OCHRE PROCUREMENT AND DISTRIBUTION

ON THE

CENTRAL COAST OF BRITISH COLUMBIA

By

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A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfillment of the Requirements

for the Degree

Master of Arts

McMaster University

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Master of Arts (2008) McMaster University

Department of Anthropology Hamilton, Ontario

TITLE: Ochre Procurement and Distribution on the Central Coast of British Columbia

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NUMBER OF PAGES: vii, 90

OCHRE PROCUREMENT AND DISTRIBUTION,

COASTAL BRITISH COLUMBIA

Abstract:

Ochre is common to archaeological sites around the world and often considered a culturally significant material. It was and continues to be used in a variety of contexts, as pigment for rock art and body paint, medicinally, and as a component of ritual and mortuary practices. However, the nature of its acquisition is poorly understood. This geochemical study uses instrumental neutron activation analysis (INAA) to examine the acquisition and distribution of ochre at and among multiple village sites on the central coast of British Columbia. INAA has shown to be a powerful tool capable of distinguishing different geochemical groups of ochre. Furthermore, the distribution over time and space of these geochemical groups indicates a mode of long-term, highly localized ochre procurement, and the potential for small-scale exchange and shared access to ochre sources. Ochre specimens from Katit (EkSt-1), have geochemically distinct signatures suggesting that the inhabitants of this village primarily accessed one source and did not engage in exchange of ochre with other villages in the region. Ochre specimens from Namu (ElSx-1) and Cockmi (EjSw-1) are from two geochemically distinct sources, which were either accessed by people from both villages, or occur at both sites as a result of small-scale exchange. These patterns of ochre-related behavior are consistent over long periods at each site. In addition to these, a small number of specimens from surrounding camp sites were analyzed to assess the geographical extent of the distribution of ochre sources in the region. These results enable a characterization of the nature and form of ochre procurement and distribution practices, and furthermore, how and what the analysis of ochre can reveal about broader notions of perception of landscape and resource use.

Acknowledgements

I would like to thank my Supervisor and Committee Members, Dr. Aubrey Cannon, Dr. Kostalena Michelaki and Ron G.V. Hancock for their advice, patience and support during the completion of this project. I would also like to sincerely thank Alice Pidruczny (McMaster Nuclear Reactor) for her years of teaching, support and kindness. Without the wisdom and guidance of these individuals, this project would have never come to fruition. Other wonderful people who have helped immensely along the way are Janis Weir, Rabia Awan, Rosita Jordan and all of the friendly staff at the Centre for Neutron Activation Analysis at the McMaster Nuclear Reactor. Field and laboratory components of this research were supported by SSHRC grants awarded to Aubrey Cannon. Laboratory work was also supported by Research Fellowships from the Centre for Neutron Activation Analysis at the McMaster Nuclear Reactor.

I would also like to take the opportunity to thank my family for their endless love and kindness—your support has meant the world to me. I would also like to thank my dear friends Rudy Reimer, Sonja Puse and Jessica Gibson and Sandeep Bhandari for always being there for laughter and love. And last, but certainly not least, my best friend Meghan Burchell— words cannot explain. Your friendship means more to me than you could ever know.

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Chapter 1: Introduction

Ochre is composed of two different forms of iron oxide (Fe_2O_3 and FeO) (Popelka-Filcoff et al. 2007:17) and ranges in colour from red to brown to yellow to purple. Red, brown and purple ochre comes primarily from the mineral hematite (Fe_2O_3), while orange-yellow ochre is derived from the minerals goethite (FeO(OH)), and limonite $FeO(OH)\cdot nH_2O$). Geologically, ochre can form in igneous, sedimentary or metamorphic conditions, and can be found around the world. The use of ochre and its presence in archaeological contexts is well documented archaeologically, ethnographically and historically. It has been recognized on a global scale and virtually throughout the entire span of human history (Roper 1991). However, despite its importance for exploring social and symbolic relations, understanding of the diverse roles of ochre in human societies has been rather limited. The most common themes in ochre-related research are the use and symbolism of ochre based on its final use and depositional context, such as in rock art or as a component of mortuary practice, or a focus on its chemical properties for provenience-based studies. Studies on symbolic use of ochre through rock art and mortuary practice are abundant, but focus on comparatively rare and special contexts and fail to address the large quantity of ochre recovered from other contexts such as middens and house floors. Geochemical characterization studies of ochre are also becoming more common, but these studies predominantly focus on long-distance trade and movement of ochre and differentiation of geographically distinct ochre sources (Erlandson et al. 1999, Smith et al. 1998). The purpose of this thesis was to determine if different geochemical groups of ochre could be distinguished through the analysis of an archaeological

assemblage of ochres. In contrast to other ochre characterization studies, this project examined the geochemistry and distribution of ochre within a relatively restricted geographical extent, and, from the contexts of shell middens at villages and camps. In other words, where other studies have more often emphasized long-distance trade and exchange and the ceremonial use of ochre, this project has sought to explore ochre use at occupational sites and the nature of its procurement within a regional settlement system. It was expected that ochre sources in the central coast of British Columbia region would be geochemically similar based on the formation processes of ochre and given the local geological conditions. Therefore, to assess the feasibility of ochre sourcing, it was necessary to first identify trends in ochre geochemistry within the archaeological assemblage. Furthermore, if different geochemical groups of ochre could be established within an archaeological assemblage, what could this reveal about ochre acquisition, movement and exchange? Is it possible to identify patterns of ochre procurement and use within and between archaeological sites, and is it possible to characterize a regional mode of ochre acquisition and use?

The analysis of archaeological materials by geoarchaeological techniques is becoming increasingly common. Characterization studies typically begin with the analysis of raw materials from local sources, or, with an archaeological assemblage in cases where source materials are not readily available (Shackley 2008). The patterns and interpretations that emerge from geochemical data are most often related to the acquisition and use of raw materials and the nature of ancient trade and exchange. Ochre

is common in archaeological sites in the region of coastal British Columbia, yet no systematic study of its geochemistry, acquisition and distribution currently exists.

