolites, feldspars, and clays (Luedtke 1992:49). They are not discussed in this thesis, since they do not occur in the study area.

Clay

Clays are present within most cherts and contain Al, Si, H, and O. The chemical bonds in clay are weak and loose, which facilitate a great deal of replacement and substitution. For this reason, clays have a highly variable composition.

Iron Minerals

Iron is an abundant element in the earth's crust, and is present in many minerals. The most common iron inclusions in cherts are hematite, goethite, pyrite, and magnetite[18]. Elements that co-mingle in cherts with iron and manganese include Co, Ni, and Cu. Iron minerals in cherts usually occur in association with clay impurities, and there is a predictable association between metals and clays within and between formations (Cressman 1962).

Carbonates

Carbonates are rocks or minerals formed of calcium carbonate ($CaCO_3$). Carbonates are common impurities in chert mainly because some cherts form through the replacement of carbonate rocks like chalk, dolomite, and limestone. In addition, many cherts contain fossils of silica-secreting organisms (i.e., radiolarians, diatoms, and sponges), and the remnants of their calcite shells appear in cherts. Calcium, C, and O are present in the carbonate elements, along with Mg, Mn, Fe, and Sr.

Cherts that form in carbonate environments are expected to have related values for such elements as Ca, Sr, C, Na, Ba, Mg, Mn, and Fe, because they are likely to contain the fossil remains of radiolarians, diatoms, and sponges. These kinds of fossil remains have been successfully used in petrographic analysis to distinguish between chert deposits (Luedtke 1992).

[18]Hematite is classified as a simple iron oxide; geothite [a-FeO(OH)] is an iron oxide mineral (Ralph 2014); pyrite (FeS_2) is an irondisulfide with large amounts of nickel and cobalt (Chesterman 1979:374); magnetite is classified as a multiple (mixed) iron oxide that sometimes contains trace amounts of Mn, Ni, Cr, and Ti (Chesterman 1979:590).

Organic Materials

The majority of the organic matter in cherts originates from the amorphous silica-secreting organisms that helped form the material. The basic elements present in these organisms are Si, Ca, Na, Fe, P, and S. However, some elements are characteristic of the organisms that produce them. For example, diatoms are high in Ge, while radiolarians are low in this element, and sponges and diatoms produce Ti.

Cherts contain a wide variety of impurities, all of which help to explain their complicated geochemistry. To be able to understand and target these impurities for analysis, consideration of their environment is an asset, and most of the impurities can be assessed through physical property analysis, or petrography.

Physical Properties

This section identifies the five primary physical variables useful in the identification of chert in archaeological contexts: 1) strength; 2) hardness; 3) elasticity; 4) homogeneity and isotropy; and 5) thermal properties.

Strength

Strength is referred to as toughness or tenacity, and is a measure of how much force must be applied to cause a fracture (Luedtke 1992:80). Due to their high quartz content, cherts are classified as brittle because they are strongest when under compressive stress[19]. The strength of chert is related to a number of factors including mineralogy, the extent to which grains are interlocked, cracks and pores, presence or absence of water, and grain size.

The size of the quartz grains within a piece of chert significantly affects its tenacity (Wrinkler 1973:41)—the smaller the grain size, the tougher the chert. The larger grained materials tend to have flaws along the grain boundaries. Also, larger grains do not absorb stress as effectively as smaller grains. Generally, cherts with interlocking grains tend to be stronger than those without, as interlocking grains prevent cracking or

[19] Compressive stress is the capacity of a material or structure to withstand axially directed pushing forces (Tarbuck and Lutgens 2002:419).

fracturing. However, grain size does not significantly affect other openings from forming in the material.

Cracks, pores, fissures, and other openings significantly impact the toughness of cherts mainly because these areas have a high potential to repeatedly fracture and increase in size, thereby weakening the rock (Howarth 1987). The size and shape of these openings are also important. For example, pores and cracks with round ends are not as brittle and do not break as easily as cracks with sharp edges. Cherts can have a number of openings and cracks, usually from the formation of fossils, chemical precipitation, or the presence of water. Cracking can also be induced in cherts as a result of specific applications of heat or force. Cracks that have been encouraged by heating or mechanical pressure are longer, sharper, and more predictable than those caused by water.

The presence of water also affects the strength of chert. Chert usually retains approximately 1% water in its cracks and pores; water gradually breaks down the chemical bonds in the material by increasing its porosity (Luedtke 1992:80-81). The primary reason for this is that the water bonds to the surfaces of the quartz grains and plates with its hydrogen ions thereby joining with the silicon ions. The quartz layers are then joined by a weak bond, and this makes fractures much more likely to occur. High moisture content increases the flexibility/elasticity of materials, reducing their brittleness (Crabtree 1967:14). Fractures have an effect on the strength and in some cases, the hardness of cherts.

Hardness

Hardness is defined as the resistance of a material to abrasion, scratching, or penetration by an indenter, and is a composite property affected by strength, elasticity, and cleavage (Palache et al. 1944:113). It is greater for materials that are made of small ions with high electrical charges that can be packed tightly. There are numerous ways in which to measure hardness, but most archaeologists use the Mohs scale. This accepted method of measurement for hardness uses a scale that ranges from a value of 1 for the softest material (talc) to 10 for extremely hard materials (diamonds). The hardness of a material is indicative of the molecular properties of its grain size and the presence or absence of water—hardness increases with smaller grain size and less water. For example, most well-formed cherts test at or near a 7 on the Mohs scale and typically have small, interlocking grains and relatively low water content.

Elasticity

Elasticity is generally equated with the ability of a material to resist fractures—the capability of a stone material to deform without permanently changing shape (Luedtke 1992:83). The deformation that chert endures when it is subjected to stress is not observable, but the changes can be measured after the stress is removed. In a general sense the elasticity of a material is determined by a combination of its minerology, grain size, and cracks. Elasticity is related to the type of bonding among the atoms of the mineral. For cherts, the bonding between silicon and oxygen makes quartz elastic. Cherts are composed of granular materials[20], not single crystals; therefore, they are more elastic than quartz. Cherts that have fissures or cracks have a greater allowance for deformation.

Homogeneity and Isotropy

The number and volume of inclusions, flaws, cracks, cleavage plains, and grains present within a sample are used to assess the purity of a material. The highest quality material is the one with minimal impurities or physical flaws. While a homogenous material has the same properties throughout, an isotropic material has the same mechanical properties in the same direction (Luedtke 1992:80). In other words, homogeneous chert nodules have no flaws, inclusions, or cavities, whereas isotropic chert nodules have the same strength regardless of their orientation.

Thermal Properties

When cherts are subjected to high temperatures either through accidental exposure (fires) or annealing (intentional heat treatment), their thermal properties are altered (Domanski and Webb 1992; Domanski et al. 1994). Quartz has a higher thermal conductivity than most other minerals, and quartzite scores even higher, and chert is likely similar to quartz. However, cherts that have cracks, pores, or fissures will have a

[20] Granular is used here as a characteristic of chert structure and chert can be composed of small grains or particles, depending on the type of silica it forms out of (Luedtke 1992:6).

lower conductivity, and are likely to explode or crack when exposed to high levels of heat. Significantly for my research, it has been noted that exposure to high temperatures can also alter the colour of chert toolstone material (Ahler 1983; Domanski and Webb 1992; Domanski et al. 2009; 1978; Rick and Chappell 1983). Early research did suggest that the presence of iron impurities may induce colour changes in heat treated cherts (Purdy and Brooks 1971).

Chert Formation Processes

Chert is a chemical sedimentary rock composed primarily of silica. Silica is found in solution all over the world within bodies of water including lakes, rivers, and oceans. Although most natural bodies of water have low silica content, the chert that is forming today is primarily found in deep marine contexts (Blatt 1992). The first step in chert formation is the presence of silica in water (Maliva and Siever 1988:688). This process is known as solubility, and it is critical to the formation of cherts. It is defined as the amount of substance that can be dissolved in a given fluid under specified conditions (Luedtke 1992). Factors controlling the solubility of silica are the temperature, pressure, pH, particle size and surface area, presence of a disturbed surface layer, and impurities. Since these variables are in a constant state of flux, they contribute to chemical differences between chert formations.

Precipitation of silica is the second critical event to occur in the formation of cherts. For precipitation to occur, atoms of silicon and oxygen bond and form a tetrahedron structure. These tetrahedrons attach to one another in configurations that correspond to the different forms of silica. To add to the variability, there are numerous types of silica including colloidal silica, opal–A, opal-CT, chalcedony, microcrystalline quartz, and macrocrystalline quartz (Luedtke 1992). Thus, chert forms through precipitation from a macrocrystalline or microcrystalline quartz solution.

Chemical sedimentary rocks such as cherts form within a variety of geologic environments including deep and shallow oceans or lakes, and in terrestrial settings. Cherts occur as nodules, lenses, or beds but have the potential to form in any area in which silica can precipitate. Initially, geologists knew only of existing chert deposits and were unaware of chert forming anywhere on the Earth (Luedtke 1992). Consequently, for the following reasons, it is not yet clear how chert deposits form. First, the majority of the physical and chemical processes involved in chert formation occur at an incredibly slow rate (on a scale of thousands of years) at regular temperatures and pressures that are not observable in a human lifetime (Folk and Weaver 1952:509; Luedtke 1992). Second, the formation of chert is sequential, and the subsequent steps destroy the previous stages along with the majority of the critical evidence pertaining to the formation process. This differs from other sedimentary rocks, which form gradually by the addition of sediment, a process that is visible on a macroscopic level. Finally, in contrast to other sedimentary rocks, chert forms in different and unpredictable ways. Thus, due to the time and particular physical and chemical requirements for cherts to form, and the somewhat inconsistent nature of the process, it is nearly impossible to replicate chert formation in a laboratory setting. Even though geologists and archaeologists have been studying chert and its formation processes since the 1950s, there is still much to be learned.

Contexts of Chert Formation

Cherts have many depositional forms, but the two most applicable to archaeological studies are nodular and bedded cherts. Nodular cherts are generally spherical and found within Neogene and Quaternary deposits adjacent to carbonates, such as limestone or dolomite formations. Chert has a tendency to form near carbonates because the water and temperature conditions preferred by carbonate-producing organisms match those suitable for silica-secreting organisms (Luedtke 1992:28). In addition, these areas have a low pH that facilitates silica precipitation. By contrast, bedded cherts occur as layers within other rocks, including shales, basalts, and other volcanic deposits. In fact, the majority of bedded cherts are found in close/direct association to volcanic sediments, probably because silica is more soluble in hot aqueous solutions. Theoretically, cherts found in association with volcanic deposits will retain unique signatures from these formations, especially volcanic dykes (Ferris and Andrefsky 2011).

Summary

Cherts are highly varied in their external appearance and elemental composition; therefore, classifying specific chert types using visual identification is unreliable. The internal inconsistencies of cherts are largely due to the clastic matrix contained within the rock. This matrix is determined by the impurities that are present in the environment in which chert rocks are formed. Understanding the impurities, sediments, solutions, and organic materials present during chert formation is essential for petrographic and elemental characterization. Different impurities can be diagnostic to specific environments, and this helps distinguish toolstone deposits in the same region. Importantly, impurities lead to the formation of different chert types, such as jasper, opal, agates and chalcedony, and silicified wood. Although these impurities are critical to characterizing cherts, they can also be varied and lack patterning. In addition, cherts that formed in similar environments will contain the same impurities and are likely to be elementally indistinguishable.

The cherts in the mid-Fraser region appear as nodules eroding out of the hillsides, or scattered across the landscape. These cherts are situated within a secondary context, moved from their point of origin and therefore, the environment of the study area may have affected their elemental composition. To determine the different chert types present within their study area, Hayden (2004) and Bakewell (1995) focused on visible properties they believed were indicative of elemental composition. Hayden (2004) attempted to classify chert material types present in the mid-Fraser using colour while Bakewell applied petrographic techniques and classified chert material types (including jaspers, pisolites, vitric tuffs, and chalcedonies) by identifying relic textures visible microscopically. Additional details on these analyses are discussed in the following chapter.

Chapter 4.

The Keatley Creek Case Study

As a case study for my analysis and discussion about chert toolstone deposits in the mid-Fraser region, this chapter outlines the work that has been conducted on toolstone deposits within the study area and their assumed relationship with the Keatley Creek site, as well as the extensive archaeological investigations carried out at the site. I also include a brief review of pivotal work done within the study area over the last 50 years to provide context for current research. The extensive body of previous research provides a wide-ranging knowledge base from which to frame a geoarchaeological investigation of toolstone use. In particular, the archaeological work that has been done at the Keatley Creek site makes it an excellent candidate for a case study for elemental characterization of known chert toolstone deposits and artefacts.

I begin with a brief outline of previous archaeological investigations in the region, and supply background information on the Keatley Creek site and the archaeological research conducted there. I discuss the previous work done on toolstone material identification and classification at Keatley Creek to set the stage for the details of the chert characterization done as a part of my case study. I also provide a brief outline of the geology of the mid-Fraser region to supply the geological context of the chert toolstone deposits in the study area. Specific details regarding the siliceous toolstone deposits of the mid-Fraser region are described in Appendix B.

Archaeological Investigations in the mid-Fraser

Archaeologists have been conducting research in the mid-Fraser region since the 1960s. As one of the pioneering archaeologists to work in the area, David Sanger conducted some of the earliest excavations at Nesikep Creek (Sanger 1964), Lochnore Creek (Sanger 1966), Texas Creek (Sanger 1968), and Chase (Sanger 1969). The former two sites are now referred to as the Lochnore-Nesikep locality, based on a series of small sites that are chronologically similar.

Between 1961 and 1965, Sanger (1964, 1966) identified and excavated a number of sites: Nesikep Creek (EdRk-3); Cow Springs (EdRk-5); McPhee (EdRk-6); Lochnore Creek (EdRk-4); Lehman (EdRk-8); and Pine Mountain (EdRk-9). Comparative analysis of the material assemblages from the archaeological sites in Chase, the Lochnore-Nesikep locality, and other late prehistoric sites in Lytton and Kamloops, led Sanger (1964, 1966; see also Richards and Rousseau 1987:8) to propose a tripartite culture-historical sequence for the region: the Lower Middle Period (5,000–3,500 years before present [B.P.]); the Upper Middle Period (3,500–2,000 B.P.); and the Late Period (2,000 B.P.–present). Later excavations in the Lochnore-Nesikep locality allowed him to construct a more localized chronology that has since been applied to other sites in the Interior Plateau by a number of researchers (e.g., Fladmark 1982; Lawhead and Stryd 1985; Richards 1978; Stryd 1973).

Richards and Rousseau (1987) refined the chronology of the mid-Fraser region and the surrounding areas in their volume *Late Prehistoric Cultural Horizons on the Canadian Plateau*. They described the three late cultural horizons—Shuswap (4,000–2,400 B.P.), Plateau (2,400–1,200 B.P.), and Kamloops (1,200–200 B.P.)—that comprise the Plateau Pithouse tradition. Their chronology is currently the most accepted amongst archaeologists working in the region. Rousseau (1993) continued to develop the chronology by focusing on Early Period sites in the Chilcotin, North and South Thompson, Nicola-Similkameen, and Okanagan areas. He also outlined the environmental conditions of the Late Pleistocene/Early Holocene and a model of Early Period adaptations and cultural change for the northern Interior Plateau. With some minor changes, this was incorporated into Stryd and Rousseau's (1996) subsequent culture-history for the region. More recently, Prentiss et al. (2005) combined the northern and southern Plateau chronologies to generate a comprehensive chronology for the entire Plateau of northwestern North America.

Having an established culture history spurred new research questions and strategies. Archaeologists began to ask questions about particular sites and the structures within them (Stryd 1973). In the late 1970s Arnoud Stryd, as part of his doctoral research conducted archaeological investigations at the Bell site (EeRk-4), a relatively large-sized housepit village located 18.5 km downstream from Keatley Creek. In addition to his doctoral studies, Stryd (1978) edited *Reports of the Lillooet Archaeological Project Number 1: Introduction and Setting* for the National Museum of Canada. These influential works inspired subsequent archaeological studies at the Keatley Creek site.

The Keatley Creek Site

The Keatley Creek site is located within the mid-Fraser region of British Columbia's Interior Plateau (Figure 1). It is part of the Ponderosa Pine and Bunchgrass biogeoclimatic zone, where vegetation consists of prickly pear cactus, bunchgrass, ponderosa pine, and sagebrush in a semi-arid environment (Meidenger and Pojar 1991). The site is situated amongst a group of large housepit village sites that are all within 50 km of the town of Lillooet, British Columbia: Bell (EeRk-4); West Fountain (EeRl-63); Pavilion (EeRl-52); Kelly Creek (EfRk-1, also known as Pear Lake); McKay Creek (EfRl-3 and 13); Bridge River (EeRl-4); and Lillooet (EeRl-1). These interior Salishan villages are located on terraces along either side of the Fraser River and one of its major tributaries, the Bridge River (Figures 1 and 6). A resource-rich area, the mid-Fraser region contains an abundance of culturally significant flora and fauna, as well as geologic deposits of material suitable for stone tool production.

The Keatley Creek site covers 19 hectares and includes 120 semi-subterranean structures (Sheppard and Muir 2010). It is one of the largest documented archaeological sites in the region (Hayden and Adams 2004). It was first occupied ca. 6,500 B.P. and continued to be used into the Kamloops Horizon (Prentiss and Kuijt 2012). The site has been the focus of archaeological investigations since the beginning of Brian Hayden's Fraser River Investigations into Corporate Group Archaeology Project in 1985 (see also Prentiss et al. 2003). The project addressed the question of why large structures occurred in the Lillooet locality of British Columbia, building upon Stryd's (1973) earlier dissertation that dealt with prehistoric social organization in the mid-Fraser region at the Bell site (Hayden 2000a:1).

In the late 1980s, Hayden began a large-scale investigation into the sizes of the housepits at Keatley Creek to determine why such a range of sizes existed among the recorded housepits in the Lillooet locality. Hayden and his team developed a list of investigative criteria that included site formation processes, resource bases, climatic change, socioeconomic organization, the relationship between large and small housepits, recovery and identification of artefact patterning on living floors, the identification of individual domestic groups within housepits, and the identification of associated artefacts. Hayden produced three volumes summarizing the project results: 1) *The Ancient Past of Keatley Creek Volume 1: Taphonomy* (2000a); 2) *The Ancient Past of Keatley Creek Volume II: Socioeconomy* (2000b); and 3) *The Ancient Past of Keatley Creek Volume III: Excavations* (2004). These comprehensive volumes present and discuss various data on paleoethnobotany (Lepofsky 2000a, 2000b), the excavations of specific structures (Beyries 2000; Heffner 2000; Prentiss 2000; Spafford 2000), geology and site formation processes (Friele 2000; Goldberg 2000; Hayden 2000c), paleoenvironments (Mathewes and Pellatt 2000), zooarchaeology (Berry 2000; Crellin and Heffner 2000; Kusmer 2000a, 2000b), and lithic toolstone deposits (Rousseau 2000).

In addition to characterizing known chert toolstone deposits within the study area, I also characterized chert artefacts excavated from ST 109. Structure 109 is located on the periphery of the Keatley Creek site on the first terrace east of the site's core (Figure 5). Archaeological excavations of ST 109 were conducted in 1988, 1989, and 1998 as part of the Fraser River Investigations into Corporate Group Archaeology Project (Hayden 2000a, 2000b, 2004). During these investigations, two occupations were recorded: 1) the earlier Plateau (stratum VII); and 2) the more recent Kamloops (stratum III) horizon floors. The excavations produced copious amounts of chert debitage associated with the Kamloops Horizon deposits relative to both the Plateau stratum within ST 109 and other excavations at the site. During the 2006 Simon Fraser University Archaeology Field School directed by Robert Muir (Muir et al. 2008), the earlier excavations of ST 109 were reopened and expanded and EHPE[21] 24 and 26

[21] EHPE refers to "extra housepit excavation," meaning outside the housepit. According to protocol established by Hayden (2000) excavations conducted within smaller cultural depressions (i.e., cache pits) are referred to as EHPE at Keatley Creek.

were excavated for the first time. Stratum II of both EHPE yielded fire-reddened chert and chalcedony flakes (Muir et al. 2008:56).

The 2006 excavations of ST 109 recovered 101 tools and 1,606 pieces of debitage (Muir et al. 2008). The identified material types were dacite, chert, and chalcedony. Although chert is the dominant material type (75%) of ST 109's Kamloops Horizon lithic assemblage, all of the formed tools found in association with both occupations were dacite (Muir et al. 2008:23-25). Considering all published excavations at Keatley Creek, chert makes up less than 7% of the total lithic debitage (Hayden 2004; Hayden et al. 1996; Morin 2006:107), making the abundance of chert recovered from ST 109 atypical.

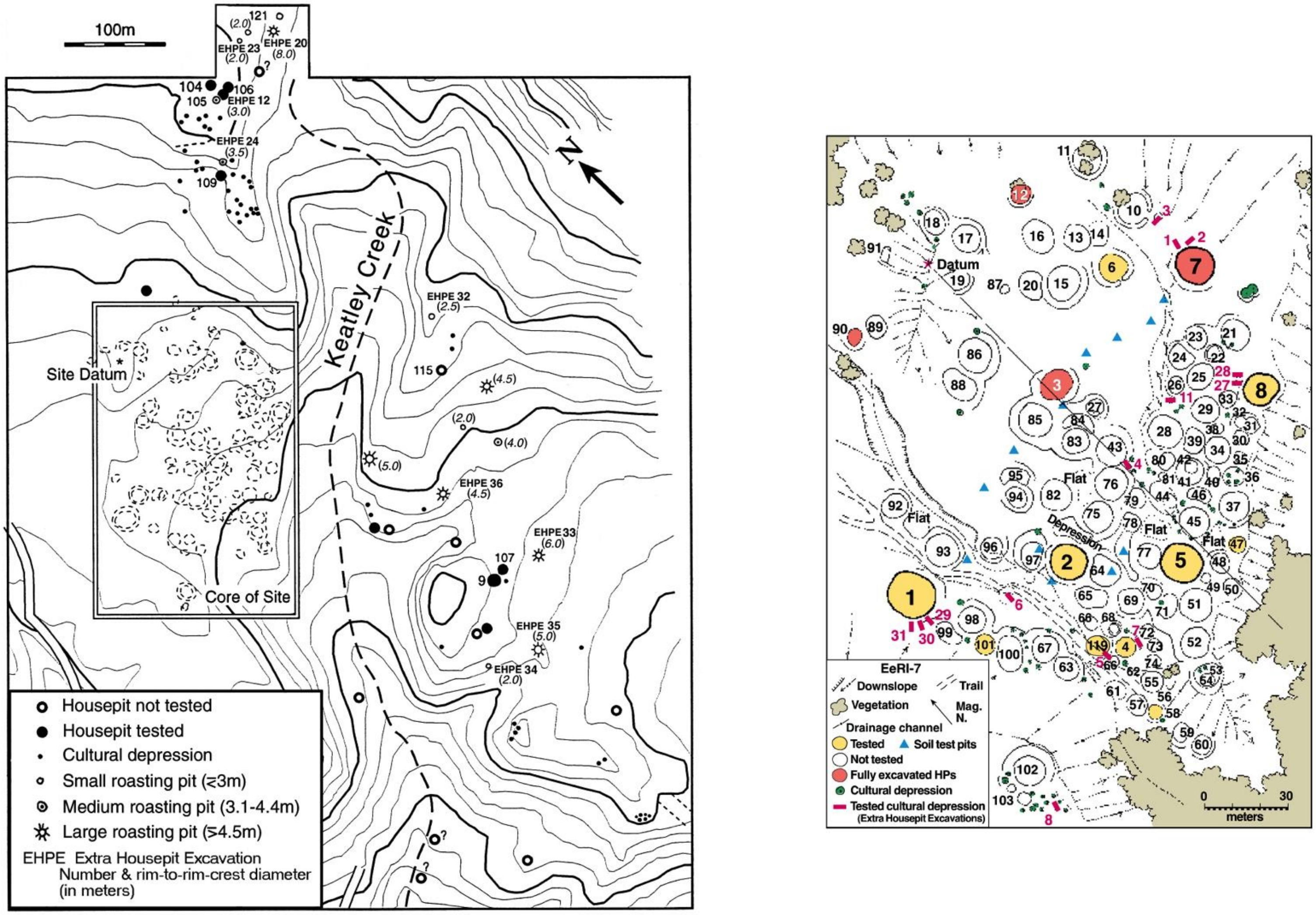

Figure 4. **The Spatial Layout of Keatley Creek (Hayden 2004).**

Previous Research on Chert Toolstone Materials

Previous research considered the location of toolstone deposits relative to the Keatley Creek site, and assumed that a relationship exists based on the use of colour as an identifying characteristic linking archaeological samples to toolstone deposits (Hayden et al. 1996). Rousseau (2000) located many of these toolstone deposit locations in 1988 and 1989 as part of the Corporate Group Archaeology Project. He identified secondary context siliceous and igneous deposits within the mid-Fraser region with the help of data from the Geological Survey of Canada, ethnographic documents, and local informants. Rousseau examined areas that had high potential to contain silicate pebbles and cobbles including the Rusty Creek Valley, the Hat Creek Valley, the Maiden Creek Valley, and the hills adjacent to Keatley Creek. In these areas, he identified and named the following toolstone deposits: 1) the Ashcroft Blue deposit; 2) the Glen Fraser Silicate deposit; 2) the Hat Creek deposit (includes the Medicine Creek and Lower Hat Creek Valley deposits); 3) the Maiden Creek Basalt and Silicate deposit[22]; and 4) the Rusty Creek Red Chert deposit.

In addition to Rousseau's toolstone location study, Edward Bakewell (1995, 2000) identified petrographic and geochemical characteristics of chert and chalcedony debitage excavated from the Keatley Creek site (EeRI-7). He took high-resolution photographs of the debitage, and used relic textures to categorize two different types of silicates: 1) Keatley trachydacites; and 2) Keatley cherts and chalcedonies (Bakewell 2000). The characteristics he observed included crystalline structure and size, opaqueness, presence/absence of clastic inclusions, mineralized cortex, lustre type, and colour. Using these visual characteristics in combination with geochemistry, Bakewell (1995) categorized the samples into jasperoid, pisolite, tuff, chalcedony, and quartzite types based on their observed relic textures. These studies produced valuable data and made significant advances toward understanding the chert deposits of the mid-Fraser region.