This project began in 2005 when I worked as a research assistant for Dr. Aubrey Cannon, as I was processing auger sample materials from villages and camp sites located in Rivers Inlet. As I sorted the >2mm fraction of the remains of fish, sea mammal and shellfish, I observed the presence of several pieces of ochre and began systematically to extract and visually characterize all of the ochre pieces. In total 1801 pieces were recovered from 14 archaeological sites. Forty-four of these were geochemically characterized using INAA in an attempt to verify the number and distribution of ochre geochemical groups at three village sites. The results of the INAA indicate that there are three distinct geochemical groups of ochre, one being accessed by the inhabitants from Katit, and the remaining two being accessed in variable proportion by inhabitants at Namu and Cockmi. A small number of specimens of ochre from three campsites surrounding Namu and Cockmi were also analyzed and their preliminary results indicated no significant patterning whereby the ochres from camps appear to be chemically similar those of the village site to which they were closest. However, a larger sample size is needed to verify the validity of these results. Overall, these conclusions suggest a highly localized, long-term pattern of ochre acquisition with the potential for shared access to a source or inter-village exchange.

Through an analysis of the procurement, movement and use of ochre, we are better able to understand localized patterns of resource use. On a broader scale, this study also serves as an example of what an analysis of ochre is able to reveal, therefore

expanding the potential of what is currently available to archaeologists as indicators of trade and exchange, cultural interaction and raw material resource procurement. The following is a brief overview of the chapters and content of this thesis.

Chapter 2 provides an overview of the methodological and theoretical concepts that influenced this study. I provide a detailed review of ochre-related archaeological, ethnographic and historical literature to illustrate the range of contexts in which ochre is used globally and with specific reference to the study region. I also provide a focused review of a group of characterization studies in archaeology to illustrate the ways that ochre has been analyzed and the conclusions that have been reached on whether ochre artifacts can be geochemically matched to ochre sources. Finally, I discuss characterization studies with reference to Northwest Coast archaeology. Chapter 3 provides a discussion on the contextual and methodological framework of this project, through a description of the archaeological context, and explanations of the qualitative and geochemical analyses of the ochre samples. In addition, in this chapter I discuss the parameters, protocols and results of the INAA component of this project. Chapter 4 presents the results of all analyses discussed in Chapter 3. Chapter 5 is a brief discussion of the interpretations and implications of the results of this project.

Chapter 2: Subject Overview

The study of ochre has taken on a variety of forms in archaeological and geoscientific research and is beginning to contribute innovative insights into the understanding of interaction, trade and exchange and the engagement of people with their natural landscape. The first section of this chapter reviews the historical, ethnographic and archaeological literature on ochre use. The second reviews the current methodological approaches to the analysis of ochre with specific reference to geochemical characterization, replication studies and rock art research. The final section attempts to situate this project within the broader theme of raw material procurement through the presentation of specific case studies.

On Ochre Use

References to ochre use exist within a broad range of ethnographic, historical and archaeological literature. Such works illustrate the diversity of ochre use as a utilitarian, symbolic, artistic and medicinal material. However, ochre often ends up being viewed as either functional and utilitarian, or, as symbolic and sacred. The assumption that such classifications are opposing is important to consider since often it underlies the types of questions asked of and the approaches taken toward ochre. The versatile nature of ochre as medicinally useful (Mahaney 1993, Velo 1984), symbolically charged (Marshack 1991, Taçon 2004) and functionally valuable as adhesive (Lombard 2005, Wadley 2005), preservative (Roper 1991, Wadley 2005), and for hide tanning (Roper 1991, Wadley 2005, Velo 1986), has likely contributed to the debate between those who attempt to categorize it as either functional or symbolic. This is especially compounded given that

ochre is found in a range of contexts, as pigment for rock art, as house floor deposits, as wall painting or pottery decoration, and in association with burials (Roper 1991). Because ochre use is so diverse, it is clear that there is no universal way in which individuals or culture groups relate to it. Therefore, for the purpose of this review I have grouped the appropriate examples of the nature of ochre study into thematic categories.

Early Ochre Use

Evidence of ochre use extends back to early hominids (Denio and McBreartry 2002, Marshack 1981, Wreschner 1976, 1980a, 1980b, 1985), Palaeoindian (Roper 1989), and upper Palaeolithic sites (Roper 1991, Schmandt-Besserat 1980). Marshack (1981) discussed early hominid ochre use as integral to the development of skilled tool use, resource extraction and colour and material symbolism. He argued that the context of early ochre finds suggests it could have been used in body adornment, to decorate tools or symbolic artifacts, to colour habitation walls or floors, to delimit symbolic spaces or simply as a marking material (1981:190). Wreschner (1976, 1980a, 1980b) argued for the symbolic use of ochre and its abstract role in human cognitive development and the capacity for speech. He suggested that it is possible to correlate its use with social actions of early hunter-gatherer groups (1976:718). Specifically, he focused on early hominid and Neanderthal ochre use and argued that red color attraction appears to have been part of an evolutionary cognitive process. He also argued that evidence for heat-treatment of ochre indicates preference for certain colour characteristics (1980a, 1980b, 1983, 1985). Biological, cognitive and linguistic research has associated basic colour recognition and memory with the colour red. Velo and Kehoe's (1990) study connected colour

recognition with the use of ochre. They stated that red is the most commonly named colour in human languages and represents death, blood, anger and danger (1990:104). Based on the physiology of human vision, the red portion of the light spectrum is the most commonly recognized among all colours (1990). Velo also argued that the colour red would have been associated with life and blood, and therefore the presence of ochre in burials might represent a continuation of efforts to save an individuals' life (1984:674).

Schmandt-Besserat (1980) provided a comprehensive chronological overview of the evolution of ochre use over the past 300,000 years. She stated that burials with ochre associations begin to appear approximately 70,000 BC, and ochres found on house floors, within hearths and associated with grinding tools such as mortars and pestles begin to appear around 40,000 BC (1980:129). She argued that based on the apparent omnipresence of ochre in ritual and mortuary contexts, it must have played a predominant role in the development of human societies. Similarly, Roper's (1991) article reviewed the presence of ochre at archaeological sites, although she focused specifically on the Upper Palaeolithic. She reviewed evidence for the use of ochre for multiple purposes, from burial to non-mortuary ritual and domestic contexts (1991:290). She emphasized that ochre use is a global phenomenon and must be considered an important component of human development. Sagona (1994:36-37) referred to ochre use in Australia that spans back to the earliest inhabitants of the continent in the form of rock art, grindstones with ochre residues, as floor deposits in rock shelters and engraved figurines, all dating back to 60,000 BP. Finally, Henshilwood et al. (2001) described 70,000 year old scraped ochre tablets at Blombos Cave in South Africa.

On Medicinal Use of Ochre

Velo (1984, 1986) focused primarily on the curative properties of ochre and provided several ethnographic accounts of medicinal use. He reviewed the healing properties of iron compounds. For example, iron salts have an astringent effect, they can arrest hemorhage, and have antiseptic and deodorizing properties (1984:674). Iron oxides also have the property of converting oxygen to ozone, which is beneficial to the healing process (1984:674). Velo reviewed historical descriptions of ochre use in eastern Asia during the 13th century for washing, purging and as an eye remedy, and for drying and treating malignant ulcers (1986:234). Ethnographic accounts from Australia describe how wounds are covered with chewed red ochre and leaves. Ochre moistened with water is used on sores on any part of the body, including parts of the body where there are internal pains, and is used for the treatment of burns (1986:234). Velo's work also reviewed four historical and ethnographic accounts of ochre and clay-eating (otherwise known as geophagia) in different parts of the world. Historical documents by explorer Alexander von Humboldt (in 1821) reported that in South America, where the activity was known as *pica,* clay and ochre were eaten, to an extent, at all times by Otomac Indians along the Orinoco River. Von Humboldt wrote that when the river overflowed each year, "they seemed to subsist for two months almost entirely on clay that contained iron oxide, and they seemed healthy and robust." (Velo 1986:232). A second account is David Livingstone's description of native African groups eating clay (where the practice was known as *safura*) as part of their regular diet, especially for pregnant women. The third account that Velo offered is that of geophagia by women in the southern United

States. As reported by obstetrics services in Georgia in 1967, 55% of patients had engaged in this practice as part of a strong cultural belief that clay-eating was integral to the health and nourishment of pregnant women (1986:233). Most detailed descriptions of the medicinal use of ochre tend to originate from Australian Aboriginal groups. For example, a group living in the Kimberly Range of Australia has high regard for the medicinal use of ochre. One account describes the use of ochre on an open wound: "Cover the wound with warm leaves. Chew ochre and spit it all over the wound. The wound will soon dry up." (Velo 1986:233).

Ellis et al. (1997) provided ethnohistorical accounts of North American aboriginal groups using ochre for medicinal purposes. For example, the Kayenta Navaho treated ear aches with a mixture of ochre, cannel coal and yellow and white corn (1997:662). The Havasupai and Apache were also documented to have dusted powdered ochre on the skin of infants to prevent chafing, and to have mixed grease with ochre and used it as lotion on the chapped skin of newborns. The Apache also used a warmed mixture of ochre and grease to treat rheumatism (1997:662). According to Ellis et al. (1997:663), groups in British Columbia treated snake bites by, "tightly tying the head of a weasel or an ermine just above the wound with one or two wet buckskin strings rubbed with wet ochre". Overall, the medicinal use of ochre, as evidenced through ethnographic and historic accounts, appears to be widespread in both Western and non-Western medicinal and curative practices.

On Preparation and Utilitarian Use

A small number of studies refer to the functional use of ochre as a medium for adhesives (Lombard 2005, Wadley 2005) and as a food preservative (Sagona 1994). Lombard's (2005) project addressed the potential for the use of ochre as a medium for natural adhesives in prehistoric tool manufacture through an example of lithic artifacts from a cave site in South Africa dating to 60,000 BP. She analyzed residues on the dull edges of lithics that were previously hafted onto wooden or bone shafts and found that ochre was often mixed with other binders to strengthen the bond between the stone and the shaft (2005:295). Similarly, Wadley (2005) tested the hypothesis that ochre was a useful binding medium by replicating stone tool assemblages. She replicated hafted stone tools from the Rose Cottage and Sibudu caves in South Africa and used four different combinations of binding mediums to strengthen the tools. One of the mediums tested was Acacia karoo resin, beeswax and water, while the rest were mixtures of Acacia resin, beeswax, water and ochre in variable quantities to determine if ochre would increase the strength and durability of the glue (2005:592). She found that the medium that included ochre was considerably easier to mould, less brittle and acted as a cementing agent, therefore, could have potentially served a functional purpose in hafted tool manufacture (2005:597). She also noted that heating the mixture improved its pliability considerably (2005:598). Arocena et al. (2008) also discussed ochre as an effective binder extender for its use as pigment. Sagona provided ethnographic accounts of Australian Aborigines using ochre to dessicate fruit, where fruits were packed in ochre to dry out and to be preserved over the winter months (1994:16). Keeley (1980) also described ochre as a

useful agent in hide tanning. Hides are composed of collagen that decays when exposed to bacteria-producing collagenase. The metal ions in ochre inhibit the action of collagenase and therefore prevent the decay of hides (Keeley 1980).

Descriptions of ochre preparation are often found in ethnographic, instructional or experimental research. When fired, the colour of ochre darkens and intensifies, and this change has been of interest to many (Velo and Kehoe 1990, Wreschner 1983). For example, Wreschner's dissertation research tested changes in ochre colour based on systematic firing tests. Williams (2001) also described preparation and use for pictographs by members of the Gwa'yi village, located in Kingcome Inlet, British Columbia. She described how the right locations are chosen for pictographs: that to hold the paint, the rock surface must have a mineral accretion flowing from above that would create a natural fresco, and the absence of lichen would indicate these ideal conditions (2001:37). The mineral accretions that flowed over the pictographs would provide adequate binding after the application of raw pigment. She also noted that the analysis of iron oxides on wooden and stone masks from other areas of coastal British Columbia showed that salmon eggs had been used as a binder (Williams 2001:38).

Ochre in Ritual and Mortuary Practice

Perhaps the most commonly recognized use of ochre is in association with mortuary and ritual practices. This would include the ethnographically known use of ochre for body adornment during dances, ceremonies and rites of passage (Boivin 2004, Matthews 1955, Sagona 1994, Tacon 2004, Williams 2001), as well as the

archaeologically attested use of ochre as a component of mortuary practice (Ames 2005, Burchell 2004, Roper 1991, Schmandt-Besserat 1980).