[22] In this thesis, I refer to the Glen Fraser and Maiden Creek Silicate deposits as the Glen Fraser deposit and the Maiden Creek deposit. I removed the "silicate" from the title because it refers to a group of rocks that are part of a larger family. As previously noted, I use the term silicate to specifically refer to the chemical sedimentary rocks, chert and chalcedony.

Within the mid-Fraser, provenance and characterization of toolstone materials has focused on igneous deposits such as basalt and dacite (Greenough et al. 2004; Mallory-Greenough et al. 2002) and the correlation of these to artefacts, whereas, the archaeometric study of cherts has been focused on characterization of artefacts using petrographic and elemental techniques (see Bakewell 1995). The study of the internal composition of cherts excavated from archaeological contexts was done by Bakewell (1995), and has been applied to economic aspects of stone tool manufacture, use, and cultural significance (Hayden et al. 1996). A fundamental element of these lithic analyses is the development and application of the Keatley Creek Lithic Typology, which uses colour and relic textures to discern chert material types.

Geology of the Mid-Fraser Region

The mid-Fraser region is situated at the margin of two geologic belts, two bedrock units, and is associated with a large terrane. The mid-Fraser also has a complex glacial history, which has directly impacted the deposits found within the study area. In this section, I describe the physiographic units (bedrock units, terrane), the glacial history, and the sedimentary deposits of the mid-Fraser region as they relate to my research.

Bedrock Geology of the Mid-Fraser Region

The Interior Plateau is an elevated region of metamorphic and volcanic rocks overlain by unconsolidated sediments of Quaternary age (<2.6 Ma). Most of the siliceous toolstone deposits in this area are located on natural terraces within the Camelsfoot Range on the west side of the Fraser River and in the Clear Range east of the river (Mathewes and Pellatt 2000:59). Together, these two ranges form the southwest edge of the Fraser Plateau, a subdivision of the Interior Plateau.

Situated between the Camelsfoot and the Clear Ranges, Keatley Creek is underlain by the Middle Permian Cache Creek Group, which comprises cherts, argillites, limestone, minor agglomerates, and tuffs (Duffel and McTaggart 1951:15-24; see also Trettin 1960: 16; Friele 2000:65).

The other bedrock unit of interest in the region is the Kamloops Group. It consists mainly of Eocene basalts, andesites, and clastic sedimentary rocks (Duffel and McTaggart 1951; Ewing 1981:1465). The sedimentary rocks contain siliceous materials such as chert, chalcedony, and quartz. The unit is found along the Fraser River from Lytton to the mouth of the Chilcotin River on valley sides and upland areas (Rousseau 2000:166) and are also found near Pavilion through to Kamloops.

The Cache Creek Accretionary Complex (Cache Creek Terrane)

The mid-Fraser locality rests on top of the Cache Creek accretionary complex or terrane[23] (Figure 5), which was accreted to North America 150 Ma. Much of the Cache Creek terrane is composed of mafic-ultramafic volcanic-plutonic complexes; it also has a substantial sedimentary component (Johnston and Borel 2007:416).

The Cache Creek terrane is distinguished from other terranes by its fossilized exotic Permian microfossils (Mathews and Monger 2010:280). Abundant fossils within sedimentary rocks may result in elevated Ca and Sr levels (Ron Hancock, pers. comm. 2010). Peaks in both of these elements can potentially indicate the presence of fossils that, if unique to a deposit, can be used to associate toolstone deposits with artefacts. While this may theoretically help to characterize chert deposits, it would take a considerable amount of fossils to significantly affect the elemental quantities of Sr and Ca within samples of chert materials. However, identification of microfossils using scanning electron microscopy within chert toolstone materials and chert artefacts may be an additional way to link deposits to archaeological sites.

[23] A terrane is a crustal block or fragment that preserves a distinctive geologic history that is different from the surrounding areas and that is usually bounded by faults. Accreted terranes are those that become attached to a continent as a result of tectonic processes (Canada's National LITHOPROBE Geoscience Project 2014; Coney et al. 1980; Tarbucks and Lutgens 2002:662).

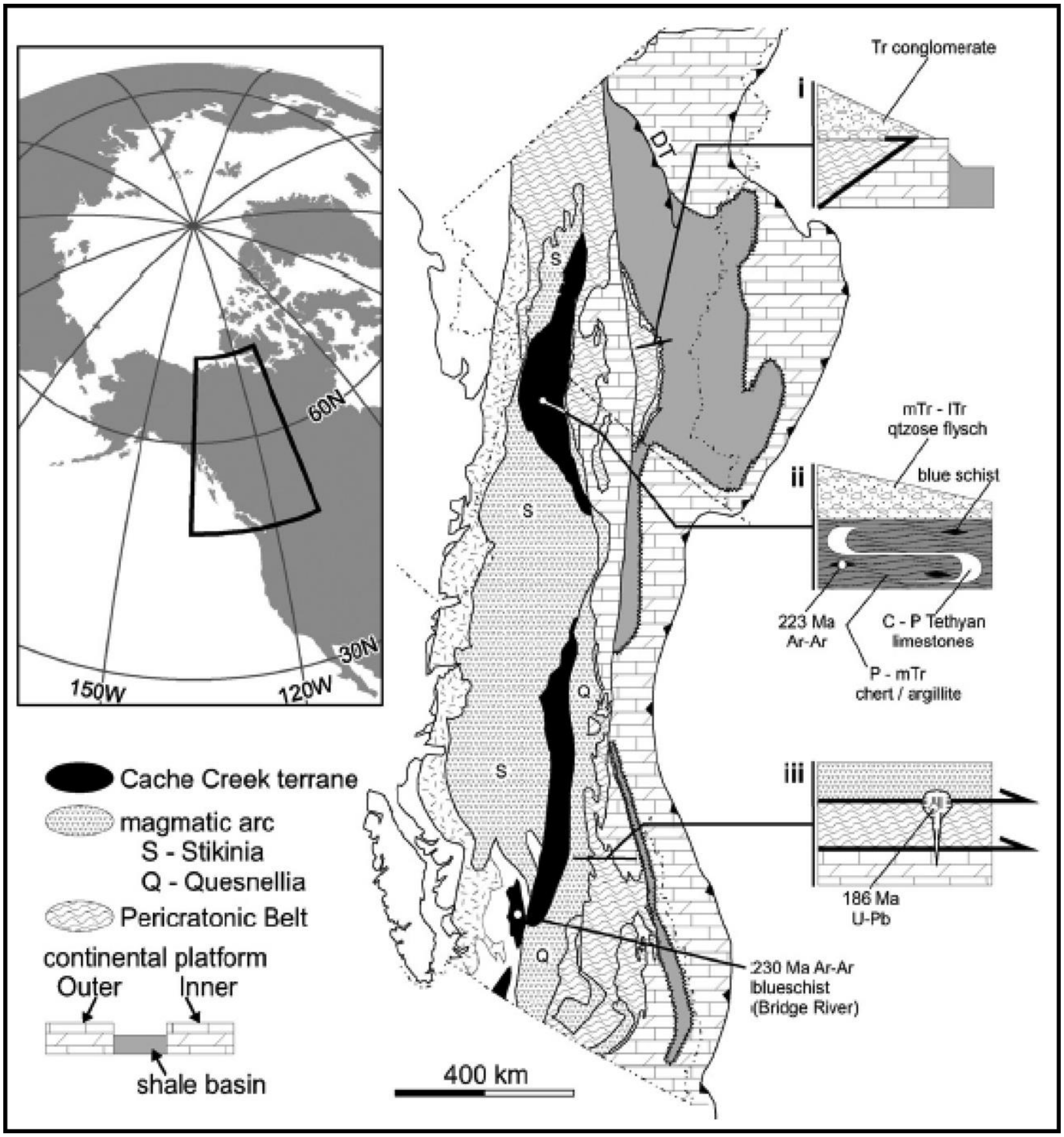

Figure 5. The Cache Creek Accretionary Complex (from Johnston and Borel 2007:416). Cross sections I to iii represent deposits from the late Paleozoic to the lateTriassic.

Late Quaternary Glacial History of the Mid-Fraser Region

Surficial materials up to 250-350 m thick within the mid-Fraser region are a product of repeated Pleistocene glaciation (Clague 1981; Ryder 1976; see also Friele 2000:65). Most surface and near-surface sediments are products of the last (Late Wisconsinan or Fraser) glaciation, when nearly all of British Columbia was covered by the Cordilleran ice sheet (Clague 1989:17; Clague et al. 1980:322; Ryder et al.

1991:366). The ice sheet covered British Columbia's Interior Plateau, and flowed northward and southward from an ice divide at the latitude of Clinton (Figure 6). The ice sheet began to form about 35,000 years ago, but only achieved its maximum extent about 18,000 years ago (Clague, 1981; Ryder et al. 1991).

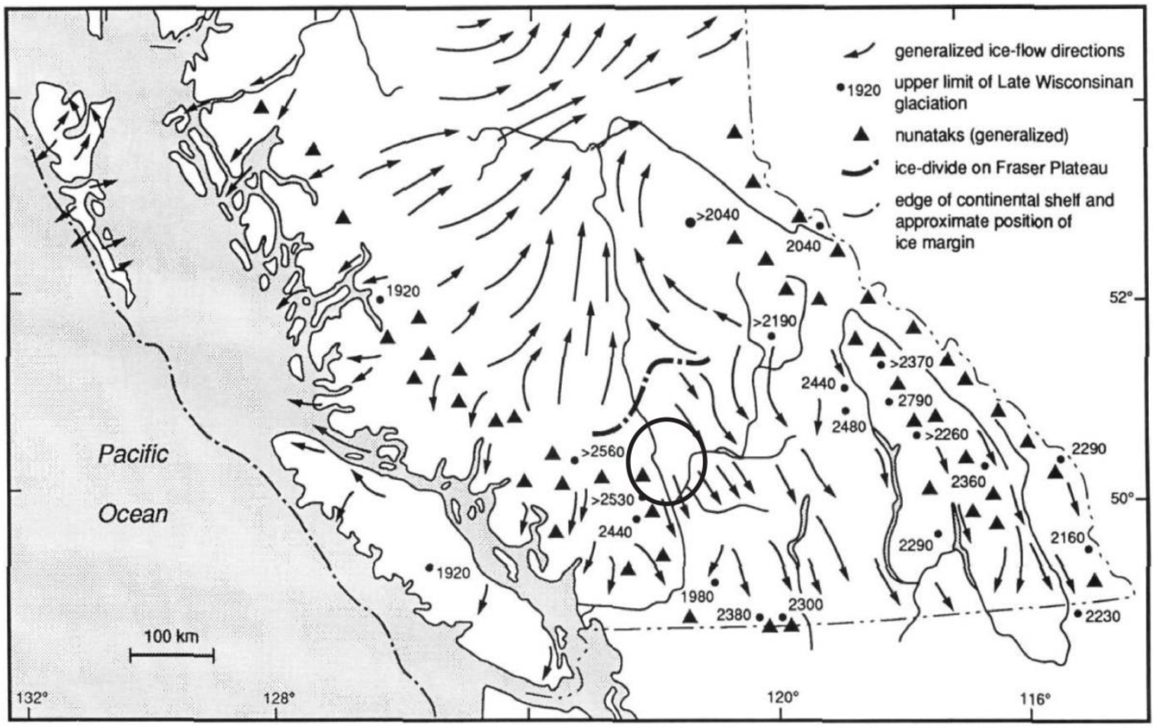

Figure 6. Flow Directions of the Cordilleran Ice Sheet (from Ryder et al. 1991:367). Black oval indicates the mid-Fraser Region.

At the beginning of the Fraser Glaciation, outwash gravels built up in the valleys of the southern interior, including the Fraser Valley. Advancing glaciers eventually blocked Fraser River, forming glacial Lake Camelsfoot, in which lacustrine silts and ands were deposited (Huntley and Broster 1994).

Deglaciation happened rapidly and was dominated by down-wasting, accompanied by northward and northwestward recession. Uplands became free of ice before valley bottoms (Ryder et al. 1991:369). Proglacial lakes formed behind decaying and stagnating masses of ice within most interior valleys at this time (Ryder et al. 1991). The chert deposits utilized by pre-contact populations in the study area were likely deposited or exposed as the glacial ice receded. Indeed, Friele (2000:68) observed that the landforms near and within Keatley Creek are a product of glacial and immediate postglacial processes.

Sediments that were deposited during the Fraser Glaciation may have originated from different areas along the glacier's path. These sediments were later deposited during glacial recession. They are thus located within secondary or tertiary contexts—removed from their original bedrock source. Cherts transported by and deposited from glaciers may have a complex history, involving several episodes of entrainment and re-deposition. The possible origin of mid-Fraser cherts is discussed in Chapter 7.

The Cherts of the Mid-Fraser Region

Chert deposits in my study area appear in two forms: 1) as a primary component of the Cache Creek Accretionary Complex that comprise the Canadian Cordillera; and 2) the much younger silicate deposits of the Neogene and Quaternary periods. These latter cherts were likely deposited or exposed during the recession of the Fraser Stade of the larger Cordilleran glacier. The deposits situated near the Keatley Creek site are on the surface or eroding out of hillsides, and appear as poorly sorted sub-angular, sub-rounded, and angular cobbles, pebbles, and gravels. Since the origin of these deposits is likely remote, gathering more data on the internal compositions of these cherts through analysis of their elemental properties is required. Meaningful comparisons of the toolstone deposits and archaeological samples can only be done once these elemental properties are understood as I demonstrate later in this thesis.

Summary

The mid-Fraser region is an archaeologically rich zone, containing numerous large and mid-scale housepit village sites. These sites have been investigated by archaeologists since the mid-1960s (Sanger's excavations at Neiskep Creek) and some are still the subject of intensive archaeological inquiry and excavation (i.e., Keatley Creek and Bridge River). This chapter has provided the background for archaeological research in the interior plateau, and specifically within my study area, the mid-Fraser region.

As one of the largest villages in the mid-Fraser, Keatley Creek has been the subject of major archaeological excavations, primarily by SFU researchers. These studies have revealed the extensive use of toolstone resources throughout a long history of human occupation at the site. Specifically, excavations at the site, particularly at ST 109, have highlighted the use of basaltic toolstone materials during the earlier Plateau Horizon, and the later use of chert toolstone materials within the Kamloops Horizon.

This chapter also outlined the basic geological background for the mid-Fraser region, to provide the context for deciphering the history of the area's chert toolstone deposits. The mid-Fraser is situated between the Camelsfoot Mountain Range and the Clear Range and is underlain by the Cache Creek and Kamloops Groups. The Cache Creek bedrock unit is composed of cherts, limestones, argillite, basaltics, and tuffs (Friele 2000), whereas the Kamloops Group is primarily composed of volcanic materials. The study area has a long glacial history, which is reflected in the density of Quaternary sediments and landforms present. Since the region has an extensive and complex glacial history involving at least three glacial periods, knowledge of the sediments and the movement of materials may help to explain some of the results for the elemental characterization of the chert analyzed for this study.

Chapter 5

X-Ray Fluorescence Results

In this chapter I present the results of my pXRF and statistical analysis of the toolstone deposits and artefact debitage. Although the bulk of this chapter is dedicated to the elemental characterization of chert toolstone materials and artefacts, I also apply the artefact elemental data to the colour- and textural-based identifications of chert types from the Keatley Creek Lithic Typology (Hayden 2004) with the toolstone elemental data using bivariate analysis to test the reliability of visual and petrographic identifications for cherts. I begin with the presentation of the toolstone and artefact elemental data, followed by the characterization of the toolstone deposits and artefacts using statistical analysis, respectively. The statistical tests presented here represent the most definitive results produced within a much larger analysis conducted using JMP 10, which included 20 PCAs, bivariate plots, and boxplots.

Elemental and Statistical Analysis

Portable X-ray fluorescence of the toolstone deposits and artefact samples detected K-Alpha peaks for 19 elements: Si, S, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Rb, Sr, Y, Zr, and La. The raw photon counts are presented in Appendix C: worksheet 2. Table 4 presents the basic statistics for the toolstone deposits elemental data quantified using pXRF. The summary statistics on these data include the minimum (MIN), maximum (MAX), mean, standard deviation (SD), and the coefficient of variation (CV) for each element per deposit.

The Toolstone Deposits

I used boxplots to discern which elements best distinguish individual toolstone deposits from the deposits analyzed using pXRF. Boxplots show the usual or normal distribution and the range of data (MIN and MAX) within a dataset as measured from the median,[24] and are thus useful for indicating if outliers skew the distribution. I plotted each deposit against one another per element to determine if there were any outliers—to see if certain deposits have distinct amounts of specific elements. I observed that the elements Cr, Ti, Zr, and Zn distinguish the Ashcroft Blue and West Fountain deposits from the others. This observation was confirmed using bivariate plots in JMP 10.

[24] Median is the middle number in the batch or the halfway between the two middle numbers (Drennan 2010:19).

Table 4. **pXRF Statistical Data.** Data are expressed as raw photon counts.

	Ashcroft Blue (*n=7*)				Glen Fraser (*n=10*)				Hat Creek (*n=6*)				Maiden Creek (*n=6*)				Rusty Creek Red (*n=10*)				West Fountain (*n=10*)			
	MIN	MAX	Mean and SD	CV (%)	MIN	MAX	Mean and SD	CV (%)	MIN	MAX	Mean and SD	CV (%)	MIN	MAX	Mean and SD	CV (%)	MIN	MAX	Mean and SD	CV (%)	MIN	MAX	Mean and SD	CV (%)
Si	17932	58024	41230 ± 11793	28	22638	89654	56568 ± 16182	28	10472	84626	54720 ± 20975	38	5505	87003	51358 ± 24204	47	4650	78821	31804 ± 20144	63	11638	80985	45780 ± 21816	47
S	1	2082	565 ± 79	79	940	2197	1221 ± 247	20	969	1431	1220 ± 146	12	763	1604	1147 ± 179	15	962	1734	1244 ± 172	13	946	1355	1110 ± 298	26
K	2427	6316	1066 ± 22	22	2490	8838	4801 ± 1475	30	1941	8662	3958 ± 1702	43	2303	6909	3927 ± 1051	26	2489	6385	3708 ± 821	22	2610	5184	3485 ± 742	21
Ca	7393	16910	12495 ± 2461	19	585	202356	16372 ± 42387	258	679	5672	1947 ± 1277	65	559	7273	2169 ± 1543	71	1226	7166	2351 ± 1182	50	772	6448	1859 ± 1948	104
Ti	5113	8641	7267 ± 1076	14	276	5995	1586.67 ± 1330	83	295	21452	2296 ± 3980	173	274	4114	1261 ± 1060	84	365	2521	722 ± 1182	56	276	1643	455 ± 1208	265
V	1	654	292 ± 153	52	1	781	210 ± 176	84	1	396	180 ± 143	79	1	535	193 ± 159	82	45	923	722 ± 408	62	1	353	138 ± 131	94
Cr	0	272	46 ± 71	154	1	502	184 ± 129	70	1	3271	287 ± 579	201	0	1365	200 ± 256	128	1	3928	362 ± 985	272	426	5067	2480 ± 1374	55
Mn	1908	4764	3042 ± 673	22	1	42134	3298 ± 8683	263	1	12438	1983 ± 3724	187	1	6585	703 ± 1234	175	3	12305	2100 ± 3209	152	1	1261	364 ± 532	146
Fe	123519	215656	180621 ± 26164	14	5771	246557	63508 ± 66720	105	2235	1104899	209255 ± 349046	166	3014	331806	120673 ± 101749	21	123393	978639	346914 ± 26707	76	104743	236856	187391 ± 43575	23
Ni	1153	1598	1338 ± 125	9	1211	3209	2235 ± 448	20	1	2804	1926 ± 839	43	1146	2750	1941 ± 415	34	203	6013	1535 ± 1395	90	4286	7277	5987 ± 1464	24
Cu	690	1534	1338 ± 236	20	392	1936	1022 ± 395	38	691	2753	1346 ± 588	43	593	2327	1092 ± 379	62	510	1789	1107 ± 357	32	489	1598	1067 ± 379	35
Zn	490	821	634 ± 98	15	0	466	186 ± 112	60	41	645	248 ± 140	56	0	656	243 ±153	43	0	416	165 ± 106	64	38	350	206 ± 110	53
As	462	462	847 ± 192	22	565	2347	1300 ± 397	28	431	8412	1938 ± 1950	100	217	2065	997 ± 438	28	229	1578	819 ± 414	50	281	1340	816 ± 331	40
Rb	679	1481	1045 ± 231	22	472	1348	802 ± 203	25	341	15427	2558 ± 4534	177	378	1450	912 ± 264	66	633	10947	2338 ± 3171	135	667	1182	940 ± 177	18
Sr	3894	6872	5442 ± 802	14	443	1845	888 ± 313	35	433	4487	841 ± 709	84	393	2433	792 ± 525	51	290	1003	625 ± 167	26	154	833	516 ± 858	166
Y	710	1462	1075 ± 212	19	91	936	434 ± 209	48	1	688	297 ± 196	65	36	869	357 ± 185	61	0	6656	237 ± 161	67	56	554	285 ± 177	62
Zr	3116	5732	4361 ± 671	15	181	4248	892 ± 1039	116	83	6657	763 ± 1284	168	2	1863	611 ± 375	31	32	632	263 ± 155	61	0	794	298 ± 736	246
La	81	602	233 ± 113	48	26	486	272 ± 95	34	31	410	228 ± 100	43	84	384	245 ± 76	47	93	393	241 ± 83	34	56	437	233 ± 103	44

The Ashcroft Blue Deposit

Seven individual Ashcroft Blue samples were analyzed and each sample was run three times on different spots of the sample. Boxplots of Ti and Zn show a clear distinction between the Ashcroft Blue deposit and the other material deposits (Figures 7 and 8). I plotted these results against the Glen Fraser, Hat Creek, Maiden Creek, Rusty Creek Red, and West Fountain deposits using a bivariate fit plot of Ti by Zn (Figure 9). I removed the single outlier, GSHC05 (Hat Creek sample 5), which made the separation of the Ashcroft Blue deposit more pronounced. The Ashcroft Blue deposit has consistently higher levels of Ti and Zn than the other toolstone deposits (Figures 7 and 8). An additional bivariate fit plot of Zr by Zn also distinguished the Ashcroft Blue deposit from the other toolstone deposits.

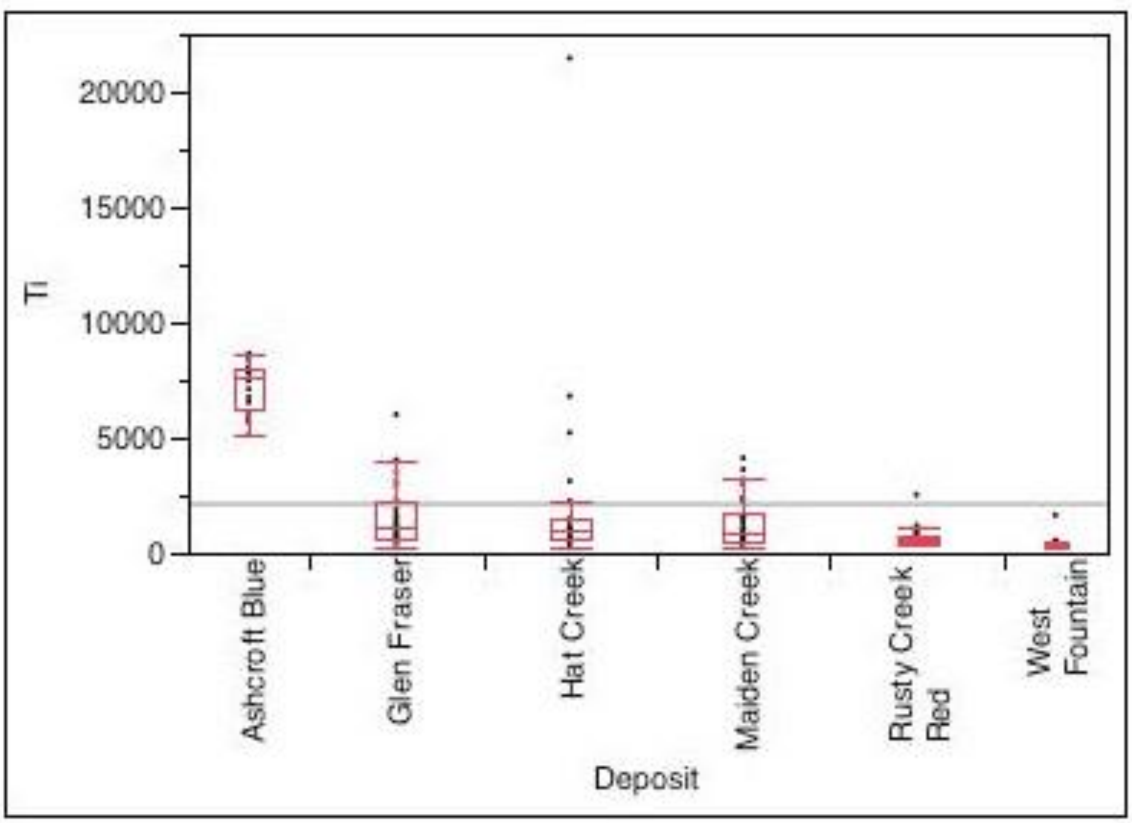

Figure 7. Boxplot of Ti Quantities between Toolstone Deposits. Gray line indicates the mean.