While the nature of the symbolic role of ochre in ceremonial activities and dances cannot be determined archaeologically, ethnographic descriptions of ritual ochre use are common. Sagona described ochre use by Australian Aborigines for ceremonial decoration of the human body, for coating ritual objects, tools and weapons, and for painting rock shelters and bark (1994:15). He explained ochre preparation for use as body paint to involve mixing it with grease or water and applying as a paste, or alternatively as a dry powder when a glistening, lustrous appearance was desired (1994:3). He also stated that the powdered hematite was also believed to have the practical purpose of insulating the body in cold weather. It was likely that the insulating component was actually the fat or grease, nonetheless, the belief in such properties was the important issue (1994:13). Ultimately, the purpose of the body decoration was to fulfill social purposes. Taçon's (1994:36) ethnographic study on Australian Aborigines discussed how colours are often associated with ancestral beings. Ochre, being one of the most important pigments, was used in every significant ceremony from birth to death (1994:37). Ellis et al. (1997:662) described the 'chief medicine man' of the Comanche group in Colorado as 'holding a pouch of yellow ochre that was used to turn the direction of any missile which may be directed against a body on which it had been rubbed'. Only this man was allowed to have and use the ochre.

Boivin (2004) discussed important examples of how the symbolic meaning of ochre affects the collection and utilitarian use of ochre by different indigenous

communities. For example, some Australian Aboriginal groups use ochre on a daily basis as a food preservative or for hide tanning, however since the material is so tightly woven into religious notions of ancestral beings (minerals in the landscape as being representative of the bodily remains, fat, pus, blood, bones, internal organs of ancestral beings), the material is only collected by specific individuals (females) at specific times (Boivin 2004:6). Among the Chumash of California, the success of male-dominated activities such as hunting requires that hunting tools not be contaminated with 'female' materials such as ochre (Boivin 2004:8).

The earliest deliberate use of ochre in mortuary ritual appears to be associated with Neanderthal burials, reflecting some of the earliest behavioural developments of humanity (Sagona 1994:32). Burials with ochre associations are common in many parts of the world. For comprehensive reviews of burial contexts with ochre associations, see Sagona (1994), Schmandt-Besserat (1980) and Roper (1991).

Ochre as Artistic Pigment

Descriptions of ochre use are also common in rock art studies (Carlson 1993; Clarke 1976; Taçon 2004), and studies on the use of iron oxide pigments to decorate pottery (Capel 2006) and wood and stone objects (Williams 2001). Carlson (1993) described rock art sites on the Northwest Coast of North America, which he attributed to a span of 4000 years based on the style and content of the rock art and on correspondence with archaeological remains. Sagona (1994) stated that ochre was the primary pigment used to decorate thousands of caves and rock shelters in southwestern France, the French Pyrenees and on the northern coast of Spain (1976:36).

Other studies explore the use of ochre as pigment for decorating ceramic vessels. Capel et al. (2006) discussed the role of ochre in pottery making in the Spanish Neolithic where a slip was made of ochre and clay to paint the outer surface of the vessels that were subsequently fired in an oxidizing atmosphere and the colour intensified. Maniscalo's (1989) study on ochre trade in the central Mediterranean found that ochre was imported from Sicily to Malta in specialized ochre-stained jars. Mioč et al. (2004) examined ochre and cinnabar residues in Neolithic pottery from Vinča, Serbia and determined that the ceramics were painted with ochre, although they were used as storage vessels for cinnabar.

Ochre Mining and Quarrying

Another theme emerging in ochre-related research is that of mining and quarrying. Geological sources of ochre are becoming increasingly recognized as sites of archaeological interest since often they contain evidence of quarrying, short-term occupation and, of course, the raw materials that were mined and distributed to different geographic locales. Taçon argued that in some areas of Australia, systematic ochre quarrying is identified as early as 65,000 BP (2004:32). Individuals moved considerable distances, sometimes greater than 500km annually to acquire ochre, and it was traded extensively within and between different Aboriginal groups (2004:34). The ochres from various sources were, and continue to be used to mark bodies, landscapes, shelters, walls, sacred objects, items of ceremony and utilitarian material culture to make them bright with spiritual and ancestral power associated with those sources (2004:39). Sagona also documented extensive and complex mining and trading networks in Australia, and well-

defined methods for bartering for ochre (1994:139). In Tasmania, ochre was procured and exchanged according to well-established customs. The owners of mines would allow adjacent and even distant communities to mine the ochre in return for goods unobtainable in their own region (Sagona 1994:133). A detailed account describes how ochre was mined:

> Ochre was extracted from the walls of the mine using heavy riverine stones and large flakes; a crude scaffold built of branches enabled the miners to scrape the ceiling. It is estimated that 15,000 cubic metres were mined this way at the Wilgie Mia ochre mine in western Australia. The ochre-bearing matrix was then carried to the entrance of the mine and pounded into manageable portions; pulverized ochre was mixed with water and kneaded into balls; if the ochre was purplish-brown it was discarded. When the men finished mining the ochre the women would carry it back (Sagona 1994:137).

Stafford et al. (2003) also discussed archaeological evidence of ochre mining at the Powars II site, located in Wyoming, USA. Continual erosion of the mine tailings exposed broken and complete projectile points and stone and bone tools. In addition, ochre from this mine has been geochemically matched to the ochre finds at another site located approximately 16km away (2003:74, see also Tankersley et al. 1995).

Ochre use in British Columbia

Historical references to ochre use in British Columbia are relatively rare. At the time of first European contact on the western coast of North America, ethnographic accounts of indigenous practices focussed primarily on kinship relations, potlatching, and trade relations. Any references to the use of ochre are cursory, as ethnographers were never primarily interested in the symbolism or meaning attached to the material, or where the material came from. Of the references that do exist, however, emphasis is placed

primarily on its use during potlatches and other ceremonies. For example, in Matthew's (1955) monologue *Conversations with Khahtsahlano*, two references are made to ochre use. In descriptions of traditional potlatch ceremonies at Seymour Creek, he states (on two occasions) that Chief George wore a leather headdress and red paint all over his face, "looking mighty important and pompous" (1955:277, 279). August Jack Khahtsahlano also "*didn't like whitemans paint that the Indian girls put on their faces, as Indian paint didn't run off cheeks like whitemans face paint*" (1955:47).

Bouchard and Kennedy's (1986) Squamish Nation Land Use and Occupancy report described an area in traditional Squamish Territory as *tumbth*, which translates as 'red ochre paint; paint; red paint for face; or red paint' (1986:246). They describe an interview with August Jack Khahtsalano where he states:

> This bit rock is *tumbth*; it's been lying in creek where the red paint comes from, and got a coating of tumbth. Indian find tumbth in soft ground… Tumbth means the red paint which warriors and maidens adorned their faces for war, ceremonies, dances…' (Bouchard and Kennedy 1986:246).

In *Social Life of the Owikeno*, Olson described the use of ochre during potlatch ceremonies of the Owikeno in which it was used to paint symbolic objects (1955:234). Another account describes a mystical being called the Cod Woman who was paid in red-dyed cedar bark (1955:230). Thomas (1980:20) described ochre preparation by artists on the Northwest Coast of North America to be a form of egg tempera, whereby ochre was mixed with chewed dried salmon eggs wrapped in cedar bark. Finally, Williams (2006) described the location of an ochre source on King Island, as well as the use of ochre and

the distribution of pictographs in Kingcome Inlet, on the central coast of British Columbia (2001).

Ochre use as a component of mortuary ritual has also been documented in coastal British Columbia (Ames 2005, Burchell 2004). Burchell (2004) reports human interments with ochre associations in 21 of 1044 known burials. Ochre is associated with male and female interments, as well as with infant, adolescent and adult individuals. Ames describes ochre burials in Prince Rupert Harbour as: a) covered in a layer of ochre; b) laid on a slab or floor deposit of ochre; c) ochre rubbed on the bones (secondary burials); or d) ochre pieces around specific parts of the body, such as head, stomach or shoulder (2005:230). Finally, reference to ochre trade between the Tsimshian and Carrier groups is made in Mitchell and Donald (1998:327). They state that the Tsimshian provided ochre and eulachon oil to the interior group in exchange for furs.

Geochemical Approaches to Ochre

Geochemical characterization of archaeological materials is becoming more common, both because of the increasing availability of and access to the necessary facilities, and more importantly, because archaeologists are more often asking questions that warrant the use of such methods. Characterization techniques are employed as a means toward understanding a multitude of things, such as the acquisition and use of lithic materials, the nature of ceramic production, and the trade and exchange of other materials such as glass, turquoise, nephrite and jasperite. Typically, much time is devoted to understanding the nature of the geological materials through systematic sampling of those sources to ensure that characterization of those materials satisfies the provenience

postulate. The provenience postulate states that the geochemical variability between different sources of materials must be greater than the internal variability within any one source (Glascock 2002:2). The following section focuses specifically on the past research on the geochemical characterization of ochre and how it has been used to understand more about this material.

Methodologically oriented research on ochre is not common, but the studies that do exist employ a broad range of methods in exploring the properties and geochemical composition of ochre. Such studies have played a critical role in determining what is methodologically suitable for the analysis of ochre. Most research initiatives have focussed on geochemical characterization of ochres for the purpose of geological proveniencing (Erlandson et al. 1999, Mooney et al. 2003, Popelka-Filcoff et al. 2008, Smith and Pell 1997, Wilen 2000, Weinstein-Evron 1994), while others have placed primary emphasis on themes such as ochre mining, trade, and the nature of pigment use (Manscalo 1989, Smith 1998, Stafford 2003, Tankersley et al. 1995). Each of the geochemical techniques used, including x-ray diffraction (XRD), x-ray fluorescence (XRF) scanning electron microscopic energy dispersive spectrometry (SEM-EDS), inductively coupled plasma mass spectrometry (ICP-MS), instrumental neutron activation (INAA), and particle induced x-ray emission (PIXE), have their own suite of advantages and disadvantages, and have been employed with varying success. For example, XRF is a technique whereby a sample is irradiated with an x-ray beam, and then emits a secondary x-ray fluorescence spectrum that is characteristic of the elements within that sample (Rapp and Hill 2006:237). The advantage of this method of analysis is that the

instrumentation can be made portable, which makes it of great value for characterization of art and museum-housed artifacts. A disadvantage is low sensitivity for certain elements relative to other elements. Also, depending on the chemical nature of the sample, there can be significant interference that would further decrease the sensitivity of the instrument. PIXE is similar to XRF, but it is more sensitive. Magnetic susceptibility and resonance analysis is an in-situ measurement of magnetic minerals within the sample. Both PIXE and magnetic susceptibility and resonance cannot be done on materials that have been heat-treated or mixed with other materials, therefore rendering it useless for some archaeological applications (Mooney et al. 2003). ICP-MS and isotopic analyses (Marshall et al. 2005, Smith and Pell 1997, Weinstein-Evron and Shimon 1994) are destructive and require a significant quantity of sample (5-10g) for the analysis, which can also prove to be a problem for minimal and fragile archaeological collections. For INAA, samples can be small in size (<1g) and do not need to be pulverized or obliterated, which is advantageous for small artifact materials, and for small sample sizes. However, after irradiation, samples remain radioactive for several weeks.

Despite these limitations, successful examples of ochre characterization have been achieved. An x-ray diffraction study by Tankersley et al. (1995) demonstrated that ochre specimens recovered from the Hell Gap site in Wyoming were acquired from the Powars II ochre mine (see Stafford et al. 2003). Smith et al. (1998) have also shown that it is possible to match archaeological ochres to geological sources using a combination of ICP-MS and SEM-EDS. Erlandson et al. (1999) were able to geochemically differentiate ochre source materials from eight different locations in western North America using

PIXE. A study by Genestar and Pons (2005) on the characterization of natural earths (including ochre) by Fourier transform infrared spectroscopy (FTIR) and SEM-EDS showed that two different groups of ochres were distinguishable, one rich in kaolinite and the other rich in sulphate (2005:271). Elias et al. (2006) attempted to compare the colours of ochre to their geochemical composition using XRD, SEM and particle size analysis using laser diffraction. Their results showed that only the nature, amount and agglomerate size of the particles were characteristic of the geographic provenience of the pigments (2006:80). David et al.'s (2001) study demonstrated how FT-Raman spectroscopy was capable of characterizing ancient pigments. Finally, Clarke's (1976) study examined the properties and durability of pigments used for rock art in Western Australia which had implications for understanding how the composition of pigments is helpful in successfully preserving them.

Characterization Studies in Northwest Coast Archaeology

The most notable ochre-based provenience study on Northwest Coast materials was by Erlandson et al. (1999) in which they geochemically characterized materials from eight ochre sources to determine variability within and between sources, and verify if ochre characterization would satisfy the provenience postulate. The sources were located in California, Oregon, Wyoming and Alaska. PIXE analysis was used on sub-samples from each source to acquire data on Al, Ca, Fe, K, Mn, Ni, Pb, Si, Sr, Ti and Zn. Principal components analysis of these data showed that each of the sources could be characterized and differentiated geochemically. While methodologically significant, this study did not emphasize the archaeological implications of these results, nor were any

archaeological ochres analyzed in comparison to the source material. However, those data can now be used by others who have access to artifactual materials from sites in the region to see if they can be matched to any of these sources.