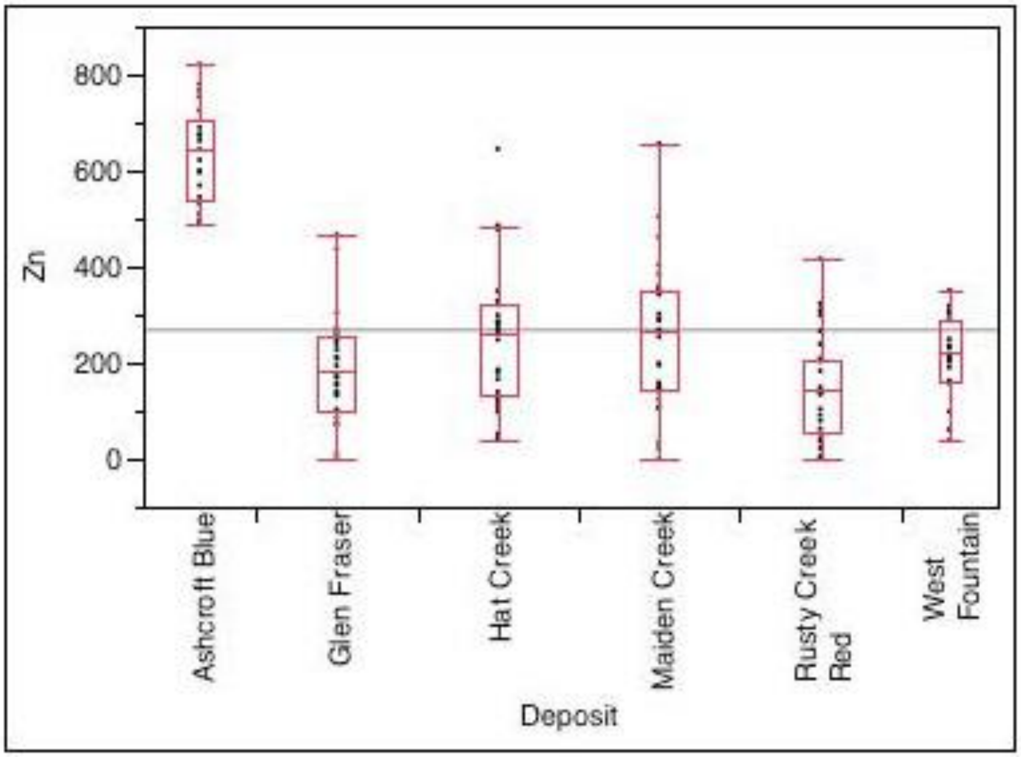

Figure 8. Boxplot of Zn Quantities between Toolstone Deposits. Gray line indicates the mean.

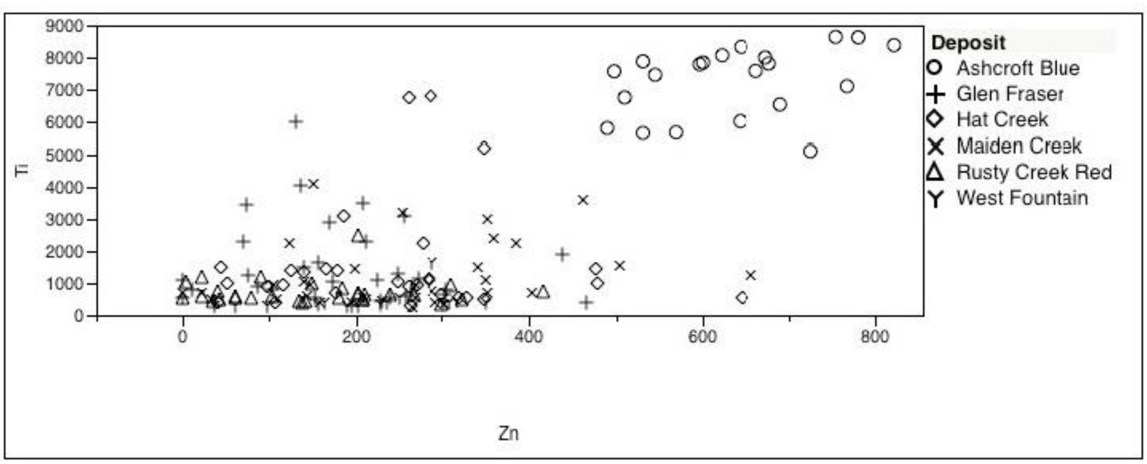

Figure 9. Bivariate Plot Ti by Zn of the Toolstone Deposits.

The West Fountain Deposit

Six individual West Fountain samples were analyzed and each sample was run three times on different spots of the samples. A boxplot of Cr showed the clear distinction between the West Fountain deposit and the other material deposits (Figure 10). I plotted these results against the Glen Fraser, Hat Creek, Maiden Creek, Rusty Creek Red, and Ashcroft Blue deposits using the bivariate fit plot of Cr by Ti (see Figure 11). The West Fountain deposit has consistently higher levels of Cr than the other toolstone deposits. Additional bivariate plots of Ni by Ti and Ni by Cr (Figure 12) confirmed this separation and characterization of the West Fountain deposit from the others.

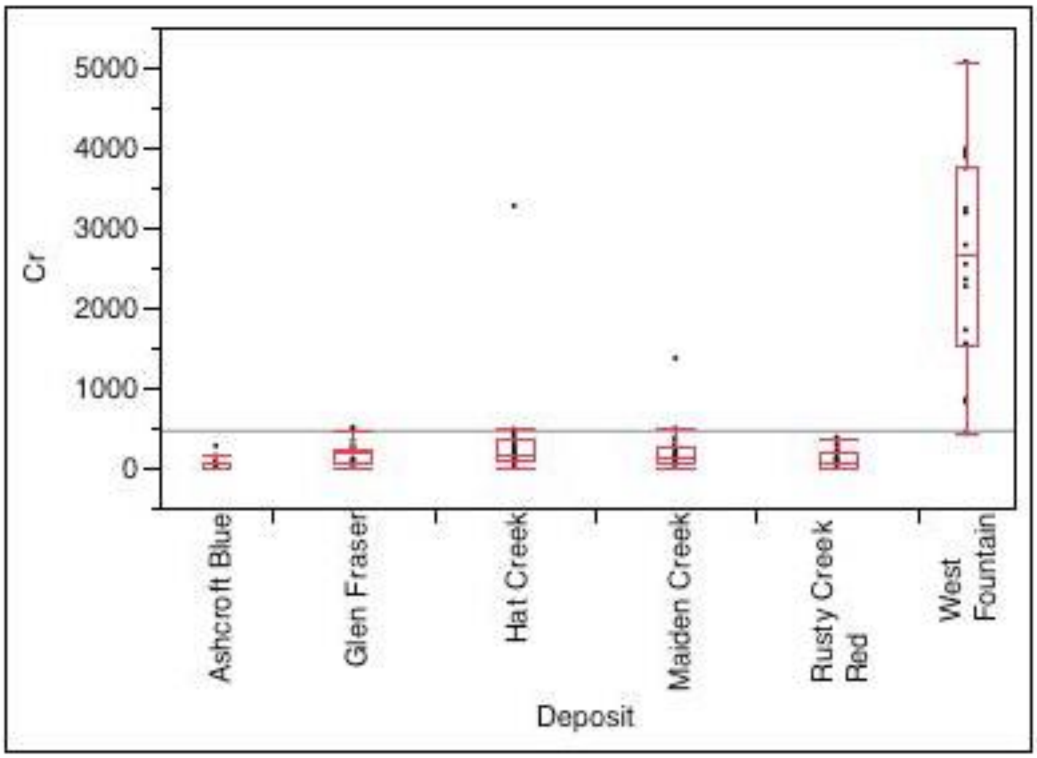

Figure 10. Boxplot of Cr Quantities between Toolstone Deposits. Gray line indicates the mean.

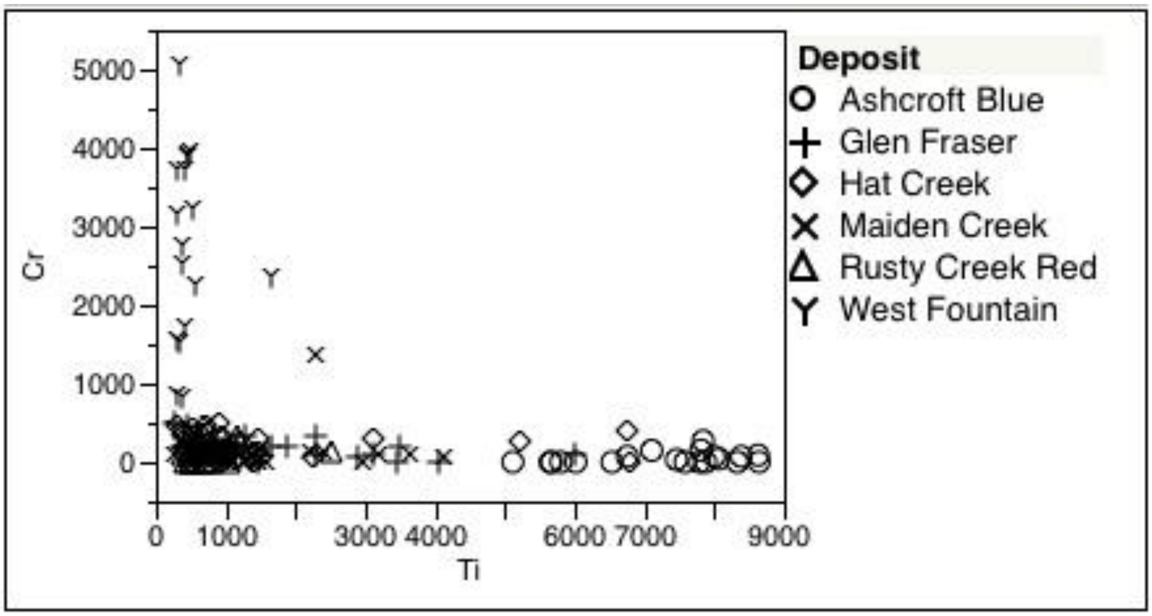

Figure 11. **Bivariate Plot Cr by Ti**

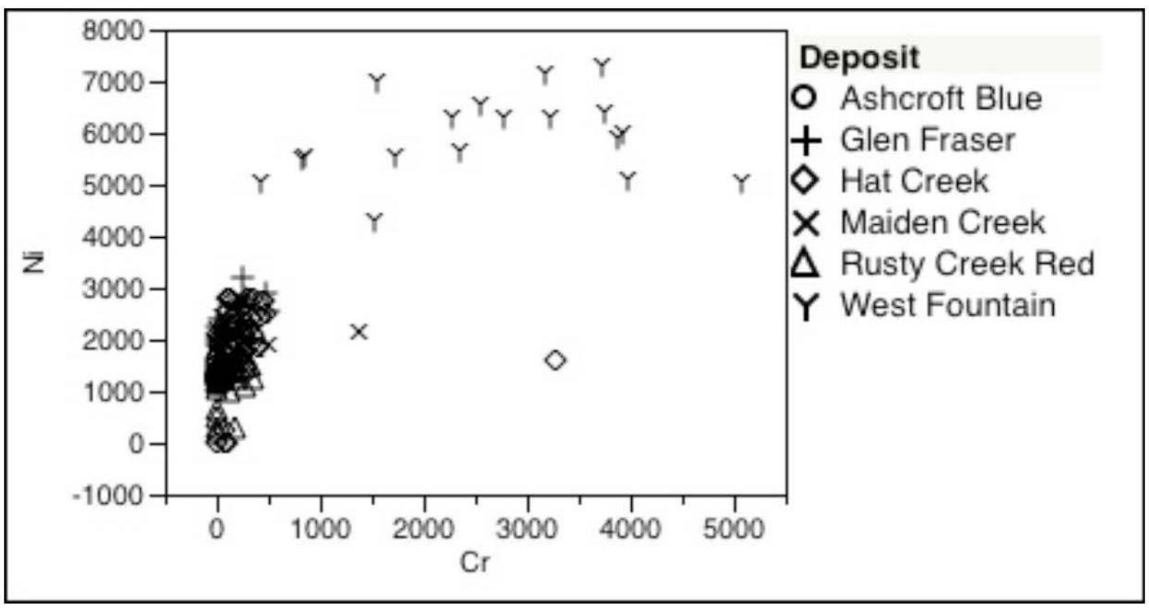

Figure 12 **Bivariate Plot Ni by Cr.**

The Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red Deposits

I analyzed ten samples each from the Glen Fraser, Maiden Creek, and Rusty Creek Red deposits. The individual samples were run three times per sample on different spots for a total of 30 tests per deposit (Table 1). I ran six samples from the Hat

Creek deposit, five times each on different spots for a total of 30 tests for the deposit (Table 1). Principal component analysis of the pXRF data considers the data with an eigenvalue of 65% of the cumulative variance in the mid-Fraser chert deposits as indicated by the first two principal components (Table 5; Figure 13). It is clear from this analysis that the trace elements Rb and Fe are responsible for most of the variation within the dataset. Principal component 1 accounts for 43% of the cumulative variance, with all of the variance accounted for within five principal components. Principal component 2 accounts for 23% of the variance within the dataset (Table 5). Elements that influence these two components include Fe and Rb (principal component 1) and K and Cr (principal component 2). Using a loading plot (Figure 14) to discern if one or more trace elements were useful in discriminating the deposits, I confirmed that there is not adequate variation between the deposits to characterize each individually, as evidenced in the clusters of trace elements. Additional (more than fifty), principal component analyses using different elemental combinations in JMP did not provide further clarity.

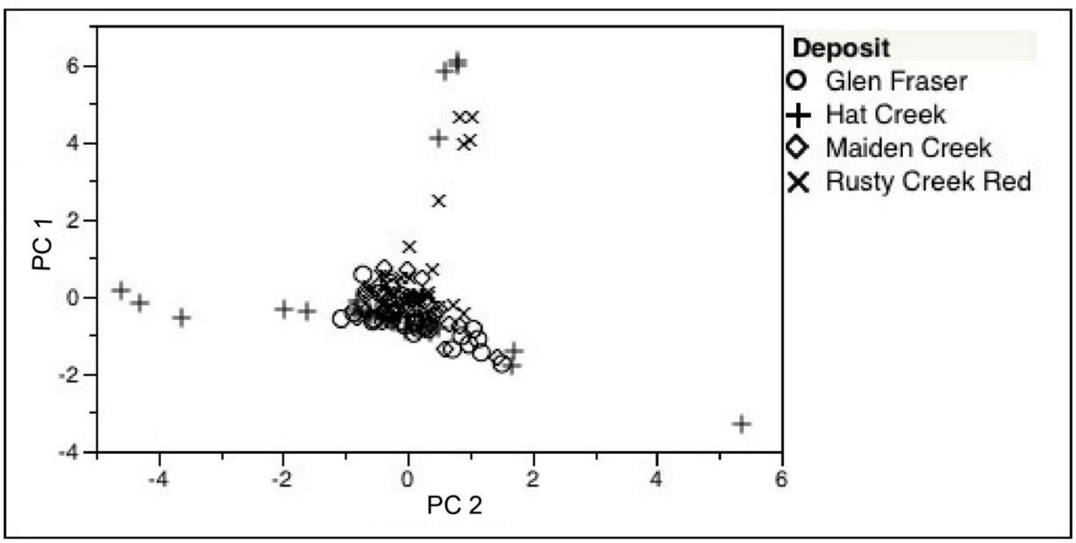

Figure 13. Principal Components Analysis Component 1 by Component 2 plot

Table 5. Principal Components Analysis of mid-Fraser Toolstone Deposits Characterized by pXRF.

	Prin1	Prin2	Prin3	Prin4	Prin5
%Variance	43.647	21.381	20.972	12.282	1.719
Cumulative % Variance	43.647	65.028	85.999	98.281	100.00
Eigenvalues	2.1823	1.0691	1.0486	0.6141	0.0859
K	**-0.58976**	**0.56009**	0.09921	**0.57305**	0.01619
Cr	**-0.32278**	**0.38215**	**0.77531**	**-0.38553**	-0.00546
Fe	**0.93142**	0.16308	0.22179	0.11344	0.20930
As	-0.13932	**-0.73170**	**0.59002**	**0.31155**	-0.00463
Rb	**0.91836**	0.21759	0.20079	0.16471	-0.20450

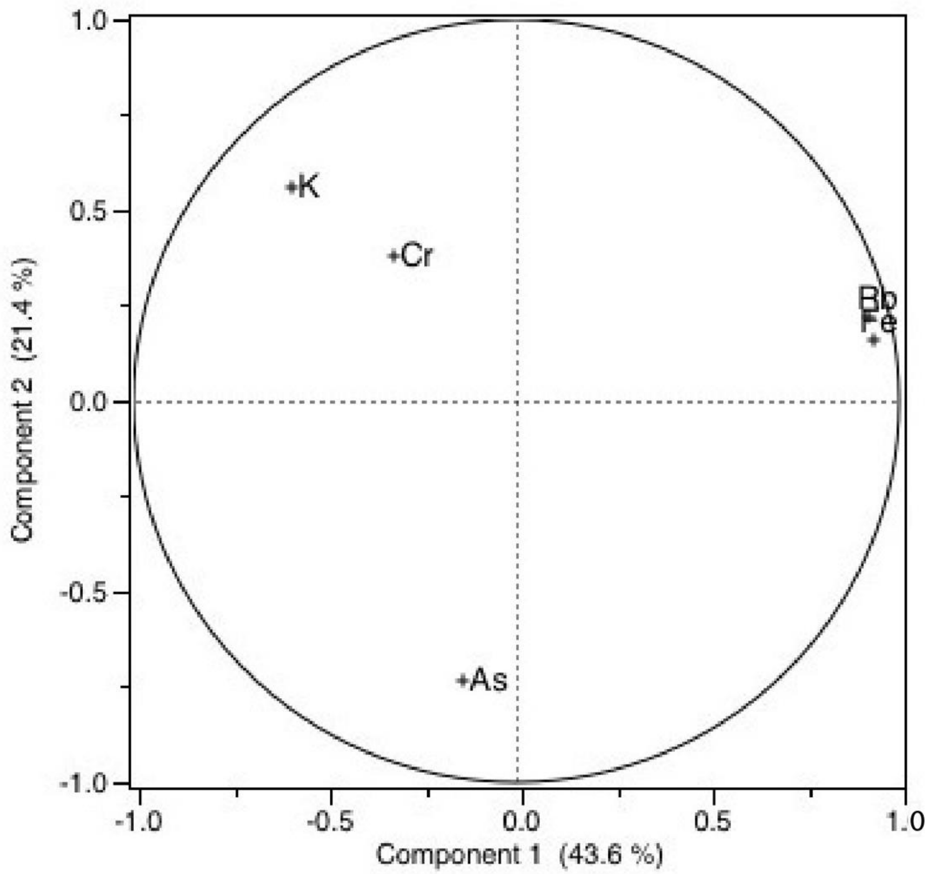

Figure 14. Loading Plot of mid-Fraser toolstone deposits elements using pXRF using the following elements: K, As, Cr, Fe, and Rb.

Artefacts

I analyzed 19 artefacts, each measured three times on different spots. The pXRF raw photon counts are included in Appendix C: worksheet 3. I then characterized the artefacts using the pXRF elemental analysis to determine how many source groups were represented.

Characterization

Using bivariate plots, I identified two groups of artefacts as possible source groups represented within the artefact samples. Artefact 5 stood out immediately as an outlier and could be distinguished using the bivariate fit plot Ca by Zn (Figure 15). This observation was confirmed using bivariate fit plots that included Zn, Sr, and Mn. Based on the bivariate plots, artefact 5 is best characterized as having high levels of Ca, Mn, and low levels of Ni relative to the other artefact samples. Figure 15 shows the best range of variation among the artefact samples, and clearly identifies artefact 5 as an outlier, while the remaining artefacts group together. This dispersal did not change with additional bivariate plots that excluded artefact 5 from the dataset; the group of artefacts remained consistently together. (Artefact 6 [Y] represents a single run of three and the dispersal from the group shown in Figure 15 likely represents an anomaly or measurement error.)

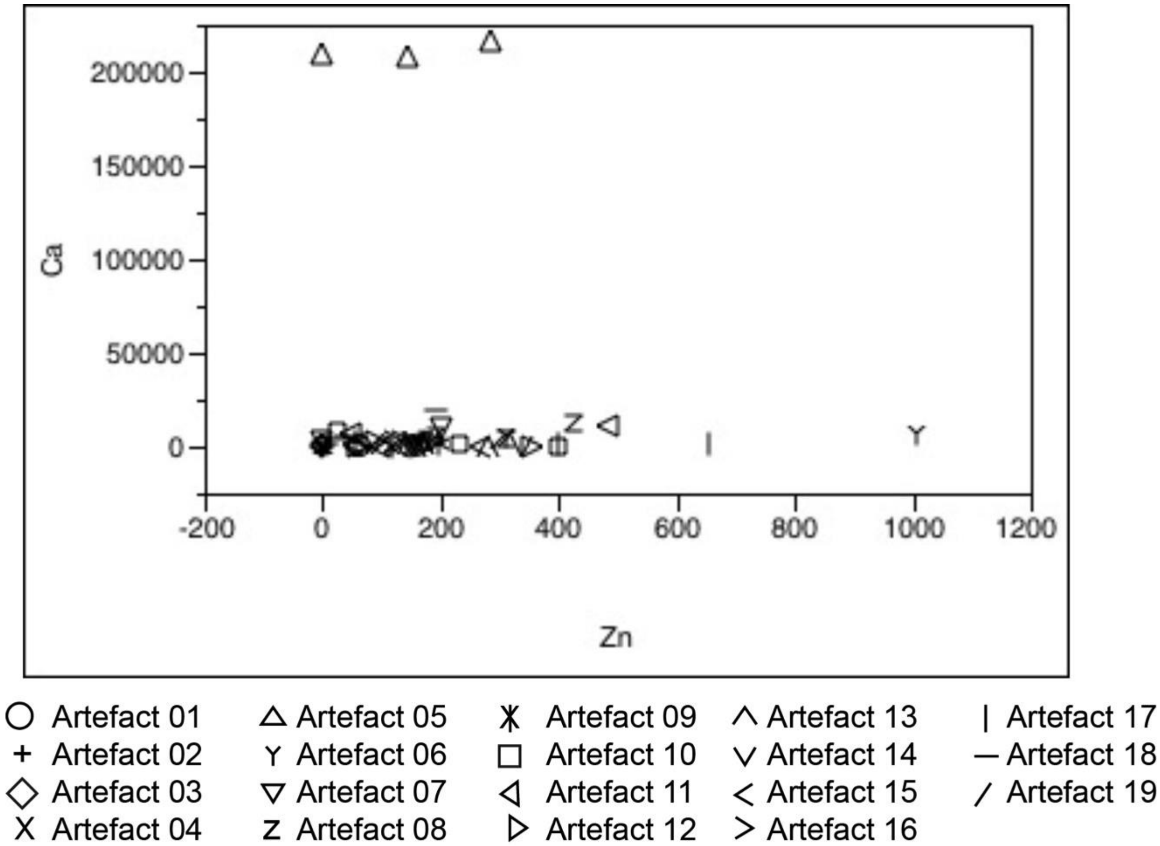

Figure 15. **Bivariate Plot Ca by Zn of Artefacts Analyzed using pXRF.**

Having established the elemental groups of artefacts represented in the dataset, I next compared the elemental data for the artefacts to the toolstone deposits that I successfully characterized—the Ashcroft Blue and West Fountain deposits. I also compared the results of the group of four toolstone deposits that could not be individually distinguished.

Artefact Provenance: Ashcroft Blue and West Fountain Deposits

I used bivariate plots to investigate the potential for a relationship between the artefacts and the Ashcroft Blue and West Fountain deposits. Artefact 5 was removed from this analysis, as it is an outlier from the rest of the artefact group, and did not cluster with the Ashcroft blue deposit samples using bivariate analyses. Using the bivariate plot Ti by Zn for the remaining artefacts, it is clear that the artefacts do not overlap or correspond at all with the Ashcroft Blue deposit (Figure 16). This was confirmed with additional bivariate plots using JMP with a variety of different elemental combinations.

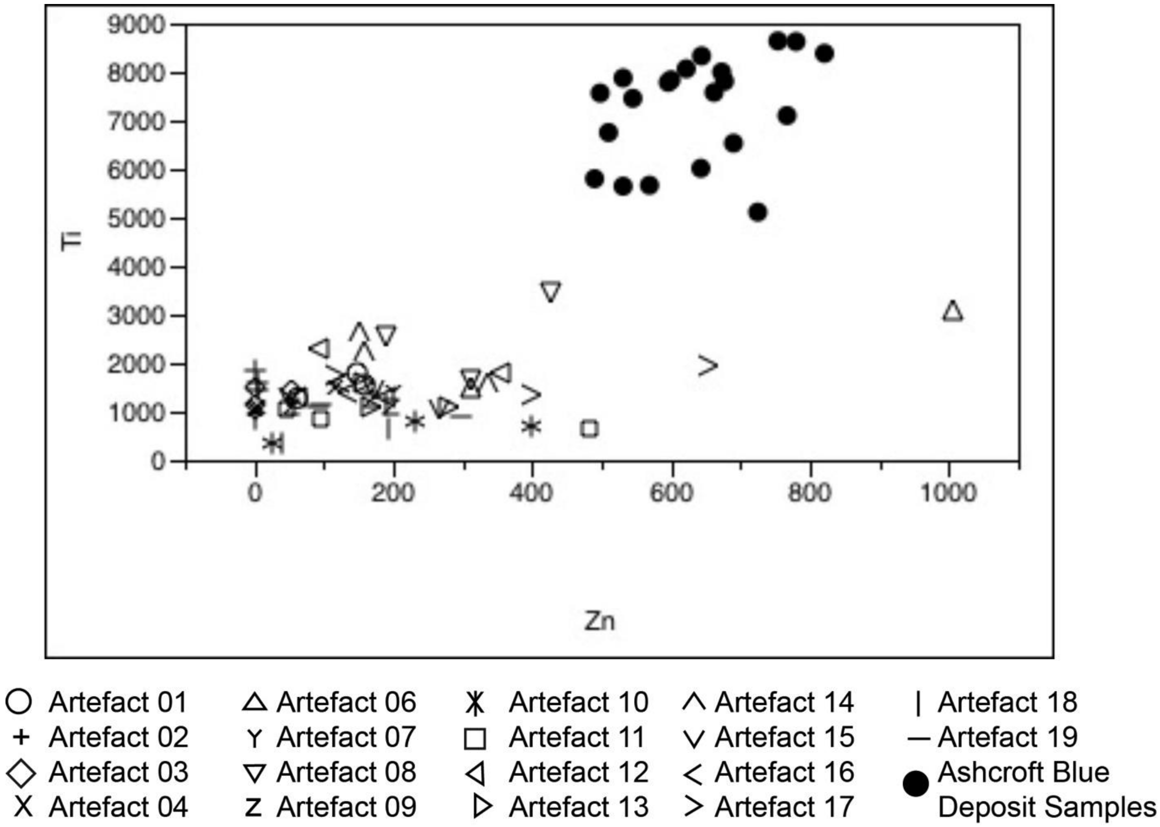

Figure 16. Bivariate Plot of Ti by Zn of Ashcroft Blue Deposit Samples and Artefact Samples.

A similar lack of correspondence was noted between the artefacts and the West Fountain deposit. The bivariate plot Cr by Ti showed that the artefacts do not associate or relate to the West Fountain deposit samples (Figure 17).

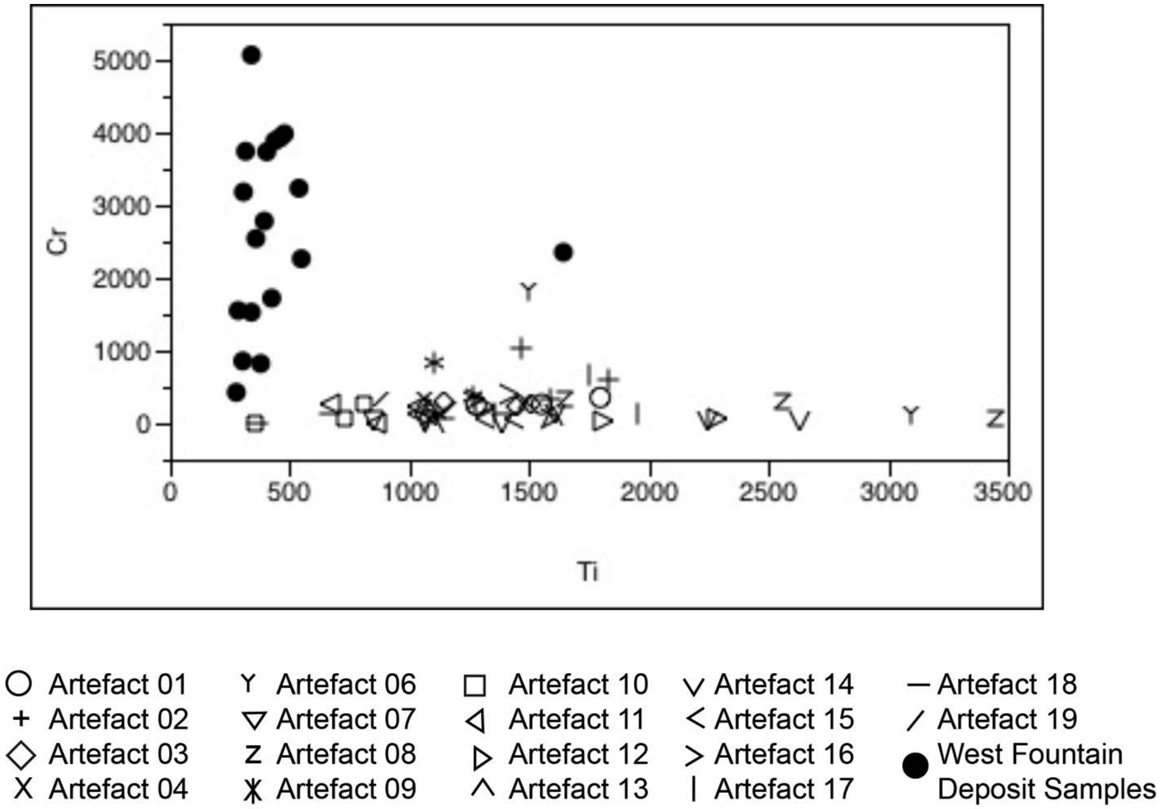

Figure 17. Bivariate Plot of Cr by Ti of West Fountain Deposit Samples and Artefact Samples.

Provenance of Artefacts: Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red Deposits

Since the Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red deposits could not be characterized individually using bivariate plots or even PCA, I used the same PCA to explore the relationship between the artefacts and this group of deposits. Using K, As, Fe, and Rb in a PCA (Figure 18; Table 6) for both the toolstone deposits and artefacts with two principal components, it is clear that the artefacts are very similar to, or closely related to this group of deposits, in most cases.

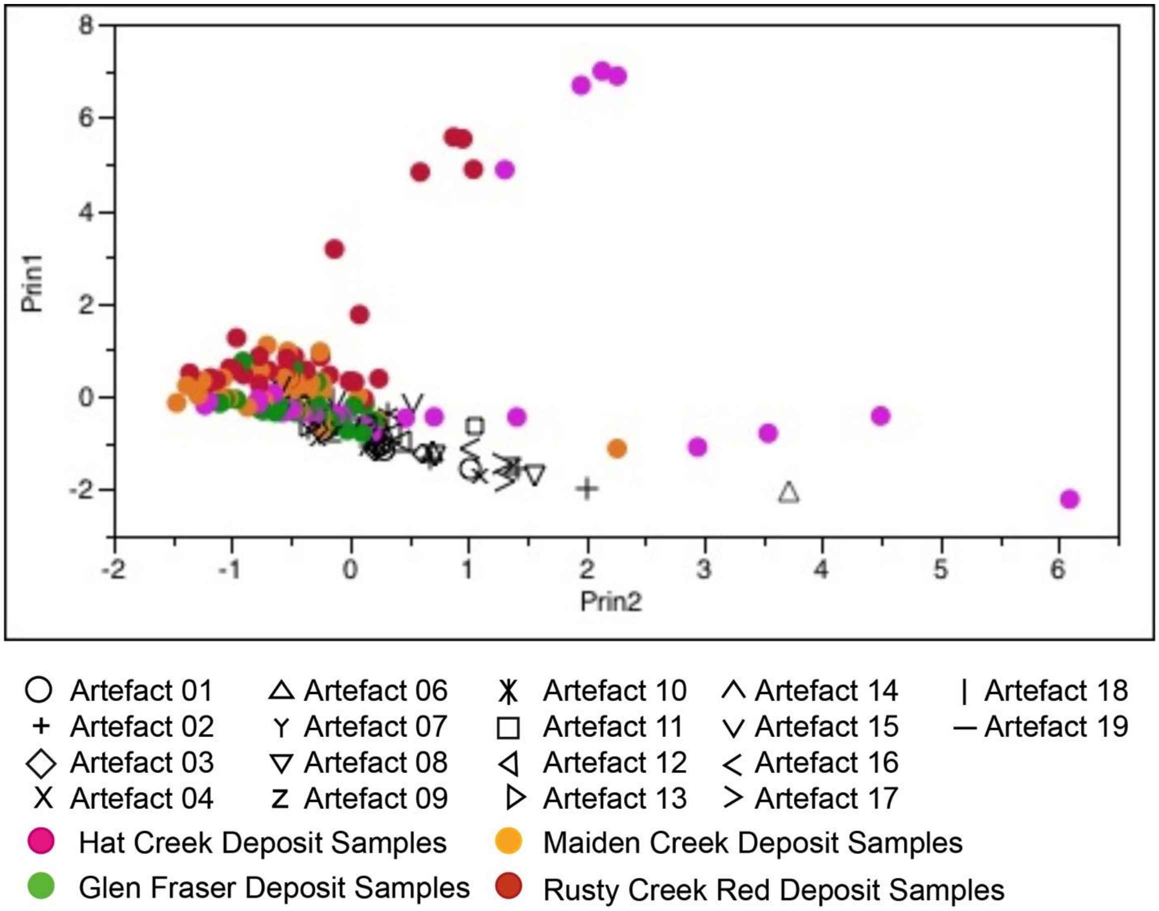

Figure 18. **Bivariate Plot of Principal Components of the mid-Fraser Silicate Deposits and Artefacts Characterized Using pXRF.** Principal Component analysis conducted using the following elements: K, As, Rb, Cr, and Fe.

Table 6. Principal Components Analysis of mid-Fraser Toolstone Deposits and Artefacts Characterized by pXRF.

	Prin1	Prin2	Prin3	Prin4	Prin5
%Variance	43.309	21.807	16,994	16.217	1.673
Cumulative % Variance	43.309	65.115	82.109	98.327	100.00
Eigenvalues	2.1654	1.0903	0.8497	0.8109	0.0837
K	**-0.55007**	0.26156	0.08528	**0.78719**	0.04552
Cr	**-0.31705**	**0.65241**	**-0.30496**	**-0.30496**	-0.00537
Fe	**0.93502**	0.28086	0.05782	0.05782	0.20852
As	**-0.31817**	**0.63976**	-0.16867	-0.16867	-0.04420
Rb	**0.88704**	**0.32881**	0.25770	0.25770	-0.19508

Principal component analysis demonstrates that the artefacts are similar to the Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red deposits (Figure 19). Principal component analysis of the pXRF data considers the data with an eigenvalue of 69% of the variance in the mid-Fraser chert deposits as illustrated by the first two principal components (Table 6; Figure 18). It is clear from this analysis that two transition metals (Fe and Cr), and one semi-metal (As) are responsible for most of the variation within the dataset. Principal component 1 accounts for 43.3% of the cumulative variance, with all of the variance accounted for within five principal components. Principal component 2 represents 21.8% of the variation within the dataset. The first two principal components represent a total of 65.11% of the cumulative variance (Table 6) within the dataset. Elements that influence these two components include Fe and Rb (principal component 1), and Cr and As (principal component 2). Using a loading plot (Figure 19) to discern if one or more trace elements were useful in discriminating the deposits, I confirmed that there is not enough variation between the deposits to characterize each individually, as evidenced in the two clusters of trace elements (i.e., Fe and Rb for principal component 1, and As, Cr, and K for principal component 2). Additional analyses in JMP did not provide further clarity.

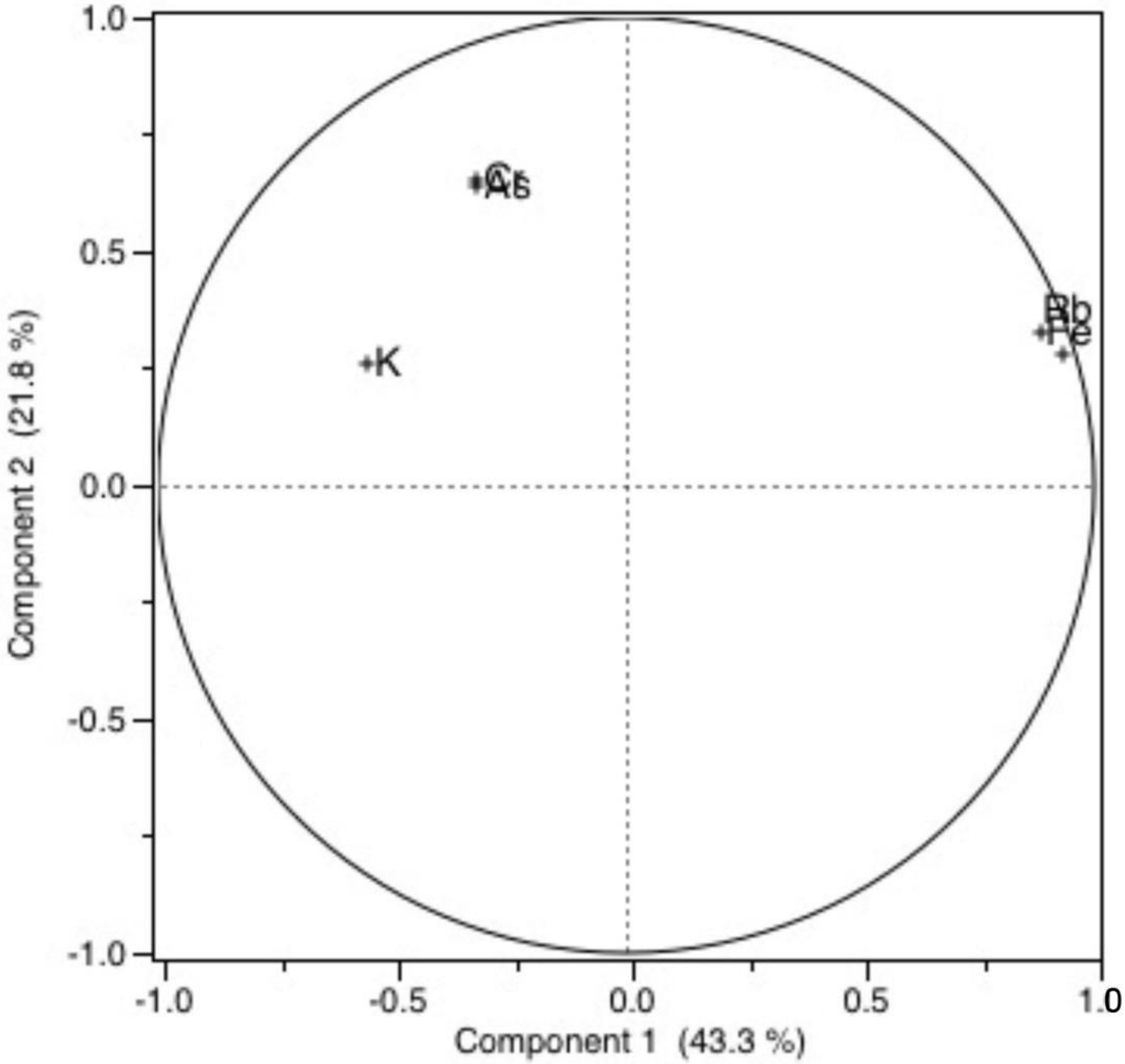

Figure 19. Loading Plot of PCA for Artefacts and Toolstone Deposits.

Visual Identification Applied to Artefact Elemental Analysis

The Keatley Creek Typology was used to assign chert types to the artefacts included in my analysis. I identified seven types of chert and chalcedony represented among the artefact samples using the Keatley Creek Typology: Chalcedony 1, Chalcedony 3, Chalcedony 7, Chalcedony 17, Chert 2, Chert 5, and Chert 6. Bakewell (Hayden 2004) redefined Chalcedony 3 and 17, and Cherts 2, 5, and 6 as jasper type cherts (Table 7). In addition, Bakewell (Hayden 2004) redefined Chalcedony 1 as a vitric tuff and confirmed that Chalcedony 7 is a chalcedony (Table 8). Chalcedony classifications are included here because Bakewell also redefined types previously labelled as chalcedony as jaspers (e.g., Chalcedony 3 was redefined as jasper). The results of Bakewell's reassessment of the chert material types are shown as a separate column in the typology (see Appendix A).

Table 7. Visual Identifications of Artefacts using Keatley Creek Typology.

Artefact	Hayden's Typology	Bakewell's Re-assessment
01	Chalcedony 7 (White Translucent)	Chalcedony
02	Chalcedony 7 (White Translucent)	Chalcedony
03	Chalcedony 3 (Mustard yellow)	Jasper
04	Not in typology	Unknown
05	Chalcedony 7 (White Translucent)	Chalcedony
06	Chalcedony 1 (light grey)	Vitric tuff
07	Chert 5 (medium-brown)	Jasper
08	Chalcedony 17 (mottled red/yellow)	Jasper
09	Chalcedony 1 (light grey)	Vitric Tuff
10	Chert 2 (reddish-brown)	Jasper
11	Chert 2 (reddish-brown)	Jasper
12	Chert 6 (medium yellow)	Jasper
13	Chert 5 (medium brown)	Jasper
14	Chert 2 (reddish-brown)	Jasper
15	Chert 2 (reddish-brown)	Jasper
16	Chalcedony 17 (mottled red/yellow)	Jasper
17	Not in typology	Unknown
18	Chert 2 (reddish-brown)	Jasper
19	Unknown material type Not in typology	Unknown

Scatterplot matrices were used to identify differences within the artefacts by comparing their internal (elemental) composition to their external colour as categorized using Hayden's (2004) Keatley Creek Typology. The results showed that the artefact samples do not consistently separate into any additional sub-groups based on the attribute of colour. I used a bivariate fit plot to compare the quantities of Fe and As as well as Fe by Sr among the artefacts, using colour as the group type to confirm the scatterplot results (Figures 20 and 21). Iron was chosen as this element is considered to be a key indicator for jasper type cherts, which are generally noted to be a reddish-brown colour. If colour is a reliable indicator of chert type, red cherts should consistently group together. Looking at Figure 21, the red Chert 2 type samples overlap with the Chert 5 and Chert 6 samples, which according to Hayden's typology are brown and yellow coloured cherts.

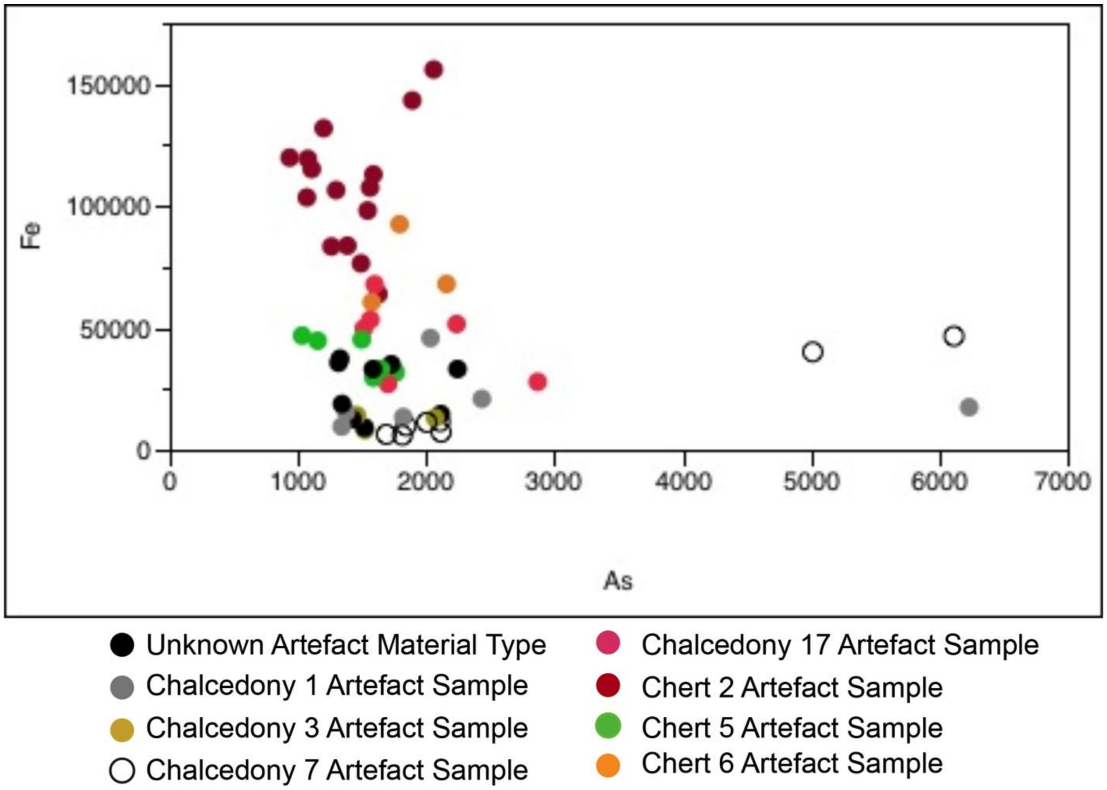

Figure 20. Bivariate Plot of Fe by As with Artefacts Classified by Colour Using the Keatley Creek Typology.

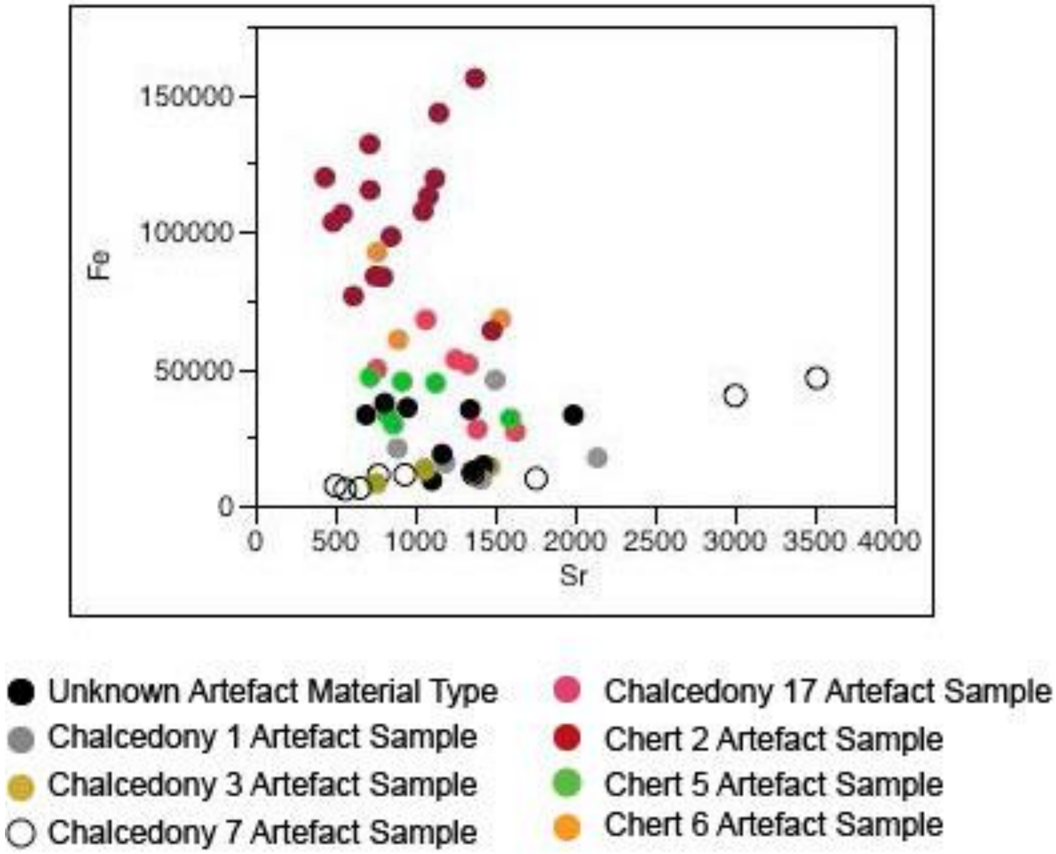

Figure 21. Bivariate Plot of Fe by Sr Classified by Colour Using the Keatley Creek Typology.

I then applied Bakewell's textural classification of chert types to my artefact samples and all the artefacts using his four categories: jasper (N=11); chalcedony (N=3); vitric tuff (N=2); and unknowns (N=3). I removed artefact 5 (the established outlier) from the dataset and plotted Fe by As and Fe by Sr using a bivariate plot (Figure 22). Based on the bivariate plot, the jasper types are high in iron (a criterion for all jaspers), which may aid in future characterization studies of chert with a larger sample size. Additional bivariate plots of Fe by Cr and Fe by Sr confirmed this observation. These results show that the chert types cannot be distinguished from one another conclusively using relic textures.

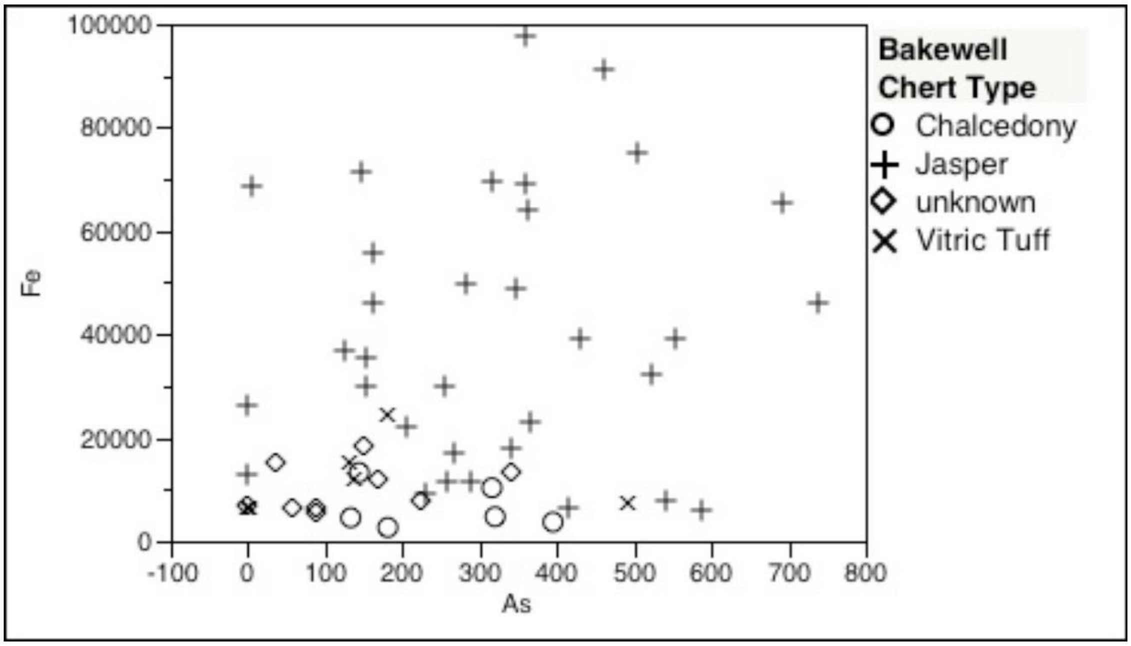

Figure 22. Bivariate Plot Fe by As of Artefacts According to Bakewell's Chert Type.

Summary

The toolstone areas were studied to gather information about their physical and geochemical properties. Many of these toolstone deposits have high potential to have been utilized by hunter-gatherer populations living in the mid-Fraser region. As such, I analyzed samples from the Ashcroft Blue, Glen Fraser, Hat Creek, Maiden Creek, Rusty Creek Red, and West Fountain toolstone deposits using pXRF instrumentation provided through the Department of Archaeology at SFU.

I identified K Alpha peaks for Si, S, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Rb, Sr, Y, Zr, and La. Using boxplots, I noted that particular elements (i.e., Fe, Rb, As, and Cr), had the potential to separate deposits from one another. In addition to the boxplots, I ran a number of scatterplot matrices to explore which elemental matches had the potential to characterize the toolstone deposits. This approach helped me characterize both the Ashcroft Blue and West Fountain deposits. High levels of Ti and Zn relative to other deposits characterized the Ashcroft Blue deposit whereas high levels of Cr characterized the West Fountain deposit. I was unable to separate out the Glen

Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red deposits from one another using bivariate plots and PCA.