Another well-known characterization study in Northwest Coast archaeology was Carlson's (1994) study on obsidian characterization. This pan-coastal study of obsidian sources and artifacts provided evidence for long-distance exchange of obsidian raw materials. His study used obsidian artifacts and source materials from 121 different locations geochemically characterized using x-ray fluorescence. In combination with chronological sequencing of sites, he was able to determine patterns of obsidian acquisition, movement and trade. His findings showed that at sites with the oldest occupations, such as Namu, obsidian materials were being transported from the inland sources to the outer coast. During this time, obsidians from 6-8 different source areas in Oregon were also moving north into the southern coast region of British Columbia. While some obsidians moved long distances, such as materials from inland Anahim and Ilgachuz sources and Glass Buttes (Oregon), other materials such as those from Mt. Garibaldi and Central Coast A and B did not move far up and down the coast resulting in relatively restricted distribution. During what Carlson refers to as the height of obsidian movement (8000-4000 BP), most of the major types overlapped in range and tended to move very long distances. After 4000 BP, the movement of obsidian appeared to slow down and contract in range, which Carlson attributes to a concomitant decline in chipped stone tool manufacture and an increase in groundstone tool use (1994:321).

Carlson's study is a positive contribution to Northwest Coast archaeology in that it has generated an extensive suite of geochemical data that can improve the quality of future obsidian sourcing studies in this region. Obsidian is a homogenous material that often has an easily definitive geochemical signature, as well as well-documented, discrete source areas. With the extensive characterization information available, Carlson was able to link materials from archaeological sites to different sources. However, because of the weak temporal resolution of many Northwest Coast archaeological sites, it is less feasible to look at more short-term, site specific phenomena related to obsidian distribution.

With the exception of these two examples, it is apparent that characterization studies are not common to this archaeological region, despite the ubiquity of lithic and ochre materials. Even from these examples, it is evident that archaeologists are simply not asking the research questions that warrant the use of such methods. However, as geochemical characterization techniques become more refined and better known, and as we continue to have an increased understanding of the nature of geological materials, the potential for rock- and mineral-based geochemical research will continue to grow.

Chapter 3: Regional Context and Methods of Analysis

The first part of this chapter describes the archaeological contexts from which the ochre was recovered. The second part describes the methods of analysis used, including the collection and characterization of the ochre fragments, followed by a description of the principles of INAA and the protocols used in the geochemical analytical component of this study. The last section briefly introduces statistical analyses used in this study.

Archaeological Contexts and Sample Extraction

The ochre samples analyzed in this study came from shell middens representing the remains of village and camp sites located in traditional Heiltsuk and Wuikinuxv (Oweekeno) territories on the central coast of British Columbia. The collection of archaeological materials from these sites was conducted by Cannon (1994, 1996-97 and 2005-06) as part of a regional-scale project focused on settlement patterns and resource use (Cannon 2000). Materials were collected by bucket auger, washed and sorted through 2mm mesh screen and analyzed microscopically (10x) to extract fish and shellfish remains. Ochre and obsidian artifacts were also retrieved and quantified. Radiocarbon dates yielded from charcoal or shell from multiple core and auger locations and depths at each site have provided chronologies for the initial and terminal occupations. Figure 1 is a map showing the core and auger sampled sites on the central coast region from which the ochre samples were collected and analysed. Figure 2 shows the sites located on Walbran Island in Rivers Inlet.