From the artefact dataset, I analyzed 19 artefacts and detected K alpha peaks for Si, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Rb, Sr, Y, Zr, and La. I began by categorizing the artefact samples using the Keatley Creek Typology to assess whether this typology, based on colour, is appropriate for use on chert toolstone materials. The results of this show that although there are seven individual material types represented according to the unedited version of the typology, this amount is reduced to four types considering Bakewell's reassessment of lithic material types at Keatley Creek. These groups were not identified or reflected in the pXRF analysis, as I was only able to identify a single outlier (artefact 5), and the artefacts represented a single group based on the elemental data.

I was able to identify a single outlier (Artefact 5) within the pXRF artefact samples based on its high levels of Ca, Sr, and Mn. I was not able to identify other source groups using bivariate plots. The remaining artefacts likely represent multiple toolstone deposit sources but these could not be conclusively identified, an issue discussed further in Chapter 7.

Chapter 6.

INAA Results

In this chapter, I present the results of the statistical analysis of the elemental compositions detected using INAA for the chert toolstone materials and artefacts. The chapter is divided into two sections: the first focuses on the characterization of the toolstone deposits and the artefact samples; and the second section tests the reliability of visual properties (colour) and petrographic properties (relic textures) by applying the Keatley Creek lithic typology to the artefacts analyzed using INAA.

Elemental and Statistical Analysis

Geochemical analysis of the cherts at McMaster University Reactor produced elemental concentration values for 34 elements—Al, As, Au, Ba, Br, Ca, Ce, Cl, Co, Cr, Cs, Dy, Eu, Fe, Hf, K, La, Lu, Mg, Mn, Na, Nd, Rb, Sc, Sm, Sr, Ta, Tb, Ti, U, V, Yb, and Zn—associated with 18 geological and 51 archaeological chert samples. At the suggestion of McMaster University Reactor staff (Macdonald 2009; see Appendix D), sample GSLMD101 (geological sample, Medicine Creek number 101) was removed from the study due to its irregular reaction during the INAA process.

Toolstone Deposits

I used boxplots to discern patterns and identify outliers within the toolstone deposit samples. Using these plots, I identified Cr, Fe, and Zn as elements that have the potential to characterize some of the deposits. I then plotted these elements using bivariate plots for the toolstone deposits. Where these provided inconclusive results for some of the deposits, I used PCA.

Table 8 presents the basic statistics for the INAA data. The summary statistics presented were calculated using the elemental data and include the minimum (MIN), maximum (MAX), mean, standard deviation (SD), and the coefficient of variation (CV) for each element per deposit. Summary statistics were only calculated for deposits with a sample size greater than 1; therefore, summary statistics for the Ashcroft Blue and West Fountain deposits are not included.

Table 8. **INAA Statistical Data.** Data are expressed in ppm.

	Glen Fraser *(n=6)*				Hat Creek *(n=8)*				Maiden Creek *(n=6)*				Rusty Creek Red *(n=2)*			
	MIN	MAX	Mean and SD	CV(%)	MIN	MAX	Mean and SD	CV (%)	MIN	MAX	Mean and SD	CV(%)	MIN	MAX	Mean and SD	CV(%)
Al	845	6617	4581 ± 2519	55	570	11693	3814 ± 3778	99	64	25029	7676 ± 10937	142	1172	1467	1319 ± 208	16
As	0	4	1 ± 2	109	0	391	143 ± 169	118	0	43	10 ± 17	169	9	13	11 ± 3	26
Au	0	0	0	39	0	0	0	93	0	1	0	218	0	0	0	16
Ba	21	438	130 ± 159	123	15	1451	299 ± 483	162	17	698	144 ± 272	189	23	32	28 ± 6	23
Br	0	1	1 ± 0	76	0	1	0	61	0	99	17 ± 40	237	1	1	1	11
Ca	154	2018	698 ± 682	98	137	3762	1503 ± 1338	89	204	6433	1996 ± 2339	117	445	483	464 ± 27	6
Ce	2	22	6 ± 8	126	1	8	3 ± 2	72	0	32	7 ± 12	187	0	0	0	34
Cl	7	28	11 ± 8	73	10	140	38 ± 46	120	5	31	14 ± 10	73	8	9	9	2
Co	0	2	1	81	0	3	1 ± 1	70	0	3	2 ± 1	91	1	1	1	35
Cr	1	6	2 ± 2	80	0	10	4 ± 4	113	1	12	3 ± 4	121	1	1	1	9
Cs	0	1	0	117	0	8	2 ± 3	143	0	1	0	112	0	0	0	10
Dy	0	3	1±1	137	0	1	0	47	0	1	0	44	0	0	0	1
Eu	0	0	0	89	0	0	0	68	0	1	0	176	0	0	0	8
Fe	539	42928	9071 ± 16670	184	935	274978	75216 ± 114291	152	111	48103	14242 ± 18750	132	23667	36921	30294 ± 9372	31
Hf	0	1	0	61	0	0	0	106	0	4	1 ± 2	223	0	0	0	57
K	89	1608	949 ± 629	66	25	742	311 ± 273	88	67	4001	913 ± 1522	167	45	59	52 ± 10	19
La	2	12	5±4	81	1	2	1±1	42	1	20	4 ± 8	184	1	1	1	8
Lu	0	0	0	106	0	0	0	107	0	0	0	90	0	0	0	9
Mg	45	429	248 ± 145	59	36	1084	366 ± 373	102	87	980	287 ± 352	123	50	55	53 ± 4	7
Mn	5	348	86 ± 129	150	3	767	196 ± 254	129	2	191	66 ± 75	114	34	41	38 ± 5	13
Na	31	283	106 ± 93	88	43	419	165 ± 124	76	0	7437	1231 ± 2997	227	106	109	108 ± 2	2
Nd	2	4	3±1	36	1	3	2 ± 1	41	0	21	4 ± 8	180	0	1	1	45
Rb	0	0	0	85	0	0	0	116	0	0	0	46	0	0	0	28
Sb	0	1	0	101	0	6	2 ± 2	106	0	3	2±1	69	42	46	44±3	7
Sc	0	2	1±1	78	0	1	0	82	0	5	1±2	170	0	0	0	25
Sm	0	2	1±1	105	0	1	0	38	0	0	0	78	0	0	0	9
Sr	342	2448	1551 ± 774	50	450	8000	4030 ± 2740	68	1600	3200	1963 ± 611	31	201	1046	623 ± 597	96
Ta	0	0	0	37	0	0	0	55	0	0	0	16	0	0	0	8

Tb	0	0	0	78	0	0	0	59	0	0	0	156	0	0	0	17
Ti	40	361	197 ± 117	59	14	646	188 ± 229	122	70	1142	353 ± 404	114	31	42	37 ± 8	21
U	0	1	0	49	0	7	3 ± 3	85	0	3	1 ± 1	118	0	0	0	1
V	2	119	26 ± 46	178	4	111	36 ± 37	105	3	80	21 ± 30	143	45	72	58 ± 20	34
Yb	0	1	0	112	0	1	0	128	0	5	1 ± 2	190	0	0	0	4
Zn	1	67	14 ± 26	192	0	20	9 ± 7	79	1	30	8 ± 11	143	0	0	0	23

Ashcroft Blue Deposit

The INAA analysis of the Ashcroft Blue deposit consisted of a single sample, as the second sample underwent an irregular reaction to the INAA process. As such, these results should only be considered as a compliment to the pXRF results, and should not be taken as a stand-alone result. Boxplots demonstrated that the Ashcroft Blue deposit contains different amounts of Ti, Sr, and Zn compared to the other toolstone deposits (Figure 23). A second set of elements—Fe, Ca, and Cu—also distinguished this deposit, in some instances. I used bivariate plots of varying combinations to determine if these elements consistently characterized the Ashcroft Blue deposit compared to the other deposits. The bivariate plot Ti by Zn shows the separation of the Ashcroft Blue deposit (Figure 24).

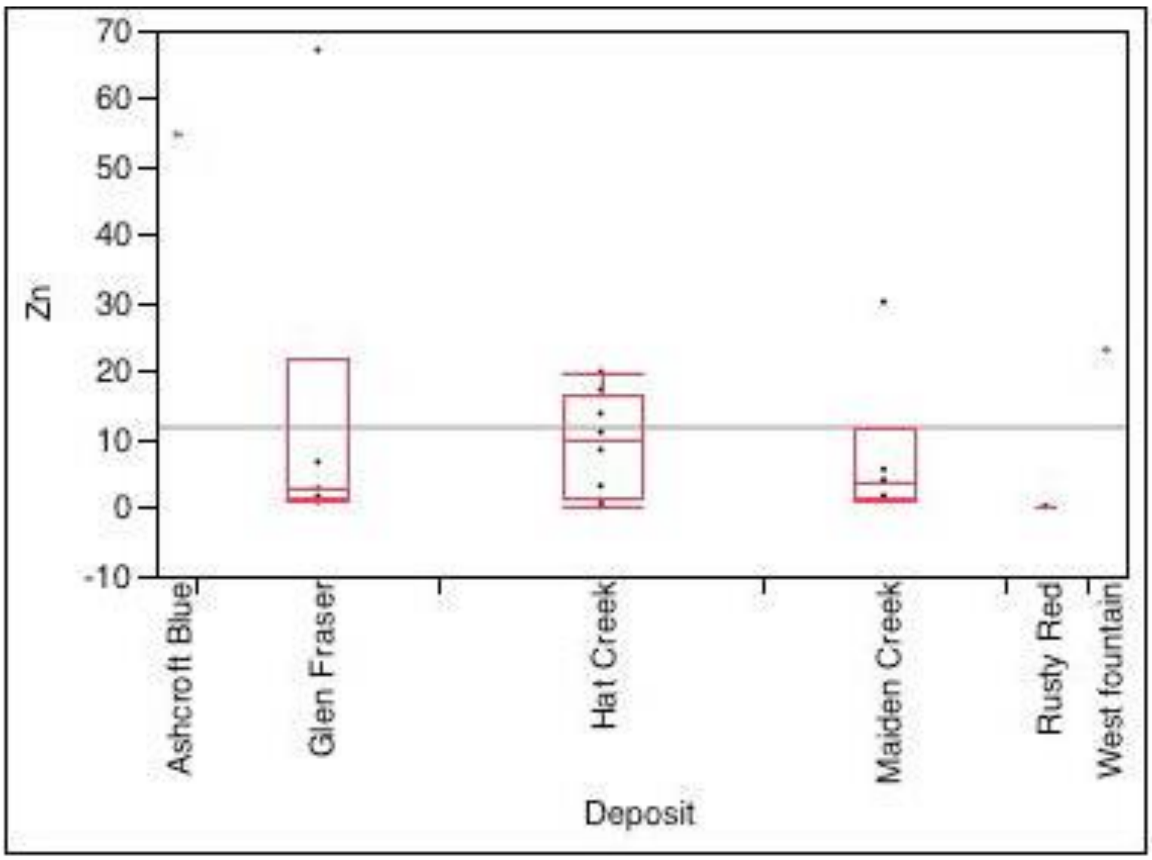

Figure 23. Boxplot of Zn.

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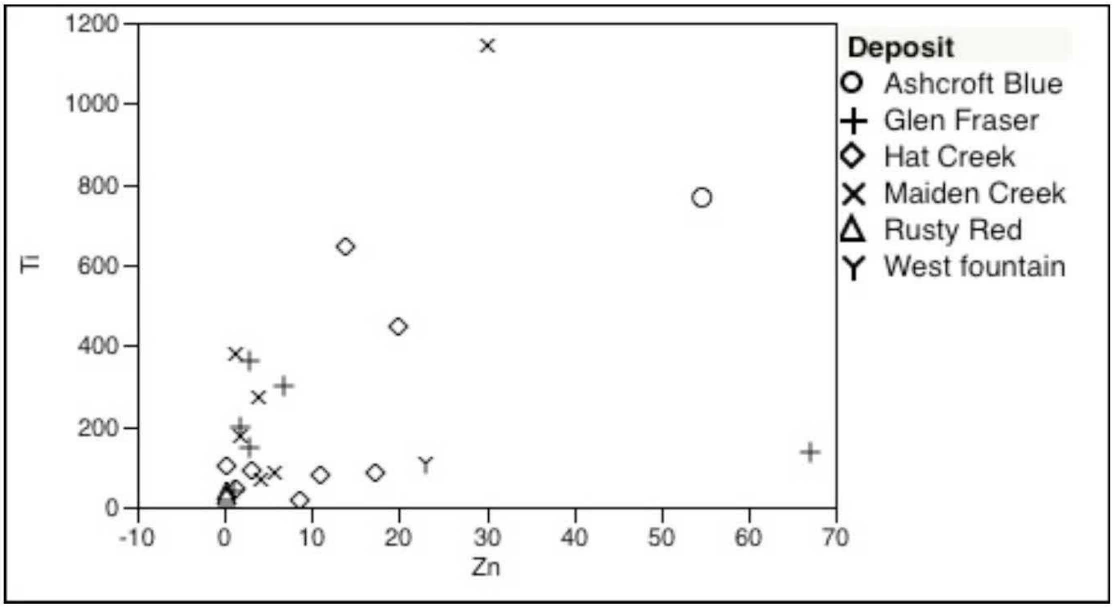

Figure 24. **Bivariate Plot Ti by Zn.**

West Fountain Deposit

Similar to the Ashcroft Blue deposit analysis, the INAA analysis of the West Fountain deposit consisted of a single sample. As such, the results shown here should also only be considered as a compliment to the pXRF results, and should not be taken as a stand-alone result. I used boxplots to discern which elements set the West Fountain deposit apart from the others. The plots showed that West Fountain contains different amounts of Cr, Ti, and Zn when compared to the other deposits (Figure 25). Figure 26 illustrates the difference between West Fountain and the other deposits; it has lower levels of Ti, but higher levels of Cr. Additional bivariate plots of Cr by Zn confirmed this observation.

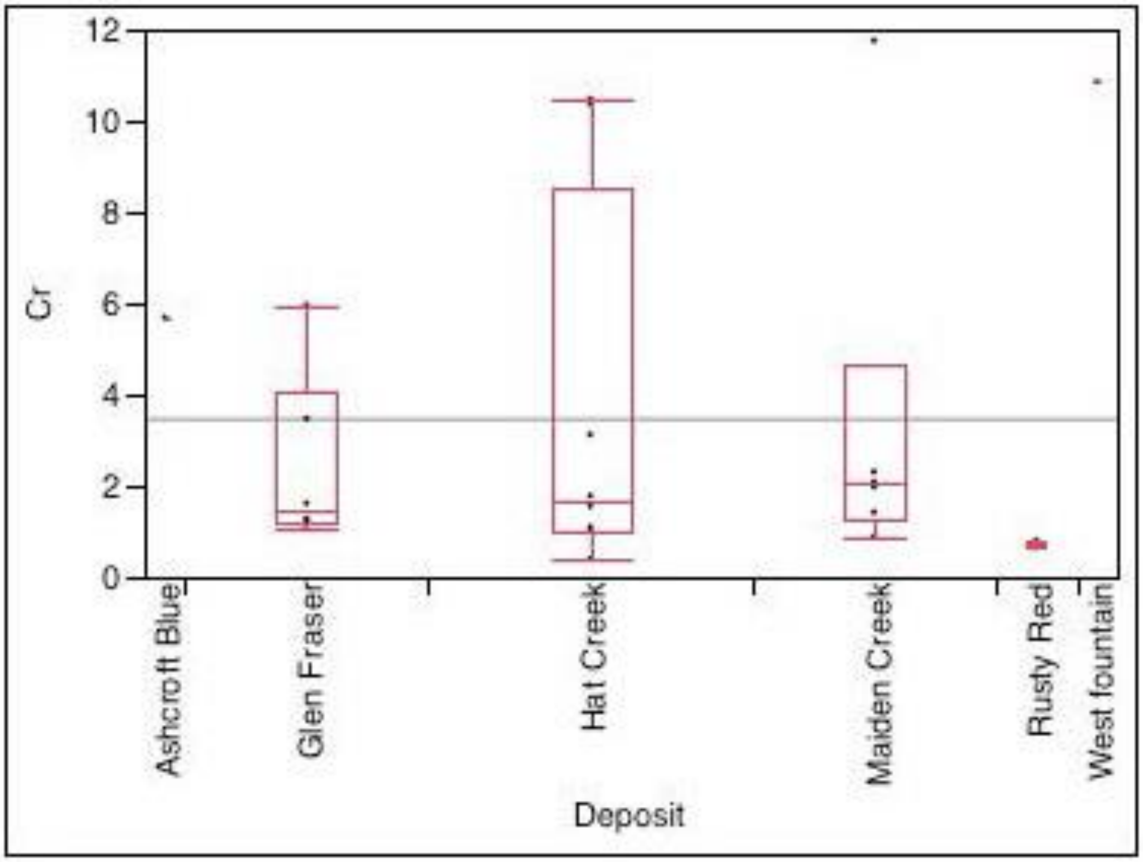

Figure 25. **Boxplot of Cr.**

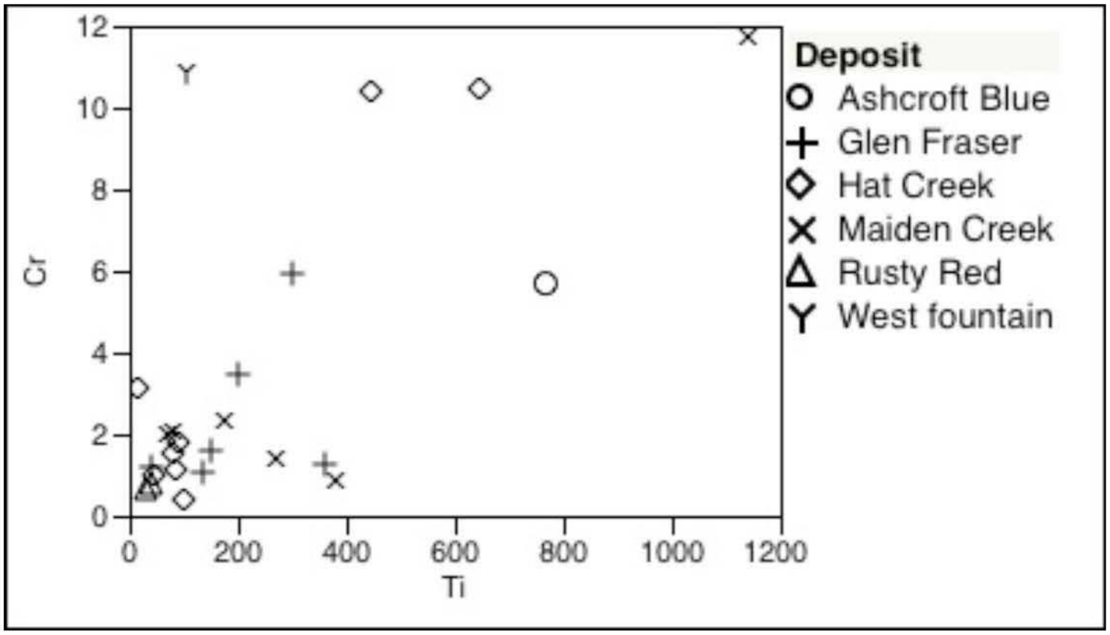

Figure 26. Bivariate Plot Cr by Ti.

The Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red Deposits

Although I was able to distinguish the Ashcroft Blue and West Fountain deposits from the other deposits, I was unable to individually characterize the Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red deposits. The boxplots suggested that Fe, As, Rb, and Zn had the potential to help separate these deposits; however, bivariate plots using these elements were inconclusive.

I conducted numerous PCAs using different variations of elements, but a PCA of K, As, Rb, Cr, and Fe produced the best results. Additional PCAs did not provide further clarity or insight into the individual deposits. Ultimately, the results of the PCAs were inconclusive in terms of distinguishing the toolstone deposits from one another. As illustrated by the first two principal components (Figure 27; Table 9), PCA of the INAA data separated the toolstone deposits with an eigenvalue of 68.4% of the cumulative variance in the mid-Fraser chert deposits. One transition metal (Fe), one alkaline earth metal (Cr), one alkali metal (K), and one semi-metal (As) are responsible for most of the variation within the dataset. Scores for the first and second principal components suggest that the mid-Fraser toolstone deposits are not homogeneous and all of these elements are loading (or weighting) the analysis for all of the deposits, which inhibits individual characterization—there is not enough inter-variation between these four deposits to characterize each individually. Figure 28 shows the elemental loading that occurs within this PCA, confirming the observed lack of variation as evidenced in the clusters of trace elements (As, Rb, Fe and Cr, K). Additional analyses in JMP 10 did not provide further clarity.

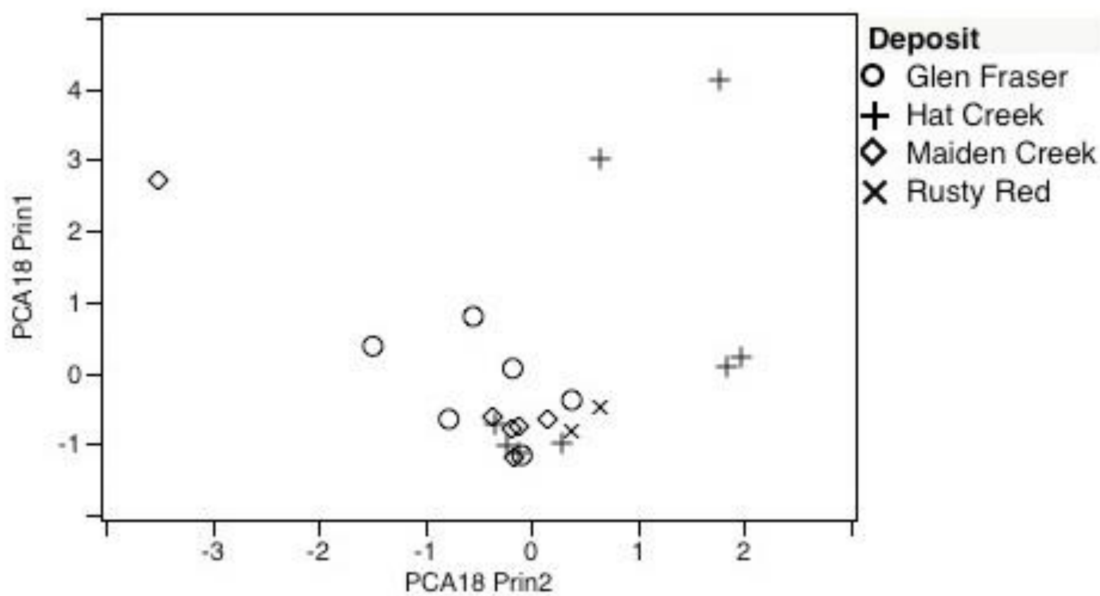

Figure 27. Bivariate Plot of Principal Components of the mid-Fraser Toolstone Deposits Characterized Using INAA.

Table 9. Principal Components Analysis of the mid-Fraser silicate deposits characterized using INAA. Values in bold indicate strong elementally loading

	PC1	PC2	PC3	PC4	PC5
% Variance	42.298	26.131	17.847	13.133	0.592
Cumulative % Variance	42.298	68.428	86.275	99.408	100.00
Eigenvalues	2.1149	1.3065	0.8923	0.6566	0.0296
As	**0.40948**	**0.62793**	**-0.34643**	**0.56392**	0.00197
Cr	**0.92152**	-0.29908	-0.18493	-0.11485	-0.11817
Fe	**0.78143**	**0.40445**	-0.10260	**-0.45565**	0.08742
K	**0.56511**	**-0.75078**	0.07834	**0.32147**	0.08661
Rb	0.40992	0.30910	**0.84938**	0.12030	-0.02236

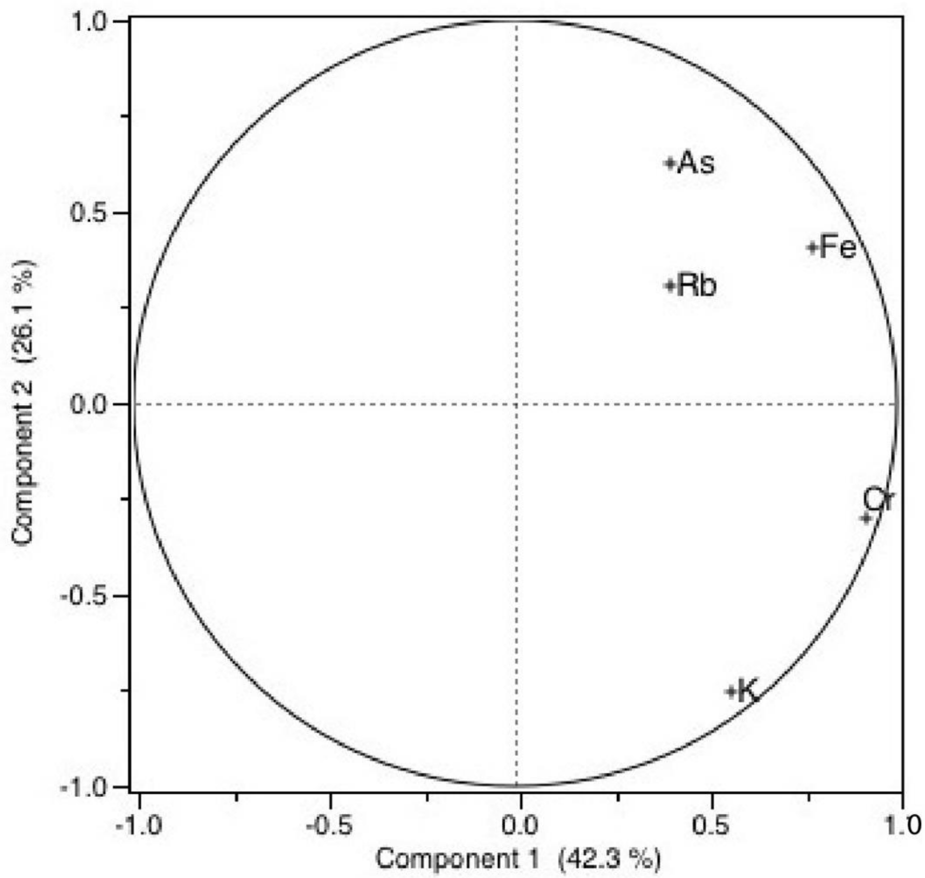

Figure 28. Loading Plot of mid-Fraser Toolstone Deposits Elements Using INAA.