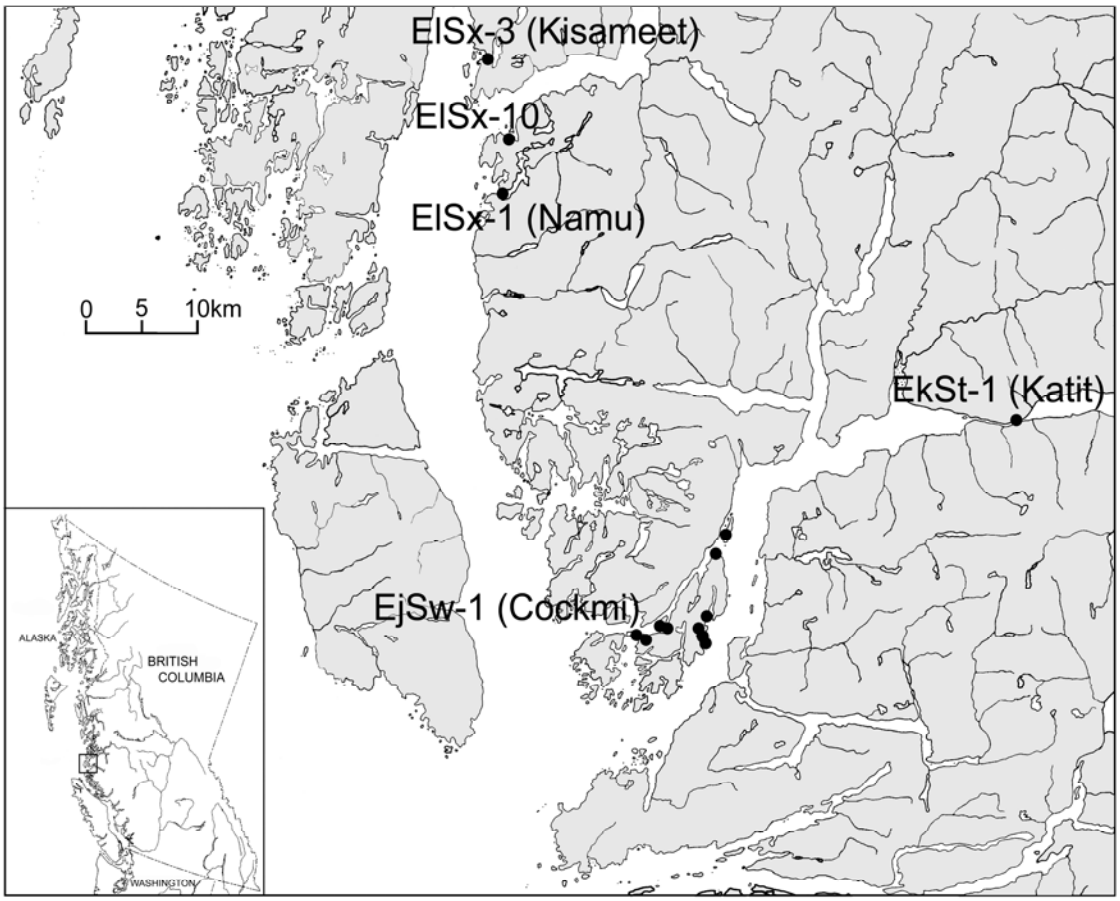

Figure 1: Central Coast Archaeological Sites Examined for Ochre Samples

Ochre was retrieved from a total of 14 sites, and specimens from seven sites were chosen for geochemical analysis. These included sites described as villages and camps based on a variety of criteria including site size and the density and diversity of faunal remains (Cannon 2000, 2002:320). The majority of ochre was recovered from village locations. Some camp sites also yielded ochre fragments, however less frequently than villages. In an attempt to assess the relative quantities of ochre by site location, the number of ochre pieces per litre of fine midden matrix per site was calculated and compared. There was no clear difference in overall density between the small number of

village and camp sites examined. Table 1 summarizes all sites and their pertinent information. (See Appendix A for ochre distribution by site).

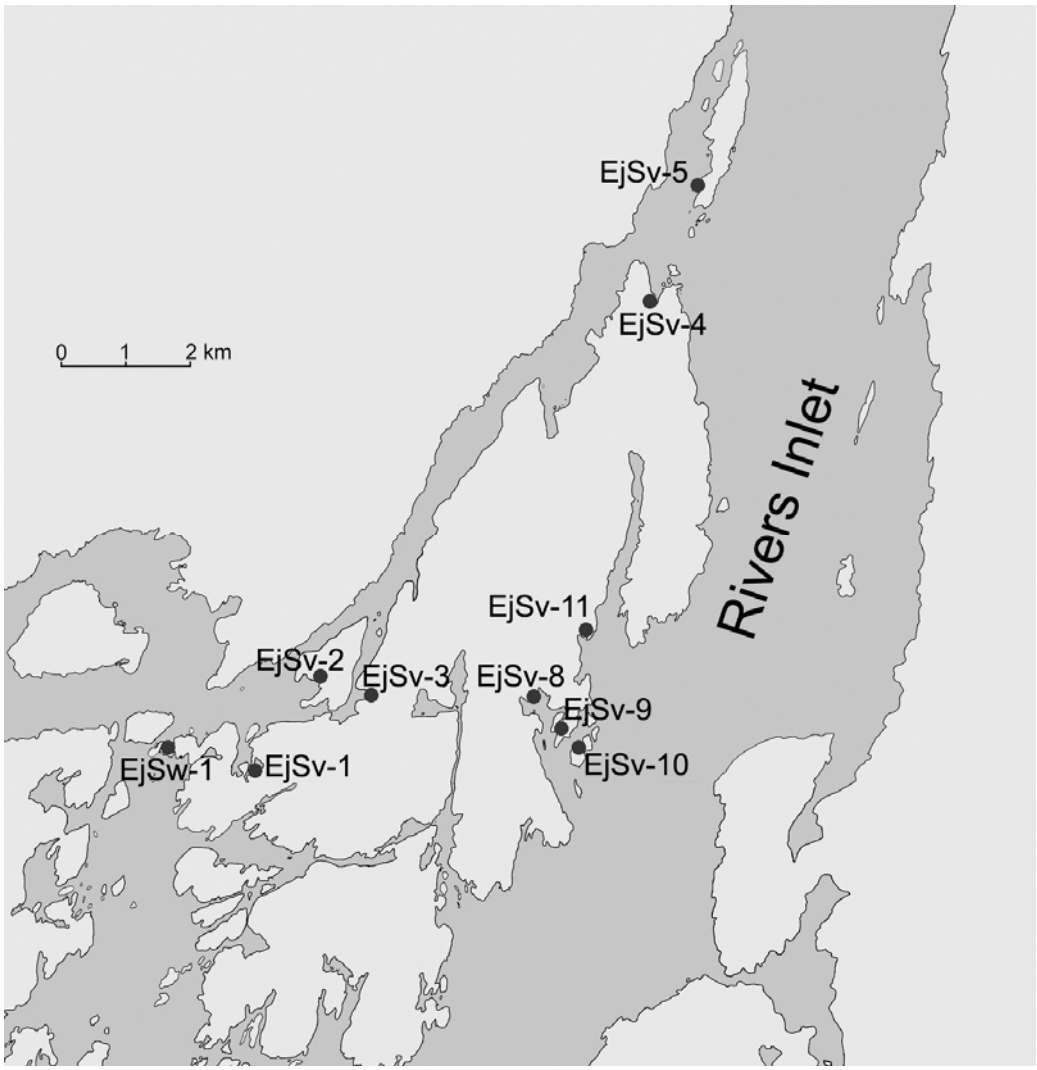

Figure 2: Sites in Rivers Inlet

Table 1: Summary List of Sites, Dates and Quantities of Ochre
(Radiocarbon dates taken from Cannon 2000 and Carlson 1996)

Site name	**Location**	**Site type**	**Site Area (m^2)**	**Date range (^{14}C years BC/AD)**	**Number of ochre pieces**	**Total Vol. of Auger Sample Matrix (ml)**
*Namu (ElSx-1)	Fitz Hugh Sound	Village	8100	**9000 BC - contact	370	20215
*Kisameet (ElSx-3)	Fitz Hugh Sound	Village	1630	940 BC - contact	309	4905
*ElSx-10	Fitz Hugh Sound	Camp	840	4315 BC- contact	3	1755
*Cockmi (EjSw-1)	Rivers Inlet	Village	6930	560 BC- AD 1230	740	30075
*Katit (EkSt-1)	Rivers Inlet	Village	4260	AD 1320- contact	115	8847
EjSv-4	Rivers Inlet	Camp	320	AD 70-450	9	4120
*EjSv-5	Rivers Inlet	Camp	480	2210 BC- AD 880	17	5685
EjSv-1	Rivers Inlet	Camp	240	AD 640-1470	58	2200
EjSv-2	Rivers Inlet	Camp	320	1900 BC- AD1650	36	5780
*EjSv-3	Rivers Inlet	Camp	330	AD 1260-1650	38	2225
EjSv-8	Rivers Inlet	Camp	560	AD 140-1450	68	5768
EjSv-9	Rivers Inlet	Res. camp	2040	1490 BC- AD 1640	1	5140
EjSv-10	Rivers Inlet	Camp	900	800 BC – AD 220	7	22620
EjSv-11	Rivers Inlet	Camp	240	2290 BC- AD 1420	30	3705
Total					1801	

**Ochre from these sites was selected for geochemical analysis.*
*** While Namu dates to 9000 BC, only materials from the last 2800 years of occupation were included in this study.*

Village sites are typically large in size and have indicators of multi-seasonal occupation. Villages included in this study include Namu and Kisameet, located in traditional Heiltsuk Territory, and Katit and Cockmi, located in traditional Wuikinuxv Territory. For more detailed description of excavation at Namu and Kisameet, and auger sampling at these and other sites within the vicinity see Cannon (2000) and Hester and Nelson (1978). Camp sites are typically small in size and may have been occupied seasonally for the purpose of specialized resource extraction. The camps included in this study are listed in Table 1.