Artefacts

Fifty-one artefacts were analyzed at McMaster University Reactor. The ppm data are included in Appendix C: worksheet 5. In this section, I use the elemental data derived from INAA to identify source groups represented among the artefacts through the application of boxplots, which are then confirmed using bivariate plots.

Characterization

Using a series of scatterplot matrices and boxplots, I could not identify different source groups represented within the INAA artefact samples, nor were there consistent outliers. The artefacts appear to consistently cluster together and do not contain enough variation within the group to represent different sources. Figure 29 shows a bivariate plot of Fe by Cr. I chose to show this plot because high levels of Fe have been associated with jasper type cherts. Additional bivariate plots of these elements did not consistently separate out groups of artefacts or provide further clarity.

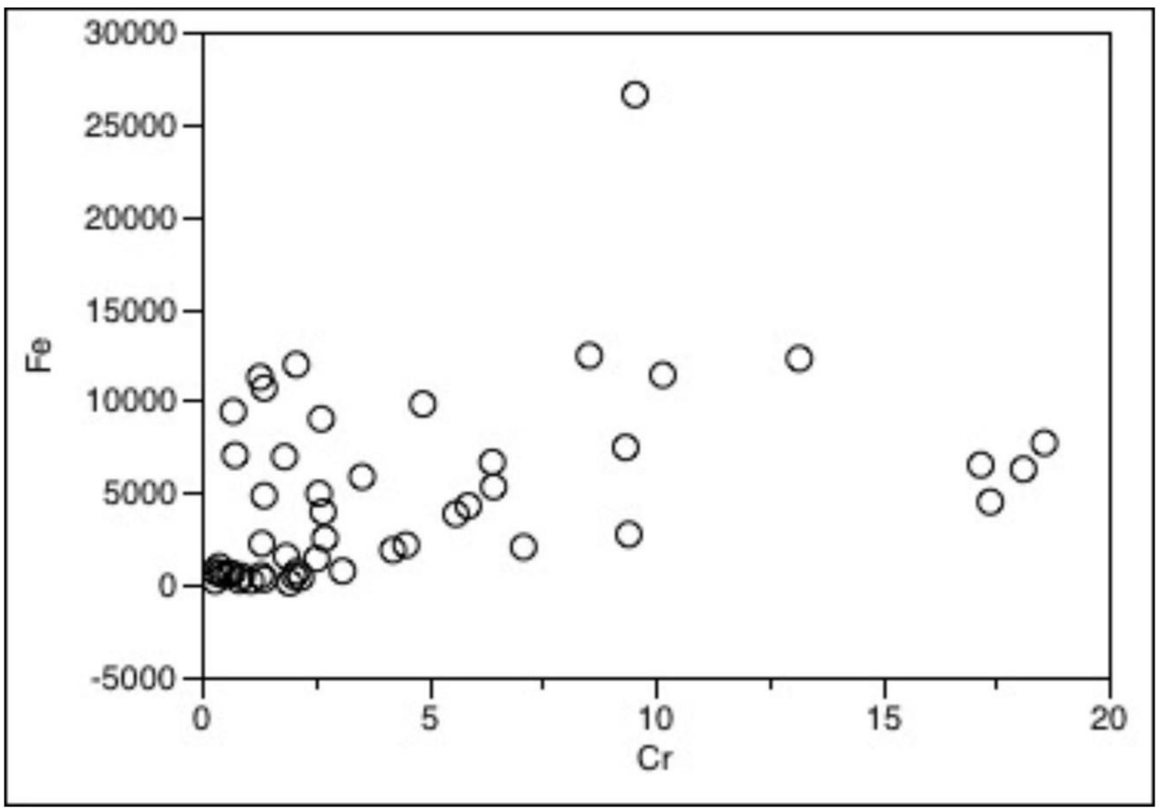

Figure 29. Bivariate Plot of Fe by Cr of the Artefact Samples Analyzed Using INAA

Provenance of Artefacts: Ashcroft Blue and West Fountain Deposits

The Ashcroft Blue sample and the artefact samples do not overlap or associate with each other when plotted using Ti by Zn (Figure 30). The artefacts cluster together, showing low levels of Ti and Zn, whereas the Ashcroft Blue sample is situated in the opposite corner of the plot with higher levels of both elements. There is a single outlier among the artefacts—sample ATCA616—identified as a Chalcedony 5 in the Keatley Creek Typology and reclassified as jasper by Bakewell (Hayden 2004).

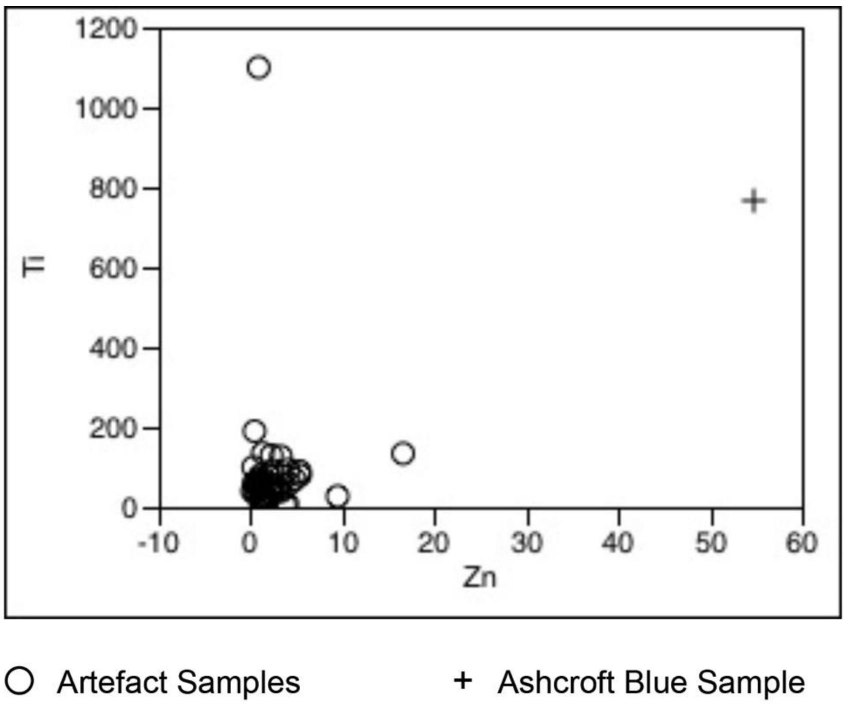

Figure 30. Bivariate Plot Ti by Zn of Ashcroft Blue Deposit Samples and Artefacts.

By contrast, the West Fountain deposit, when plotted using Cr by Ti, overlaps with some of the artefacts; specifically with those that are classified as Chert 2 type (jasper type) artefacts as defined by the Keatley Creek Typology. This relationship is displayed in Figure 31, which shows that West Fountain sample GSWF101 is surrounded by the artefact samples ATCH220, ATCH223, ATCH226, and ATCH522. Similar to the Ashcroft Blue plot, the single outlier is artefact sample ATCA616; a Chalcedony 5 type subsequently reclassified by Bakewell as jasper (Hayden 2004).

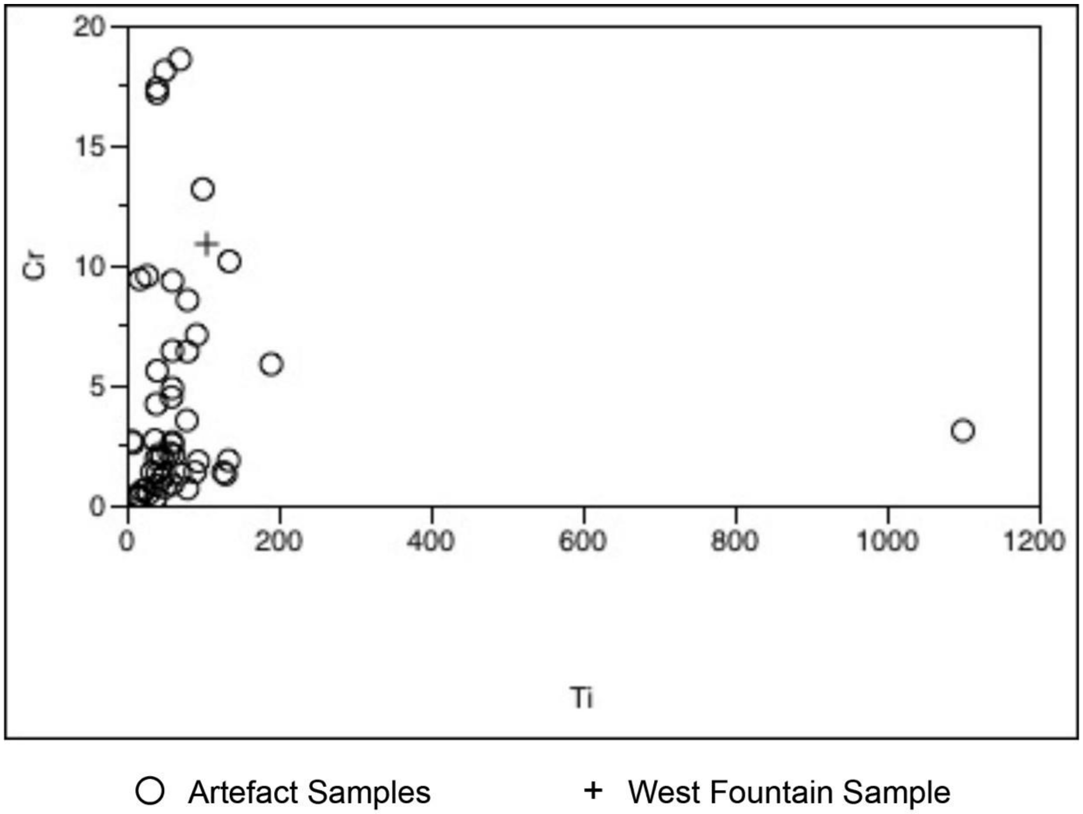

Figure 31. Bivariate Plot Cr by Ti West Fountain Deposit Samples and Artefacts

Provenance of Artefacts: Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red Deposits

I was unable to individually characterize the Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red toolstone deposits using the INAA dataset. The PCA which produced the best results included K, Cr, As, Fe, and Rb. Figure 34 shows the relationship that exists between these toolstone deposits and the artefact samples—the artefacts overlap with the Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red deposits suggesting the artefacts may have been made from toolstone materials from one or all of these locations.

This PCA accounts for 55.9% of the cumulative variance within the dataset in the first two principal components, and 100% of the cumulative variance is accounted for within five components (Figure 32; Table 10). The majority of the variation within the first two principal components is caused by all of the elements used in the PCA, with Rb contributing less, in terms of elemental loading (Figure 33).

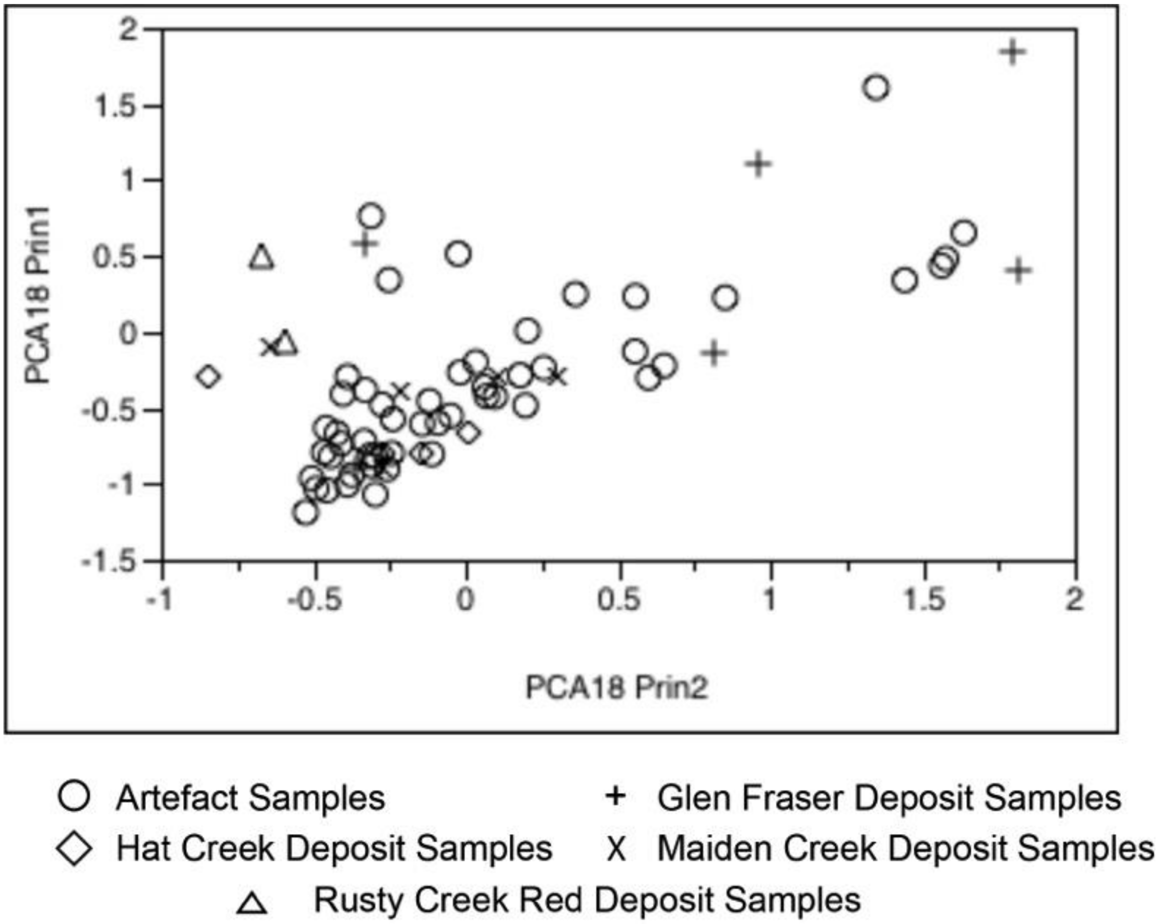

Figure 32. **Bivariate Plot of Principal Components Analysis of the mid-Fraser Silicate Deposits and Artefacts Characterized Using INAA.** The principal component's analysis was conducted using the following elements: K, As, Rb, Cr, Fe.

Table 10. Principal Components Analysis of the mid-Fraser Silicate Deposits and Artefacts Characterized Using INAA. Values in bold indicate strong elementally loading

	Prin1	Prin2	Prin3	Prin4	Prin5
%Variance	34.477	21.424	20.733	13.543	9.823
Cumulative % Variance	34.477	55.901	76.634	90.177	100
Eigenvalues	1.7238	1.0712	1.0367	0.6772	0.491
K	**0.47023**	**0.66266**	-0.30473	**0.48300**	-0.11669
Cr	**0.38412**	**0.53146**	**0.66600**	-0.24869	0.25417
Fe	**0.78985**	-0.23980	0.21137	-0.17169	**-0.49444**
As	**0.64675**	**-0.53904**	0.13919	**0.39200**	**0.34368**
Rb	**0.55947**	0.03982	**-0.66045**	**-0.44597**	0.22433

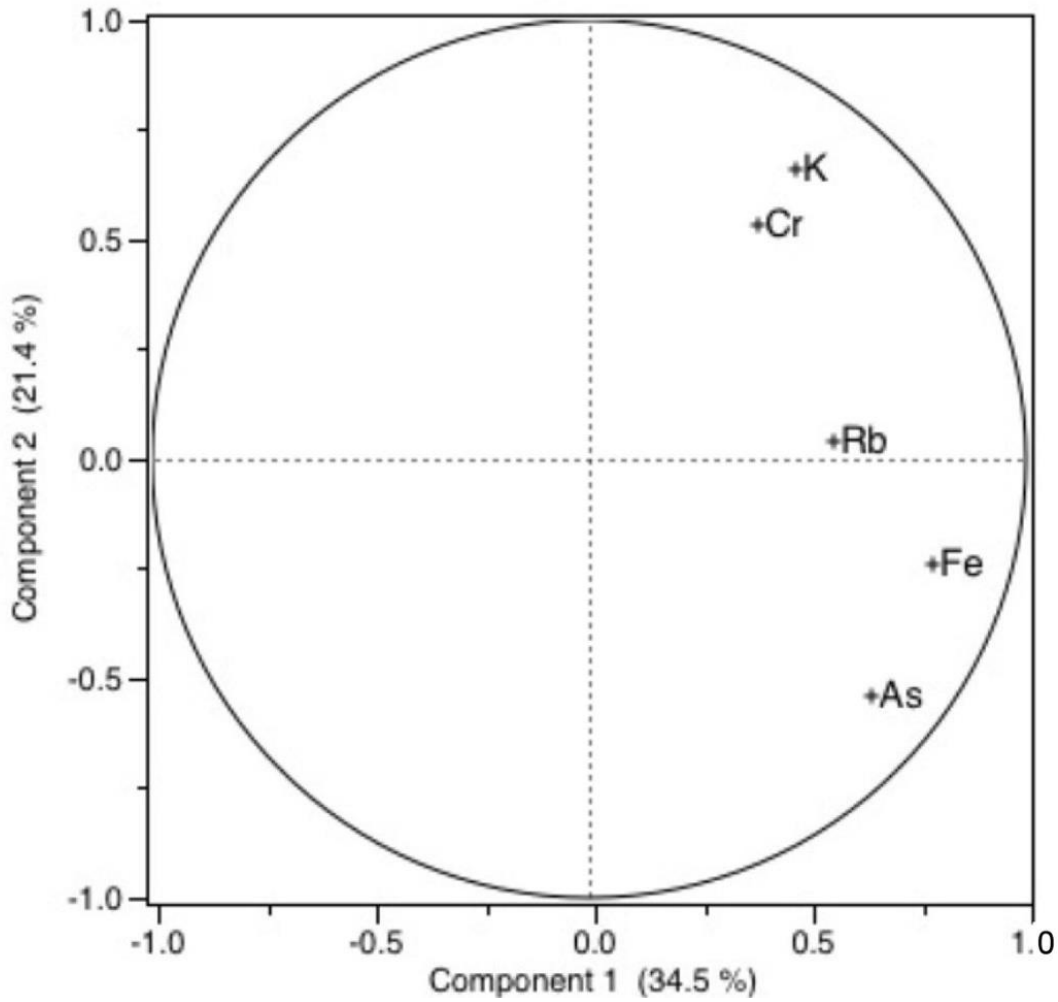

Figure 33. Elemental Loading Plot of Principal Components Analysis of the mid-Fraser Toolstone Deposits and Artefacts.

Visual Identification Applied to Artefact Elemental Analysis

In this section, I apply the Keatley Creek Lithic Typology material types to the artefact elemental data using both Hayden's colour-based (2004) cherts and Bakewell's (Hayen 2004) petrographic texture-based chert types to the artefact samples. I do this by assigning each artefact a designation based on colour and texture, and running subsequent bivariate plots using the elements employed in the artefact characterization. These plots indicate that material types defined by Bakewell and Hayden do not reliably cluster together using elemental data.

According to the Keatley Creek Typology, 25 of the artefacts analyzed using INAA in my study are classified as Chert 2, a reddish-brown chert subsequently redefined as jasper by Bakewell (Hayden 2004). Chalcedony classifications were included here because Bakewell (Hayden 2004) redefined types previously labelled as chalcedony as jaspers and cherts (e.g., Chalcedony 3 was redefined as jasper). Bakewell's adjustments are shown as a separate column in the typology (see Appendix A).

I identified 12 types of chert and chalcedony represented among the artefact samples using the original visually-based Keatley Creek Typology: Chalcedony 2 (N=2), Chalcedony 3 (N=1), Chalcedony 5 (N=1), Chalcedony 6 (N=3), Chalcedony 7 (N=3), Chalcedony 10 (N= 2), Chalcedony 11 (N=1), Chalcedony 17 (N=2), Chert 2 (N=25), Chert 5 (N=2), Chert 6 (N=3), and unknowns (N=6; materials that did not fit into the typology). Bakewell (1995; Hayden 2004) redefined Chalcedony 2, 3, 10, and 17, and Cherts 2, 5, and 6 as jasper type cherts (Table 11); in addition, he redefined Chalcedony 1 as a vitric tuff and confirmed Chalcedony 7 as a chalcedony (Table 11; Hayden 2004).

I applied Hayden's colour-based chert types to the samples analyzed using INAA, to a bivariate plot of Fe by Cr, the plot used to display the range of variation present among the artefact dataset for characterization (Figure 34). According to Figure 34, the artefacts do not cluster by colour, instead, the artefacts group together regardless of colour designation.

Using Bakewell's reassessment (Hayden 2004) of the material types represented at Keatley Creek, I found that five different materials are present within my artefact sample assemblage (Figure 35): vitric tuff (N=2); jasper (N=33); pisolite[25] (N=3); chalcedony (N=3); and unknowns (N=9; listed by Bakewell as "other"). These artefacts do not cluster together based on their assigned material type; instead all of the material groups fall together, with some outliers.

[25] A pisolite is a sedimentary rock that is composed of pisoids (concretionary grains) that are composed primarily of calcium carbonate (Bakewell 1995: 49). Bakewell used pisolites to identify a specific texture within some of the Keatley Creek cherts. Pisolitic texture has a speckled appearance, and is often described by archaeologists working at the site as "speckled chert" (Bakewell 1995: 50).

Table 11. Visual Identifications of Artefacts Using Keatley Creek Typology.

Artefact	Material Type (Hayden)	Material Type (Bakewell)
ATCA602	Chalcedony 6	Pisolite
ATCH606	Chert 2	Jasper
ATCA606	Chalcedony 6	Pisolite
ATCA707	Chalcedony 7	Chalcedony
ATCA1708	Chalcedony 17	Jasper
ATCA210	Chalcedony 2	Vitric Tuff
ATCA2111	Chalcedony 2	Vitric Tuff
ATCA713	Unknown material type- not in typology	Unknown
ATCA616	Chalcedony 5	Jasper
ATCH219	Chert 2	Jasper
ATCH1008	Unknown material type- not in typology	Unknown
ATCA1103	Chalcedony 11	Pisolite
ATCA1704	Chalcedony 7	Chalcedony
ATCA305	Chalcedony 3 (mustard yellow)	Jasper
ATCA2114	Chalcedony 7 (white translucent)	Chalcedony
ATCH205	Chert 2 (reddish-brown)	Jasper
ATCH624	Chert 6 (medium yellow)	Jasper
ATCH232	Chert 2 (reddish-brown)	Jasper
ATCH1025	Unknown material type- not in typology	Unknown

Artefact	Material Type (Hayden)	Material Type (Bakewell)
ATCH1028	Chert 2 (reddish-brown)	Jasper
ATCH207	Chert 2 (reddish-brown)	Jasper
ATCH213	Chert 2 (reddish-brown)	Jasper
ATCA1015	Chalcedony 10 (white translucent)	Unknown
ATCH201	Chert 2 (reddish-brown)	Jasper
ATCH211	Chert 2 (reddish-brown)	Jasper
ATCH514	Chert 5 (medium brown)	Jasper
ATCH215	Chert 2 (reddish-brown)	Jasper
ATCH616	Chert 2 (reddish-brown)	Jasper
ATCH217	Chert 2 (reddish-brown)	Jasper
ATCH202	Chert 2 (reddish-brown)	Jasper
ATCH903	Chert 2 (reddish-brown)	Jasper
ATCH229	Chert 2 (reddish-brown)	Jasper
ATCA619	Chalcedony 6 (light pink)	Pisolite
ATCH227	Chert 2 (reddish-brown)	Jasper
ATCH1409	Unknown material type- not in typology	Unknown
ATCH212	Chert 2 (reddish-brown)	Jasper
ATCA1709	Chalcedony 17 (mottled red and yellow)	Jasper
ATCA1001	Chalcedony 10 (white translucent)	Unknown
ATCH210	Chert 2 (reddish-brown)	Jasper

Artefact	Material Type (Hayden)	Material Type (Bakewell)
ATCH218	Chert 2 (reddish-brown)	Jasper
ATCH220	Chert 2 (reddish-brown)	Jasper
ATCH204	Chert 2 (reddish-brown)	Jasper
ATCH221	Chert 2 (reddish-brown)	Jasper
ATCH223	Chert 2 (reddish-brown)	Jasper
ATCH226	Chert 2 (reddish-brown)	Jasper
ATCH230	Chert 2 (reddish-brown)	Jasper
ATCH634	Chert 6 (medium yellow)	Jasper
ATCH233	Chert 2 (reddish-brown)	Jasper
ATCA2112	Unknown material type-not in typology	Unknown
ATCH231	Unknown material type-not in typology	Unknown
ATCH522	Chert 5 (medium brown)	Jasper

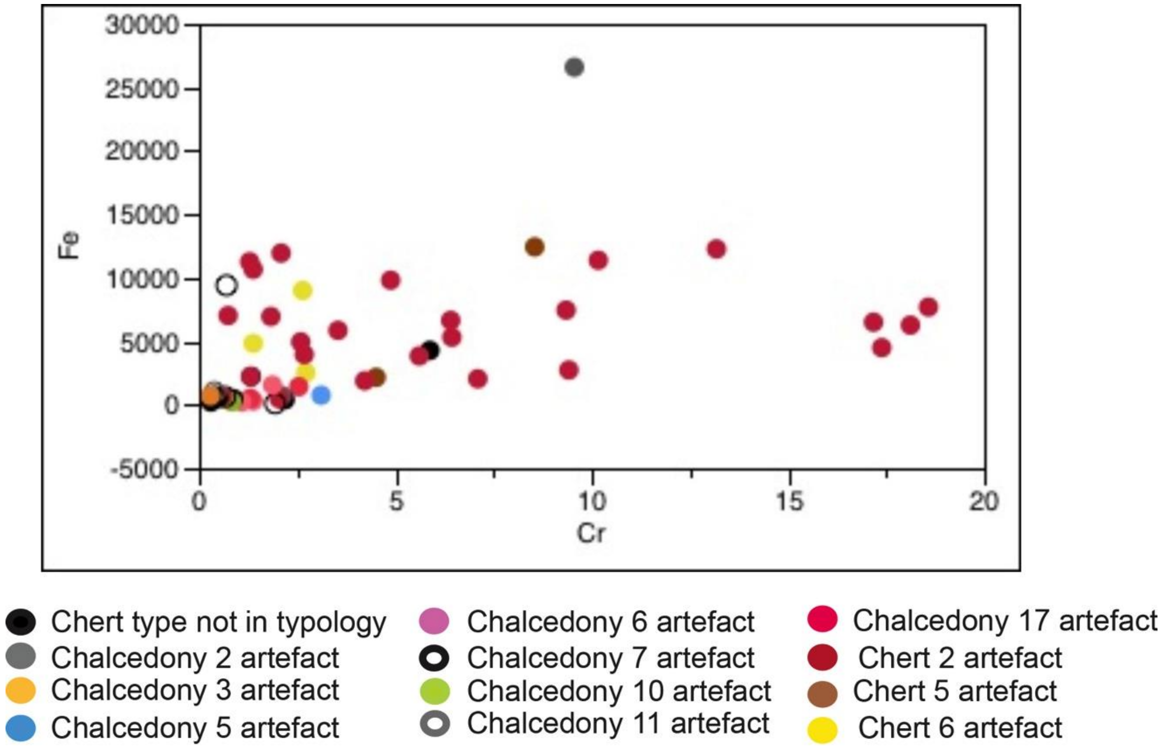

Figure 34. Bivariate Plot Fe by Cr of Artefact Samples Analyzed Using INAA Elemental Data. Chert type classified using Hayden's (2004) material types.

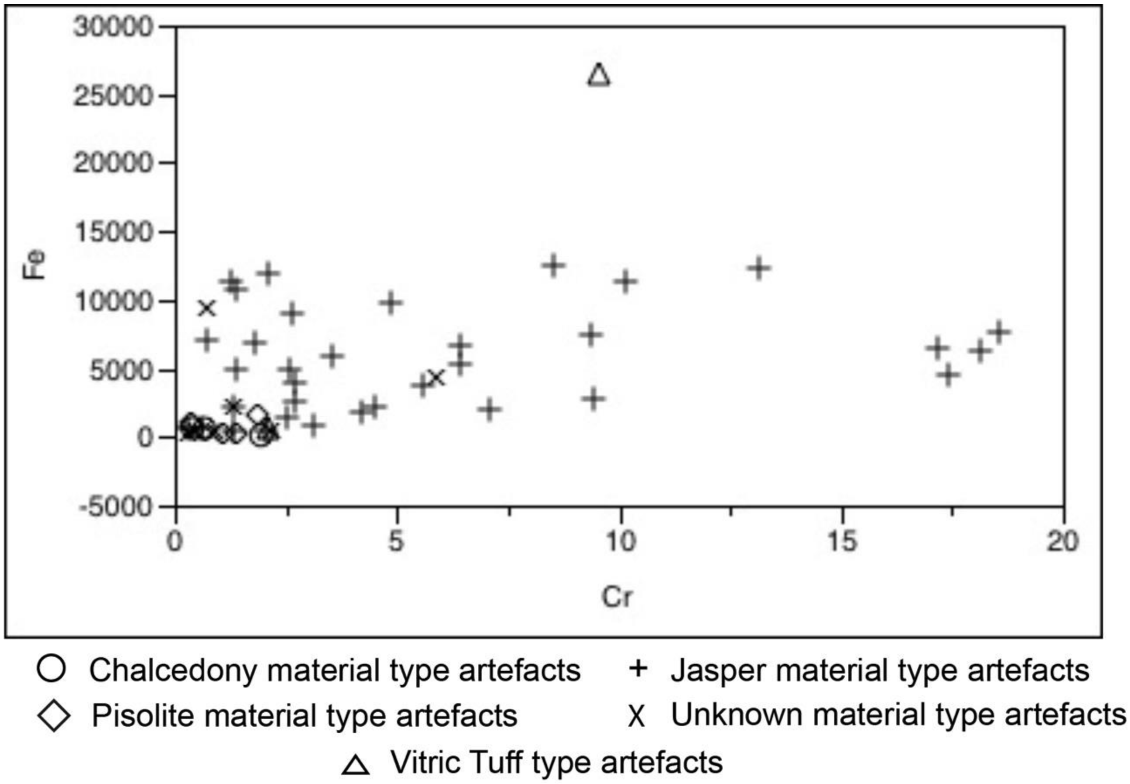

Figure 35. Bivariate Plot Fe by Cr of Artefact Samples Analyzed Using INAA Elemental Data. Chert type categorized using Bakewell's classifications.

Summary

I sent 22 toolstone deposit samples and 51 artefact samples for INAA at McMaster University Reactor. The analysis produced elemental data (ppm) for Al, As, Au, Ba, Br, Ca, Ce, Cl, Co, Cr, Cs, Dy, Eu, Fe, Hf, K, La, Lu, Mg, Mn, Na, Nd, Rb, Sc, Sm, Sr, Ta, Tb, Ti, U, V, Yb, and Zn. Employing JMP 10 statistical software, I characterized the Ashcroft Blue and West Fountain deposits using Cr, Ti, and Zn in bivariate plots. However, I was not able to individually characterize the remaining Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red deposits as they are elementally too similar to be individually distinguishable.

After exhausting the toolstone data and identifying a single PCA that produced the best results (using As, K, Fe, Cr, and Rb), I then considered the artefact INAA data. I applied the Keatley Creek Typology and observed 12 different chert and chalcedony types based on colour. However, when I applied Bakewell's reassessment of the visual typology, the jasper artefacts do show a slightly different distribution based on amounts of Fe, but these still overlap with unknown types, and this is not reflected in bivariate analyses that do not involve Fe. Using bivariate plots, I could not consistently identify more than one source group represented among the artefact samples within the INAA dataset.

In an attempt to determine the origin of the toolstone material used to make the artefacts, I discovered that the Ashcroft Blue deposit does not overlap or associate with the artefacts. Yet, I found that the West Fountain deposit does overlap with some of the Chert 2 artefact samples (identified as jasper by Bakewell [Hayden 2004]). I also determined through PCA that the artefacts completely overlap and are integrated with the Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red deposits.

Although the sample size for INAA is significantly lower, the statistical analysis provided similar results to the statistical analysis of the pXRF data—using Ti, Cr, and Zn, I was able to demonstrate that the Ashcroft Blue and West Fountain deposits differentiate from the other toolstone deposits; however, these results are based on a small (n=1) sample size for both deposits, and while these results appear similar to the pXRF results, they need to be qualified using a larger sample size. Future research should include analyzing more samples (at least 10), using INAA to confirm these results. However, since I was unable to locate the Ashcroft Blue deposit area, it is possible that the deposit no longer exists, and the materials used in this analysis are the last available pieces.

The remaining four deposits, Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red could not be individually characterized and distinguished from one another. Also as observed during the pXRF analysis, the artefacts could not be definitively linked to one toolstone deposit using the INAA elemental data, but they consistently grouped together in close association with the four deposits that could not be individually characterized. Statistical Analysis was conducted using JMP 10 and consisted of 20 PCA, boxplots, and bivariate plots. The results included here represent the most reliable and significant analyses produced within the larger analysis.

Chapter 7.

Discussion and Conclusions

The purpose of my research was threefold. The first was to use pXRF and INAA to characterize (a) known chert toolstone deposits within my study area that have been previously assumed to be connected to Keatley Creek as resources for lithic raw material, and (b) the artefact debitage excavated from ST 109. The second was to utilize the elemental data generated using pXRF and INAA to test the effectiveness and reliability of the colour-based and petrographic material identifications found within the Keatley Creek Lithic Typology. The final goal was to develop and refine the hypothesis that the toolstone deposits characterized as part of my research are likely representative of a single deposit located elsewhere; therefore, these deposits may have shared the same formation processes and context in the same geographic location, as part of a larger parent chert deposit.

In this final chapter, I present my interpretations of the statistical analysis and results described in Chapters 5 and 6. I begin with the characterization of chert toolstone deposits and the artefact debitage, and then move to a discussion about the use of categorizing chert material types based on colour and texture. The results of the elemental characterization of the deposits and artefacts are applied to the overall discussion regarding the origin of the toolstone deposits. This final section uses the elemental analysis to explain the apparent lack of inter-variation among the toolstone deposits, and what this may reveal about the origin of the toolstone deposits involved in this study.

Elemental Characterization

Characterizing chert toolstone material presents many complications, which have been discussed throughout this thesis. Two issues are particularly significant to my attempts to characterize the chert deposits: 1) the variability of the elemental composition of chert is largely due to the environment in which it was formed; and 2) the research previously conducted on the elemental compositions of chert has focused on bedrock deposits and not chert found in tertiary contexts. These issues complicate my study since the chert toolstone deposits found in the mid-Fraser are not bedrock cherts, but are surficial deposits appearing scattered across the landscape or eroding out of hillsides. To better understand the composition of the deposits within my study area, I quantified a combination of trace, minor, and major elements using pXRF and INAA instrumentation, and interpreted these data through a stepped process that involved summary, bivariate, and multivariate statistics in the JMP 10 statistical program.

Toolstone Deposits

I characterized the Ashcroft Blue and West Fountain deposits based on their distinctive amounts of Cr, Ti, Ni, Zn, and Zr. Specifically, the Ashcroft Blue deposit contains higher levels of Zn and Ti compared to the other deposits. Additional bivariate plots using pXRF data showed that the Ashcroft Blue deposit also contains relatively higher levels of Cr and Ni. The West Fountain deposit has comparatively low levels of Ti and higher levels of Cr; additional bivariate plots using Zn, Zr, and Ni also discerned the West Fountain deposit from the others.

The remaining four deposits—Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red—do not show sufficient inter-variation within the pXRF and INAA datasets to allow for individual characterization. Bivariate plots using many different elemental combinations were inconclusive. As discussed in Chapter 4, I ran 20 different PCAs, employing three principal components, all of which were unsuccessful in separating the four deposits, as they appear to have similar levels of major, minor, trace, and rare earth elements. Portable X-ray florescence analysis showed one consistent outlier (sample HC05); however, INAA did not show any samples as consistent outliers. The inability of both of these instruments to characterize the chert deposits suggests two possibilities: 1) the sample size is insufficient to properly measure and account for the variation within a single deposit and between the deposits; and 2) the chert toolstone deposits represent a series of deposits that originated from a common northern chert source.

The compositions of chert deposits in my study area have the potential to be highly varied meaning that the elemental composition of cherts within a single valley could be very similar, radically different, or a combination of the two. However, I argue that the inability of pXRF and INAA to distinguish all of the deposits is not due to an issue of sample size; rather, the variation revealed in the data represents the variation inherent within a single larger chert deposit. Due to these intricacies, a much larger sample size may have been necessary to confirm or disprove this. My argument is based on the fact that the chert deposits are currently situated within a tertiary context. The differences in the elemental compositions of the three groups of chert deposits—Ashcroft Blue, West Fountain, and the four that could not be differentiated (Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red)—likely show the range of variation across a single, larger deposit; therefore, the individual deposits analyzed may represent different locations within the larger parent source that were transported to the mid-Fraser region by the advance of the Fraser stade. Following this argument, the Ashcroft Blue and West Fountain deposits would have been situated far enough apart within the parent deposit to make their respective internal range of variation adequate to facilitate characterization. By contrast, the remaining deposits that could not be characterized due to the lack of internal variation were likely in close proximity within the larger parent deposit. All of the above components of the parent source were separated and placed in their current locations during the recession (frontal down-wasting) of the Fraser stade and, as such appear as individual deposits on the landscape.

Artefacts: Visual and Elemental Characterization

Previous research at the Keatley Creek site has consisted of lithological analysis and basic visual classification (Rousseau 2000). Bakewell (1995) and Hayden (2004) conducted petrographic analysis on chert lithic artefacts to discern raw material types. Their results were used to create and later modify the Keatley Creek Lithic Typology, which relies heavily on colour to determine material type. I applied these classifications to the artefacts included in my elemental analysis to discern if a reliable relationship existed between relic textures, colour, and elemental composition. Based on the results presented in Chapters 5 and 6, the application of Bakewell's petrographic classifications of chert type using relic textures was unreliable as a means of identifying a relationship between relic textures and elemental composition (see Figures 22 and 33). Similarly, neither pXRF nor INAA demonstrated a reliable correlation between Hayden's colour-based identifications and elemental composition (see Figures 21 and 32).

Although intended to differentiate individual chert types, the colour-based material identifications used by Hayden instead generally reflect variations in hue found within a single type. This is especially true of the range of variation that exists within jaspers, caused by the varying levels of Fe present in jaspers (relatively high levels of Fe is a criterion for jasper type cherts). This issue is further complicated by the fact that colour is affected by the process of heat treating chert materials (see Domanski et al. 2009; Rick and Chappell 1983; Purdy and Brooks 1971), and some have specifically attributed this to the Fe impurities within the rock (Purdy and Brooks 1971:323). As discussed in Chapter 4, all of the chert artefacts excavated from ST 109 exhibited signs of heat treatment. Exposure to extreme heat may have altered the appearance of the cherts; therefore, the colour differentiation may be a result of the annealing process, and not an indication of material type.

According to my analysis, the artefact samples show the same patterns in their elemental composition as the toolstone deposits. The artefacts consistently group together with the exception of a single outlier (artefact 5)—this outlier was part of the pXRF analysis, and appears to be an anomaly (see Figure 15). No outliers were identified during the INAA. Considering the results generated using both of these techniques, the artefacts could not be separated into different source groups—they do, however, reliably cluster together as a single group based on their elemental compositions.

To determine if the artefact grouping is similar to the toolstone deposits grouping, I plotted the artefacts against the toolstone deposit groups. When compared to the toolstone deposit pXRF data, the artefacts consistently clustered (overlapped) with the Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red deposits using PCA (Figure 19). When plotted against the toolstone deposit INAA data, the artefacts were integrated (overlapped) with these same four toolstone deposits (Figure 30). However, when plotted against the Ashcroft Blue and West Fountain pXRF data however, the artefacts did not associate with these deposits (yet the INAA data show that some of the jasper artefact samples were associated with West Fountain). This association is likely related to the elemental commonalities between jasper type cherts (i.e., high levels of Fe and Cr), and is not a direct function of the artefact material originating from the West Fountain deposit.

Although the results of the toolstone characterization show that the deposits cannot be defined individually, the Glen Fraser, Hat Creek Valley, Maiden Creek, and Rusty Creek Red deposit data dispersal within the PCA plots matched the artefact elemental data dispersal on the same PCA plot. The apparent similarities and overlap of the elemental data as shown on the PCA plots demonstrates that the chert materials used at ST 109 were likely taken from within the mid-Fraser region. Furthermore, the similarities of the elemental variation among the toolstone deposits and the artefacts lend further credence to my hypothesis that the chert toolstone deposits within the study area are from a single parent source. I have found that chert deposits of varying quality and size are common throughout the mid-Fraser landscape. As I have already noted, the concentrations of materials that exist as chert outcrops or deposits along the Fraser River (see Figure 7), and chert and other silicate materials that are also found scattered along the terraces and hillsides, were all likely deposited during glacial recession.

The study area was covered by the advance of the Cordilleran ice sheet, reaching beyond the mid-Fraser region (Ryder et al. 1991). As the glacial ice receded, the ice sheet deposited large amounts of unsorted sediments through down wasting—emptying vast quantities of sediments into river valleys—rather than frontal recession. The large-scale deposition of these sediments created unstable slopes, which are now observed as eroding out of local hillsides. Given this, I propose that the cherts within the study area are themselves originally of remote origin, removed from their original northern context during the advance of the Fraser stade, and then deposited within the mid-Fraser during the recession of the Fraser stade 11,500 years ago.

Conclusions

Lithic materials are an important component of archaeological assemblages worldwide, and are often the primary materials that survive while other materials (i.e., organic artefacts) decompose. Lithic analysis is one of the most important avenues for archaeological research. One important aspect of lithic studies is the identification of toolstone deposits that may have been utilized as raw materials for stone tool manufacture. Of the many different types of toolstone materials, chert, due to its ubiquity, flakeability, and malleability, stands out within archaeological assemblages as one of the most widely used materials.

During the past 40 years, archaeologists have begun to apply geochemical techniques to locate toolstone deposits utilized by precontact populations as resources for making stone tools. Initially, deposits or flows of obsidian and basalt were subjected to geochemical testing using a variety of techniques including INAA and XRF. These materials were found to be well-suited to characterization and provenance studies due to their unique compositions and variation between flows. However, studies that focused on characterizing chert and other siliceous materials did not experience the same measure of success. Although geochemical studies of chert have proven to be complicated due to the nature of chert formation, this can be better understood through a comprehensive knowledge of the geomorphology and depositional context within a given study area.

The primary goal of my research was to characterize the chert toolstone deposits in the mid-Fraser region, and the artefacts excavated from ST 109 at the Keatley Creek site using pXRF and INAA. The other goals of my research were to present a hypothesis that the toolstone deposits characterized as part of my research are of remote origin and redeposited in the mid-Fraser by glacial recession, and to test the reliability of colour- and texture-based identifications of chert material type as applied to elemental data.

The range of variation observed in the elemental composition of the toolstone deposits is comparable to the range of variation observed within the artefacts as analyzed using pXRF and INAA. These similarities are reflected in the clustering of both the artefacts and the four deposits that I was unable to individually characterize—Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red. This was further supported by the overlap of the artefacts and these four toolstone deposits using PCA. I argue that this is not indicative of the variation within the cherts of the mid-Fraser region; rather it reflects the range of variation within a single larger chert deposit. The toolstone deposits I was able to characterize—Ashcroft Blue and West Fountain—likely represent the extent of the overall variation of this parent deposit. As noted above, using PCA, I was able to connect the artefacts to the Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red deposits, and dismiss the Ashcroft Blue and West Fountain deposits as places of origin for the material used to create the lithic debitage excavated from ST 109. Given these results, it can be inferred that the artefacts were manufactured using local toolstone materials, and that the toolstone material deposits are of remote origin, placed in their current location within the study area as a result of the recession of the Fraser stade, prior to human occupation of the mid-Fraser region.

The results of my study show that colour-based identification and petrographic identifications using relic textures are unreliable. I applied Hayden's (2004) colour-based identifications of chert material types to the artefact elemental data produced using pXRF and INAA. Bivariate plots of Fe by Cr of these data showed no relationship between colour and elemental composition. The colour-based identification emphasized reddish and brown hues, which are caused by Fe inclusions and are most common in jaspers. These colours are enhanced through the process of annealing (Purdy and Brooks 1971:323), evidence of which was observed in all of the artefacts analyzed for this study, further confounding the reliability of colour-based chert material identifications. In addition, I applied Bakewell's petrographic chert material type identifications, which relied on relic textures of pisolite, jasper, vitric tuff, and chalcedony, to the artefact elemental data. Using the same bivariate plots of Fe by Cr, I demonstrated that no relationship exists between relic textures and elemental composition for chert toolstone materials.

My research strongly indicates that the six toolstone deposits discussed in this thesis were likely from a single chert deposit, located far to the north and that the variation observed between these deposits is reflective of the variation that exists in this larger parent deposit. This point of origin explains why some of the deposits could be characterized, while others simply do not have sufficient inter-variation to facilitate individual characterization. Furthermore, I have shown that the elemental compositions of the chert deposits in the mid-Fraser are not reflected in their physical appearance, and therefore any efforts made to classify or source chert based on visual characteristics will produce unreliable results.

Recommendations for Future Research

This study was restricted in both the number of samples that could be tested and in the methods available. Although pXRF became available late in the progress of this research, it was used to complement the INAA testing already conducted. Instrumental neutron activation analysis is the preferred method, as it quantifies powdered samples, while pXRF measures only the outer portion of the sample using X-rays. In either case, both methods require a large number of samples to facilitate confident results. Although adequate, my sample size was further limited due to restrictions inherent within the artefact assemblage. As discussed, the majority of the artefacts did not meet the 1g weight requirement for INAA, and these same artefacts were too thin to produce reliable pXRF results. Despite these issues, my research contributes to the growing interest in toolstone materials of the mid-Fraser region of British Columbia. The results of my study also contribute significantly to the archaeometric research that has been conducted on lithic resource use and distribution in the Interior Plateau of British Columbia and the Columbian Plateau in Washington and Oregon States (e.g., Bakewell 1995, 2000; Bakewell and Irving 1994; Greenough et al. 2004; Mallory-Greenough et al. 2002; Morin 2012; Rousseau 2000).

This research established that a relationship exists between the artefacts excavated from ST 109 and the Glen Fraser, Hat Creek, Maiden Creek, and Rusty Creek Red deposits. To further explore the range of variation identified in these toolstone deposits, additional sampling of the source material is necessary. Furthermore, the focus of additional studies should emphasize the technique of INAA in combination with other supplementary methods such as SEM and pXRF to explore the discriminatory trace, major, and/or minor elements. In addition to this, archaeological excavations should be done to recover materials that are indicative of quarrying behaviours such as primary reduction (e.g., Mierendorf 1993). Types of lithics expected in these contexts may include hammerstones, blanks, preforms, and primary flakes (removal of cortex). Identifying archaeological evidence for quarrying at the toolstone deposit is also a worthwhile endeavour and will assist archaeologists in proving and interpreting hunter-gatherer resource use and procurement. Systematic subsurface testing across each toolstone deposit will reveal the extent of prehistoric impact of the area, and, if done in conjunction with toolstone sampling, may facilitate correlations between site and deposit over time. Subsurface tests (shovel tests, large augers, or excavation units) should also be placed at Keatley Creek away from the housepit depressions to determine if toolstone materials exist within the site.

During the laboratory analysis and sampling of the artefacts, I identified evidence of heat-treatment on all of the chert artefacts. The effect of this treatment on the colour or external appearance of chert toolstone has been observed, but, its effect on the internal composition is debated and may vary by region. Magnetic resonance or additional elemental analysis should be done on chert toolstone deposits in the study area to determine what the effects of extreme heat/annealing practices have on the elemental structure of the cherts included in the mid-Fraser region. Elemental analysis should be conducted first on toolstone materials that have not been heat-treated. Analysis of the same samples should be conducted following heat-treatment at varying temperatures (e.g., Domanski et al. 2009). A regimented testing strategy of the effects of heat on chert materials will likely show how this process affects or inhibits the results of provenance studies.

Finally, in my research, I put forth the hypothesis that the cherts of the mid-Fraser are glacially redeposited, and were likely derived from a larger parent deposit to the north. Efforts should be made to locate the northern chert deposit. Assuming it exists testing at the source could help to better understand the elemental compositions of the mid-Fraser toolstone deposits. This, in turn, would help to clarify relationships between artefacts and toolstone sources found in the region. To locate this northern chert deposit, researchers should follow the evidence for glacial recession (i.e., orientation of drumlins, eskers, moraines, and other glacially deposited sediments) identified by Ryder et al. (1991).

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Appendix A.

Keatley Creek Lithic Typology

Material Code	Material Type (Defined by Hayden)	Material Type (defined by Bakewell)
Unknown	Unknown	Unknown
Basalt1	Fine basalt	Not Defined
Basalt2	Coarse basalt	Not Defined
Chert 1	White,speckled chert	Pisolite
Chert 2	Reddish-brown chert	Jasper
Chert 3	Dark-grey banded chert	Trachydacite
Chert 4	Light grey chert	Pisolite
Chert 5	Medium-brown chert	Jasper
Chert 6	Medium-yellow chert	Jasper
Chert 7	Dark green chert	Other
Chert 8	Medium-grey chert	Other
Chert 9	White-pink banded chert	Other
Chalcd1	Light grey chalcedony	Vitric Tuff
Chalcd2	White opaque chalcedony	Vitric Tuff
Chalcd3	Mustard yellow chalcedony	Jasper
Chalcd4	Medium-grey chalcedony	Tuff
Chalcd5	Mottled-light yellow chalcedony	Jasper
Chalcd6	Light pink chalcedony	Pisolite
Chalcd7	White translucent chalcedony	Chalcedony
Chalcd8	Medium-brown chalcedony	Jasper
Chalcd9	Dark grey-brown chalcedony	Jasper
Chalcd10	White translucent chalcedony	Other
Chalcd11	Light yellow/grey chalcedony	Pisolite
Chalcd12	Orange/brown mottled chalcedony	Jasper
Chalcd13	Light grey-brown chalcedony	Jasper
Chalcd14	Mottled grey/pink/red chalcedony	Jasper
Chalcd15	Medium grey-pink chalcedony	Pisolite
Chalcd16	Translucent brown banded chalcedony	Other
Chalcd17	Mottled red/yellow/translucent chalcedony	Jasper
Chalcd18	Light brown chalcedony	Jasper
Chalcd19	Medium yellow/grey/brown mottled chalcedony	Jasper
Chalcd20	Mottled grey/brown chalcedony	Not Defined
Graphite	Graphite	Graphite
Quartz 1	Orange-brown quartzite	Not Defined
Quartz 2	Light grey-brown quartzite	Not Defined

Material Code	Material Type (Defined by Hayden)	Material Type (defined by Bakewell)
Quartz 3	Orange-pink quartzite	Not Defined
Quartz 4	Light grey quartzite	Not Defined
Quartz 5	Light pink quartzite	Not Defined
Obsidian	Obsidian	Not Defined
Olivine	Olivine	Not Defined
Andesite	Andesite	Not Defined
Muscovite Mica	Muscovite Mica	Not Defined
Nephrite	Nephrite	Not Defined
Steatite	Steatite	Not Defined
Metamorph	Unknown metamorphic	Not Defined
Petrified. wood	Petrified wood	Not Defined
Sandstone	Sandstone	Not Defined
Ochre	Ochre	Not Defined
Shale	Shale	Not Defined
Siltstone	Cherty siltstone	Not Defined
Slate	Slate	Not Defined
Serpent.	Serpentinite	Not Defined
Iron	Iron	Not Defined
Lead	Lead	Not Defined
Copper	Copper	Not Defined

Appendix B.

Toolstone Deposits

As part of this archaeometric case study, I visited and collected samples from a number of siliceous deposits within the mid-Fraser region: the Glen Fraser deposit; the Rusty Creek Red deposit; the Hat Creek Valley deposits; the Maiden Creek Valley deposit; the Ashcroft Blue deposit; and the West Fountain deposit. All of the deposits, with the exception of the Ashcroft Blue Deposit, are situated within 50 km of the Keatley Creek archaeological site, and are accessible by game trails and ethnographically described trails (Teit 1906; Tyhurst 1992). This appendix describes the geographical setting, material types present, and the condition of the toolstone materials present at of each of these deposits.

To facilitate the geologic sample collection process, I created forms to record hydrological, topographical, and geological features associated with the deposit areas. The forms included here are transcribed from the originals that were completed in the field at the Glen Fraser, Maiden Creek, and the Hat Creek deposits. The Rusty Creek Red, West Fountain, and Ashcroft Blue deposits were not visited as part of this study, as samples were provided by the Department of Archaeology at SFU, Michael Rousseau, and Jesse Morin.

Ashcroft Blue Deposit

This deposit was not visited as part of my study. Rousseau provided specimens in 2009 that were used for analysis. The Ashcroft Blue chert deposit is situated near the small town of Ashcroft, British Columbia, and is outside the mid-Fraser region. It was included in this study to determine if the mid-Fraser deposits could be differentiated from those outside the study area.

The Ashcroft Blue samples are brittle, with a hardness of 7 on the Mohs scale and do not have any inclusions observable using a standard microscope at 30X magnification. When knapped, the material fractures conchoidally, producing a sharp cutting edge. It is opaque with a matte lustre and slightly vitric appearance (Figure B.1).

The flakeability of the Ashcroft Blue material is high—it flakes predictably and the raw material is available as large cobbles. However, the deposit is non-local, located at least 55 km from the Keatley Creek site beyond the Hat Creek Valley. The terrain required to navigate to the deposit from the Keatley Creek site is strenuous, and involves crossing through the Hat Creek Valley into the Ashcroft area.

Figure B.1. Ashcroft Blue Deposit Geological Samples. Photo taken by author.

The Glen Fraser Deposit

Located approximately 0.6 km north of Keatley Creek, this area was named by Rousseau (2000) for the Canada Railway Switching Station immediately west of the deposit. The central portion of this deposit is an eroding debris flow lobe about 150 m east of the station near the apex of an alluvial fan (Rousseau 2000:168; Figure B.2). The deposit consists of poorly sorted angular and sub-angular nodules of cherts and chalcedonies of varying colour; however, the most common cherts are red, orange, purple, pink, and yellow (Figure B.3).

Samples analyzed from this deposit were assessed for physical properties that aid in proper material identification. Generally, material from this deposit is considered strong as many of the samples measure from 5 to 7 on the Mohs scale. Yet many of the samples from this deposit contain cracks, pores, and numerous quartz inclusions which make the material hard to work, as it will fracture inconsistenty and unevenly. Therefore, the materials observed from the Glen Fraser deposit are of low to medium quality, possibly due to past and modern overuse of the resource. This is even more likely when considering the close proximity of the Glen Fraser deposit to the Keatley Creek site. Based on its location and lack of topographic hinderances, the deposit is easily accessed from Keatley Creek (Figures B.4 and B.5). In addition, it is known to local agate collectors and this recent attention to the Glen Fraser deposit has contributed to the exploitation of these materials, limiting their availability.

Figure B.2. **The Glen Fraser Silicate Deposit.** Photo taken by author facing east. Arrows indicate dense deposit areas.

Figure B.3. **The Glen Fraser Deposit Geological Samples.** Photo taken by author.

Deposit: Glen Fraser Silicate Deposit
Date Visited: August 10, 2008

I. References Consulted

Michael K Rousseau, Owner and Senior Archaeologist, Antiquus Archaeological Consultants Ltd.
Dr. Robert Muir, Limited Term Lecturer, SFU
Dr. Jesse Morin, Archaeologist,Tsleil-Waututh Nation
Dr. Brian Hayden, Professor Emeritus, SFU

Geological Map Numbers: Geology and Crustal Structure of the Southern Coast and Intermontane Belts, Southern Canadian Cordillera (Journeay and Monger 1994)

Topographic Map Numbers: 092 I 13 Pavilion

II. The Deposit Area Geography

Location: 581001E 563133N 534 m Elevation; west hill: 581011E 5630163N 534 m elevation; east hill: 581052E 5630200N 563 m elevation.

Biogeoclimatic zone: Ponderosa Pine/Bunchgrass

Flora/Fauna: pine (*Pinus ponderosa)*, sagebrush (*Artemisia tridentata*), prickly pear (*Opuntia sp*.), and dryland grasses/ mountain goat, deer, burrowing owl, and rattlesnakes.

Description: Talus slopes at the eastern extent of the deposit, with gently sloping hillsides to the west. The toolstone materials are scattered within and across these hillsides. The deposit contains an assortment of material including cherts and chalcedonies of varying colours (green, yellow, red, purple, and grey) and sizes (pebbles, gravel, and cobbles).

Drainage: To the west is the Fraser River with no swamps, lakes, or areas of run-off.

Setting: Coastal ☐ Interior ☒ Island ☐

Mountainous ☒ deltaic☐ ocean shore ☐ lake shore ☐ riverine ☐
Beach (sand) ☐ Valley (name:_______) ☐ Inlet (name:________) ☐

III. Toolstone Materials Present

Basalt ☐ Chert ☐ Chalcedony ☒ Slate ☐ Obsidian ☐ Quartz ☐

Deposition: Bedrock ☐ Bedrock Vein ☐ Fluvial ☐ Glacial* ☒

Material Size: Pebble (4mm-64mm) ☐ Cobbles (64mm-256mm) ☐
Boulders (>256mm) ☐ Length and Width of vein: ___________ m

Additional Information: situated on a belt margin (intermontane and coastal belts).
**Evidenced by the deposit material in unpolished cobble or nodule form.*

Figure B.4. The Glen Fraser Deposit Field Form, Page 1.

IV. Archaeology of the Deposit Area

a. Evidence of quarrying behaviour at the deposit: None were observed, but given the ubiquity of the deposits and proximity to known archaeological sites there is potential for evidence of lithic production activities buried beneath deposits.

b. Trails used by migrating animals: small game trails (deer and goat) along the hillsides, one runs south, likely through the valley and into the Keatley Creek area.

d. Archaeological sites in the immediate vicinity: Keatley Creek EeRl-7 is 0.6 km southeast of the deposit

e. Impacts/disturbances: BC Rail/CN Rail switching station and rail which trends north south on the west side of the deposit.

V. Sampling

Strategy: 3 samples per 10 m
Total Number collected: 15 samples
Extraction technique: hand

VI. Photographs

Film Camera ☐
Digital Camera ☒
Photos are in possession of the author and available upon request.

Figure B.5. The Glen Fraser Deposit Field Form, Page 2.

The Maiden Creek Deposit

The Maiden Creek deposit (Figure B.6) is situated within the upper Hat Creek Valley in close proximity to Pavilion and northwest of the Bonaparte Indian Reserve No. 2. Pavilion elders have stated that the Maiden Creek Valley was an area traditionally used to gather toolstone materials (Rousseau 2000:177).

Unfortunately, the Maiden Creek deposits were heavily exploited by “rockhounds” in the 1970s. It has been noted that up to 50 cars per day visited the site (Pike 1975:5), and it is referenced in local rock and gem collection guides (Pokotylo 1976). It is very likely that rockhounds have exhausted this toolstone deposit. This is supported by the fact that the cherts found at Maiden Creek during my visit there were of low quality while samples supplied to me by Rousseau, collected 20 years earlier were of medium to good quality that flake predictably and consistently with minimal obvious inclusions. Based on Rousseau’s samples, the most common Maiden Creek cherts were yellow to yellowish-brown in colour (Figure B.7) and came in the form of cobbles ranging from 5 to 10 cm in diameter. Additional details of the deposit are provided on the field forms below (Figures B.8 and B.9).

Figure B.6. Access to Maiden Creek Deposit. Photo taken by author, facing north.

Figure B.7. Maiden Creek Chert Geologic Sample. Photo taken by author.

Deposit: Maiden Creek Chert Deposit
Date Visited: May 5, 2008

I. References Consulted

Michael K Rousseau, Owner and Senior Archaeologist, Antiquus Archaeological Consultants Ltd.
Dr. Robert Muir, Limited Term Lecturer, SFU
Dr. Jesse Morin, Archaeologist,Tsleil-Waututh Nation
Dr. Brian Hayden, Professor Emeritus, SFU

Geological Map Numbers: Geology and Crustal Structure of the Southern Coast and Intermontane Belts, Southern Canadian Cordillera (Journeay and Monger 1994)

Topographic Map Numbers:092 J 13 Pavilion

II. The Deposit Area Geography

Location**:** 605449 E 5641216 N 1157 m Elevation;

Biogeoclimatic zone: Ponderosa Pine/Bunchgrass

Flora/Fauna: pine (*Pinus ponderosa)*, sagebrush (*Artemisia tridentata*), prickly pear (*Opuntia sp*.), and dryland grasses/ mountain goat, deer, burrowing owl, and rattlesnakes.

Drainage: Maiden Creek runs east – west

Description: Pedestrian survey of the area where the deposit is reported to be (Rousseau 2000) produced negative results. Area is well known by local "rockhounds" and visited often. It is possible that the majority of the deposit has been depleted; In the 1970's Lehman noted that up to 50 cars were observed in the area removing large amounts of chert every day (Pike 1975). Samples collected by Michael Rousseau and stored at SFU laboratory of Archaeology, were used in this study.

Setting: Coastal ☐ Interior ☒ Island ☐

Mountainous ☒ deltaic☐ ocean shore ☐ lake shore ☐ riverine ☒
Beach (sand) ☐ Valley (name:_______) ☐ Inlet (name:________) ☐

III. Toolstone Materials Present

Basalt ☐ Chert ☒ Chalcedony ☐ Slate ☐ Obsidian ☐ Quartz ☐

Deposition: Bedrock ☐ Bedrock Vein ☐ Fluvial ☐ Glacial* ☒

Material Size: Pebble (4mm-64mm) ☐ Cobbles (64mm-256mm) ☐
Boulders (>256mm) ☐ Length and Width of vein: ___________ m

Additional Information: situated on a belt margin (intermontane and coastal belts).

** Evidenced by the deposit material in unpolished cobble or nodule form.*

Figure B.8. Maiden Creek Deposit Field Form, Page 1.

IV. Archaeology of the Deposit Area

a. Evidence of quarrying behaviour at the deposit: None.

b. Trails used by migrating animals: worn game trails, likely goat or deer.

c. Archaeological sites in the immediate vicinity: The deposit is 30.7 m northeast of EeRj-4; 1 km east of EeRj-93; 1.1 km east of EeRj-94; 502 m north of EeRj-110; 601 m north/northeast of EeRj-68; 713 north/northeast of EeRj-69. All of these are either subsurface or subsurface lithic scatters manufactured from cherts (jaspers) and basalt (Pokotylo 1976)

d. Impacts/disturbances: BC Hydro Transmission line that runs northwest/southeast through the valley.

V. Sampling

Strategy: provided by SFU laboratory of Archaeology, Collected by Michael Rousseau as part of the 1989 study (Rousseau 2000).
Total Number collected: 10 samples
Extraction technique: hand

VI. Photographs

Film Camera ☐
Digital Camera ☒
Photos are in possession of the author and available upon request.

Figure B.9. Maiden Creek Deposit Field Form, Page 2.

The Hat Creek Valley Deposit

Archaeologists and rockhounds have long known that the Lower Hat Creek Valley contained deposits of chert and chalcedony. There are two primary areas of silicate deposits. The first is the Lower Hat Creek deposit (Figure B.10) and the second is the Medicine Creek Valley deposit (Figures B.11 and B.12). Both of these areas were visited as part of this project (Figures B.13 and B.14), but the Lower Hat Creek and Medicine Creek sources contained very little chert cobbles or pebbles. Similar to the Maiden Creek deposit, this area is very popular and well known amongst rockhounds, who have consistently returned to this deposit to collect samples, exhausting the resource (Pike 1975).

Figure B.10. Hat Creek Chert Geological Samples. Photo taken by author.

Both the Lower Hat Creek and Medicine Creek deposits were sampled but many of the specimens collected were of low to medium quality and did not reflect the descriptions of samples previously collected by Rousseau. To improve the sample quality from this deposit, I met with him in 2009 and was given three samples from the Lower Hat Creek deposit to use for elemental analysis. The Medicine Creek Valley deposits yielded small nodules and pebbles of chert and chalcedony material of varying quality. The samples collected from this area contained multiple inclusions, and were coarse to medium grained (Figure B.11). It is likely that this material would improve if it was exposed to extensive heat-treatment.

Figure B.11: Medicine Creek Geologic Sample. Photo taken by author.

Figure B.12. Medicine Creek Locality. Photo taken by author facing north. Arrows indicate dense deposit areas.

Deposit: Medicine Creek Deposit
Date Visited: August 10, 2008

I. References Consulted

Michael K Rousseau, Owner and Senior Archaeologist, Antiquus Archaeological Consultants Ltd.
Dr. Robert Muir, Limited Term Lecturer, SFU
Dr. Jesse Morin, Archaeologist,Tsleil-Waututh Nation
Dr. Brian Hayden, Professor Emeritus, SFU

Geological Map Numbers: Geology and Crustal Structure of the Southern Coast and Intermontane Belts, Southern Canadian Cordillera (Journeay and Monger 1994)

Topographic Map Numbers: 092 I 13 Pavilion

II. Geography

Location: Medicine Creek: 600306E 5623480N 965 m elevation; 600385E 5623503N 965m elevation; 600372E 5623531N 978 m elevation

Biogeoclimatic zone: Ponderosa Pine/Bunchgrass

Flora/Fauna: pine (*Pinus ponderosa)*, sagebrush (*Artemisia tridentata*), prickly pear (*Opuntia sp*.), and dryland grasses/ mountain goat, deer, burrowing owl, and rattlesnakes.

Description: Silicate materials are eroding out of the northern bank/hillside immediately north of Medicine Creek.

Drainage: The deposit is located on the hills immediately north of Medicine Creek.

Setting: Coastal ☐ Interior ☒ Island ☐

Mountainous ☒ deltaic☐ ocean shore ☐ lake shore ☐ riverine ☐
Beach (sand) ☐ Valley (name:_______) ☐ Inlet (name:________) ☐

III. Toolstone Materials Present

Basalt ☐ Chert ☐ Chalcedony ☒ Slate ☐ Obsidian ☐ Quartz ☐

Deposition: Bedrock ☐ Bedrock Vein ☐ Fluvial ☐ Glacial* ☒

Material Size: Pebble (4mm-64mm) ☒ Cobbles (64mm-256mm) ☐
Boulders (>256mm) ☐ Length and Width of vein: ___________ m

Additional Information: situated on a belt margin (intermontane and coastal belts).

** Evidenced by the deposit material in unpolished cobble or nodule form.*

Figure B.13. Medicine Creek Locality Field Form, Page 1.

IV. Archaeology of the Deposit Area

a. Evidence of quarrying behaviour at the deposit: None.

b. Trails used by migrating animals: worn game trails, likely goat or deer.

c. Archaeological sites in the immediate vicinity: The deposit is 1.1 km east of EfRj-68 (basalt lithic scatter) and 1.9 km southwest of EfRi-86 (lithic scatter).

d. Impacts/disturbances: The Lower Hat Creek Road runs north south along the hat Creek Valley floor and is approximately 25 m east of the deposit.

V. Sampling

Strategy: 3 samples per 10 m
Total Number collected: 15 samples
Extraction technique: hand

VI. Photographs

Film Camera ☐
Digital Camera ☒
Photos are in possession of the author and available upon request.

Figure B.14. Medicine Creek Locality Field Form, Page 2.

Rusty Creek Red Deposit

The Rusty Creek Red deposit was not visited as part of this study. Instead, two specimens were taken from samples provided by Rousseau (Figure B.15). The Rusty Creek Red deposit is located within Lot 3453 in the upper Rusty Creek Valley, in the vicinity of the Fountain archaeological site. This area is situated on high slopes above the Fountain Valley, and access requires negotiating challenging, sloped terrain. Given the high flakeability of the Rusty Creek Red chert and its location on a riverbed, it is likely people collected the material as it was deposited downstream, possibly with the spring run-off. Rousseau (2000) reported an absence of evidence for quarrying behaviours at the deposit.

The deposit contains a red, fine-grained brittle chert with a matte lustre (Figure B.15) that rate a 7 on the Mohs scale of hardness, as expected from the structure observed microscopically. When viewed using a petrographic microscope, the cherts have fine, small interlocking grains with no significant inclusions. These characteristics allow material to cleave predictably and consistently when knapped. The physical properties of the Rusty Creek Red cherts reveal high quality, flakeable materials, suitable for the construction of stone tools.

Figure B.15. The Rusty Creek Red Chert Geological Samples. Photo taken by author.

The West Fountain Deposit

The West Fountain deposit is situated to the northwest of the Fountain archaeological site, on a large terrace overlooking the Fraser River. The material is light to medium yellow, with a waxy lustre, brittle, and has a tendency to fracture conchoidally (Figure A.16). The samples used in this study were provided by Jesse Morin (Tsleil-Waututh Nation), and the location of the material was not visited during field sampling.

Figure B.16. West Fountain Geological Samples. Photo taken by author.

Appendix C.

Elemental Data and Lithic Catalogue

This appendix forms an essential part of this work, contained in a single Microsoft Excel workbook, with five worksheets. The first worksheet details the lithic analysis of the artefacts/debitage excavated from ST 109 during the 2006 archaeological field seasons. The second worksheet shows the raw photon counts by element for each toolstone deposit sample tested using pXRF. The third worksheet shows the raw photon counts by element for each artefact sample tested by pXRF at SFU. The fourth and fifth worksheets provide the data generated in ppm using INAA for the toolstone deposits and artefact samples. The data file can be opened with Microsoft Excel, Numbers, JMP, SPSS or other spread sheet programs. Additional copies can be obtained from the SFU Library, Office of Theses, or from the author.

Data Files: Appendix C.xls

Appendix D.

Report from McMaster University Reactor: Materials and Methodological Results of INAA

By:

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Data Reported 5th November, 2009

Materials and Methodological Description

Materials

The materials submitted were geological and archaeological samples of chert, chalcedony and unknown silicate rocks. All are derived from archaeological and geological locations in British Columbia, Canada.

Sample Preparation

Upon arrival samples were washed twice in an ultrasonic bath, clipped to the appropriate size and weighed to approximately 1g each in high-purity polyethylene vials. A total of 78 samples were prepared for analysis. Table 1 shows the sample codes, weights and archaeological contexts. The values of the weights are those at the time of sample submission.

Table 1: Kendall Lithic Sample Information

MNR Code	Kendall Code	Weight (g)	Provenience
HKCP 2-6	CA602	1.11	Artefact sample from EHPE 06 01
HKCP 1-6	CH606	1.45	Artefact sample from EHPE 06 01
HKCP 2-19	GSGF601	1.06	Glen Fraser geological sample
HKCP 4-18	GSGF701	2.04	Glen Fraser geological sample
HKCP 3-15	GSLMC101	2.07	Hat Creek Valley Geologic Sample
HKCP 3-17	GSMC301	1.14	Maiden Creek geological sample
HKCP 4-1	GSMC101	2.24	Maiden creek geological sample
HKCP 3-19	GSMC501	1.26	Maiden Creek chert Rousseau
HKCP 3-20	GCMC601	1.56	Maiden Creek chert Rousseau
HKCP 4-2	GSMDC201	1.2	Hat Creek Valley Geologic Sample
HKCP 2-10	CA606	1.22	Artefact sample from ST109
HKCP 2-11	CA707	1.77	Artefact sample from ST109
HKCP 2-12	CA1708		Artefact sample from ST109
HKCP 2-14	CA210	1.48	Artefact sample from ST109
HKCP 2-15	CA2111	1.06	Artefact sample from ST109
HKCP 2-17	CA713	1.09	Artefact sample from ST109
HKCP 4-6	CA616	1.49	Artefact sample from ST109
HKCP 1-19	CH219	1.19	Artefact sample from ST109
HKCP 1-8	CH1008	1.02	Artefact sample from EHPE 06 01
HKCP 3-11	GSGF101	1.22	Glen Fraser Deposit Geological Sample
HKCP 2-18	GSGF501	1.82	Glen Fraser Deposit Geological Sample
HKCP 3-3	GSHC201		Hat Creek Valley Deposit Geological Sample
HKCP 3-4	GSHC302	1.53	Hat Creek Valley Deposit Geological Sample
HKCP 3-6	GSHC401		Hat Creek Valley Deposit Geological Sample
HKCP 3-16	GSMC201	0.98	Maiden Creek Valley Deposit Geological Sample
HKCP 3-13	GSRR101	1.42	Rusty Creek Red Deposit Geological Sample
HKCP 3-14	GSRR102	1.26	Rusty Creek Red Deposit Geological Sample
HKCP 2-20	GSWF101	1.05	West Fountain Deposit Geological Sample
HKCP 2-7	CA1103	1.08	Artefact sample from ST 109
HKCP 2-8	CA1704	1.63	Artefact sample from ST 109
HKCP 2-9	CA305		Artefact sample from ST 109
HKCP 4-4	CA2114	1.24	Artefact sample from ST 109

MNR Code	Kendall Code	Weight (g)	Provenience
HKCP 1-5	CH205	2.97	Artefact sample from ST 109
HKCP 2-4	CH624	1.4	Artefact sample from ST 109
HKCP 4-14	CH232	1.47	Artefact sample from ST 109
HKCP 4-7	CH1025	1.56	Artefact sample from ST 109
HKCP 4-9	CH1028	1.32	Artefact sample from ST 109
HKCP 1-7	CH207	1.02	Artefact sample from EHPE 06 01
HKCP 1-13	CH213	1.41	Artefact sample from ST 109
HKCP 3-12	GSGF201	1.55	Glen Fraser Deposit Geological Sample
HKCP 4-17	GSGF801	4.67	Glen Fraser Deposit Geological Sample
HKCP 3-1	GSHC101	1.51	Hat Creek Valley Deposit Geological Sample
HKCP 3-5	GSHC301	1.41	Hat Creek Valley Deposit Geological Sample
HKCP 3-7	GSHC501	2	Hat Creek Valley Deposit Geological Sample
HKCP 4-5	CA1015	1.26	Artefact sample from ST 109
HKCP 1-1	CH201		Artefact sample from ST 109
HKCP 1-11	CH211	1	Artefact sample from ST 109
HKCP 1-14	CH514		Artefact sample from ST 109
HKCP 1-15	CH215	1.1	Artefact sample from ST 109
HKCP 1-16	CH616	1.1	Artefact sample from ST 109
HKCP 1-17	CH217		Artefact sample from ST 109
HKCP 1-2	CH202		Artefact sample from ST 109
HKCP 1-3	CH903	1.15	Artefact sample from ST 109
HKCP 4-10	CH229	1.05	Artefact sample from ST 109
HKCP 4-3	CA619	1.07	Artefact sample from ST 109
HKCP 3-8	GSAB101	1.27	Ashcroft Blue Chert
HKCP 4-8	CH227	1.01	Artefact sample from ST 109
HKCP 1-9	CH1409	2.05	Artefact sample from EHPE 06 01
HKCP 1-12	CH212	1.1	Artefact sample from ST 109
HKCP 3-2	GSHC102	1.43	Hat Creek Valley Deposit geological sample
HKCP 3-18	GSMC401	1.4	Maiden Creek Valley Deposit Geological Sample
HKCP 2-13	CA1709	1.28	Artefact sample from ST 109
HKCP 2-5	CA1001		Artefact sample from ST 109
HKCP 1-10	CH210	1.18	Artefact sample from ST109
HKCP 1-18	CH218	2.08	Artefact sample from ST 109
HKCP 1-20	CH220	1.14	Artefact sample from ST 109
HKCP 1-4	CH204	5.78	Artefact sample from ST 109
HKCP 2-1	CH221	1	Artefact sample from ST 109
HKCP 2-3	CH223	1.09	Artefact sample from ST 109
HKCP 4-11	CH226	1.08	Artefact sample from ST 109
HKCP 4-12	CH230	1.13	Artefact sample from ST 109
HKCP 4-15	CH634	1.07	Artefact sample from ST 109

MNR Code	Kendall Code	Weight (g)	Provenience
HKCP 4-16	CH233	15.09	Artefact sample from ST 109
HKCP 2-16	CA2112	1.41	Artefact sample from ST 109
HKCP 4-13	CH231	1.65	Artefact sample from ST 109
HKCP 2-2	CH522	1.33	Artefact sample from ST 109

Analytical Protocol

One irradiation was performed to acquire concentration data on elements that produce short-lived isotopes for each sample. Six standard reference material (SRM) samples were run with each batch, including SRM 1632c Coal (x2), SRM 1633b Fly Ash (x2), SRM 688 Basalt (x1), SRM 278 (x1) Obsidian Rock all issued by the National Institute of Standards and Technology (NIST).

Fifty-one of the samples were run through a pneumatic tube system and subjected to a 180-second thermal irradiation at a neutron flux of 5×10^{13} n cm^{-2} s^{-1}. Each sample was left to decay for 20 minutes and then measured by a HPGe detector for three minutes. A sub-group of 27 samples were re-run at a 20-second thermal irradiation at a neutron flux of 5×10^{13} n cm^{-2} s^{-1}. Each of these samples was left to decay for 10 minutes and measured by a HPGe detector for three minutes. The elements measured for this short-lived procedure include Al, Ba, Br, Ca, Cl, Co, Dy, Mg, Na, Ti, U and V. All samples were left to decay for approximately 24 hours, after which a second five minute count was performed to collect concentration data on Eu, K, La, Mn, Na, Sm and Sr. In total, concentration data on 18 elements are reported for this analysis. All elemental concentrations are reported in parts per million (ppm). An Excel spreadsheet containing the full database is provided

Notes

Two samples (designated as HKCP 3-15 GSLMC101, and HKCP 2-14 CA210) yielded significantly high concentrations of aluminum and/or manganese which, in some cases, cause interferences for the accurate detection of other elemental concentrations. At this time I would suggest excluding those two samples from the database as the results are incomplete. We have decided at this time that if you have any further long-lived analysis you would like done on a small sub-set of these samples for any of the following elements, we will gladly do so at no extra charge: Au, As, Ce, Cr, Cs, Eu, Fe, Hf, La, Lu, Nd, Sb, Sc, Sm, Tb, Th and Yb. This extra analysis might be useful if you decide that other trace or rare-earth elements might be helpful for differentiating any geochemical groups you may have been able to preliminarily identify. If you have any further questions about this analysis please do not hesitate to contact me.