Variability in Ochre Characteristics

The ochres consist of iron oxides that occur as discrete anthropogenic deposits in shell middens. During the extraction process, I made note of variability in the visual characteristics of the specimens, such as colour richness, friability, homogeneity, heterogeneity, relative grain size, and the presence and type of mineral inclusions (See Table 2 for detailed descriptions).

The purpose of this was twofold: 1) to determine any intra- or inter-site variability in the distribution of ochre qualities; and 2) to see if a loose categorization of ochre groups based on these characteristics would have matched any variability in the geochemical signatures of the ochre specimens. Prior to geochemical characterization, it appeared that there were potentially multiple source groups represented within the archaeological assemblage as indicated by the degree of variability in these visual characteristics. However, such characteristics of an ochre outcrop can vary considerably, even within a single source area. In other words, ochre pieces from a geochemically

distinctive source can, in some cases, look dramatically different because of variable weathering, exposure, or formation or diagenetic processes. As per the archaeological specimens, some ochres were fine-grained and homogenous with a deep red hue, while others were lighter and less vivid in colour, had either micaceous or silicate inclusions, and were overall more heterogeneous in appearance. Therefore, to assess the broadest range possible of ochre types, it was critical to establish whether or not these different qualities were potentially related to geochemical variability in the sample set. Overall, five loose categories were created based on these subjective characteristics, and these groupings were incorporated as part of the strategy for selecting ochre samples for INAA.

Table 2: Characteristics and Interpretations of Different Ochre Groups

Group	**Characteristics and Interpretations**
Group 1	-dark red, fine-grained homogenous; occurs as small round nodules -friable without blocky mineral inclusions -based on ethnographic descriptions of preparation for use as pigment, this would have likely been the most desirable form of ochre
Group 2	-red, fine-grained micaceous ochre; malleable -may have been less desirable for use as pigment because of mica inclusions -this may have been prepared by grinding and sorting
Group 3	-dense, fine-grained and deep purple in colour. -these specimens are the hardest and most cemented (almost lithified), however when ground produce a brilliant purple powder -this group may have been heat treated to achieve desirable hardness and colour
Group 4	-coarse-grained, orange-pink ochres with quartz and mica nodules -these have a greasy appearance, likely due to high silica content -poorer quality and difficult to homogenize with a mortar and pestle because of the presence of angular quartz clasts in the ochre matrix -this would have likely been the least desirable for use as pigment because of the effort required to obtain the appropriate grain-size, however may have been desired for other purposes, for example scrubbing, hide tanning, or for medicinal purposes
Group 5	-yellow, coarse-grained ochre with blocky quartz inclusions -like Group 4 ochres, these would have been difficult to process for use as pigment, however may have been desired simply for the yellow colour

Ochre Sampling Rationale and Preparation

A total of 39 samples from village sites were selected for characterization. In addition, five specimens from three different camp sites were chosen to determine if the ochre from village sites matched those retrieved from the surrounding camps. While the number of samples analyzed from camp sites is relatively low, my aim was to determine if it was possible to see geochemical similarity between village and camp sites. The samples were systematically chosen for INAA based on the quantity of materials, the visual group to which they belonged, and on the archaeological context from which they came. Effort was made to test the broadest possible range of inter and intra- site variability. I chose to analyze samples from multiple auger locations at any one site (wherever possible), and at variable depths at each location. This was done to cover the broadest range of possible use contexts of ochre, and to see roughly if there existed any significant temporal changes in ochre use. Effort was also made to include the broadest range of ochre groups at sites where the variability was high (See Appendix B for detailed descriptions of the ochre specimens selected for INAA).

The specimens were washed with distilled water in an ultrasonic cleaner to remove shell and dirt residue. In the case of highly friable materials, they were cleaned by hand with a clean wire brush or pick to remove outer layer, rinsed with distilled water to remove any remaining surface impurities and dried in a low-temperature oven for 24 hours. Specimens were then weighed to approximately 1 g (where possible) and sealed in polyethylene vials.

Geochemical Characterization

INAA was used to characterize the ochre specimens. Ochre is a mineral that is not as geochemically homogenous as are materials such as obsidian, however, previous work on the characterization of ochre sources indicates that sufficient geochemical variability exists to satisfy the provenience postulate (Erlandson et al. 1999, Popelka-Filcoff et al. 2007, Popelka-Filcoff et al. 2008, Smith and Pell 1997, Smith, et al. 1998, Stafford et al. 2003). Because of the potential variability in ochre sources, it is critical to obtain data on major, minor and trace elements and explore the interactions between them. Elements that are diagnostic for differentiating ochre source groups are typically transition metals and rare earth elements (MacDonald et al. 2008, Popelka-Filcoff et al. 2008). INAA is capable of measuring the abundances of 30+ elements, and is therefore one of the most suitable techniques available for bulk elemental analysis of ochre. The advantages of INAA are high precision, accuracy, and sensitivity for most elements, minimal sample preparation, and the potential for inter-laboratory calibration based on the use of international standard reference materials.

Principles of INAA and Irradiation Protocols

INAA is a method where specimens are bombarded with neutrons from a nuclear source. A tiny fraction of the nuclei from each element within the sample is transformed into unstable radioisotopes that decay with characteristic half-lives (Glascock et al. 2004:97). These radioisotopes emit gamma ray energies that are characteristic of each isotope. These energies are measured by a high-purity germanium (HPGe) gamma ray spectrometer, directed through an amplifier and are sorted into channels along an

electromagnetic spectrum measured in kiloelectron volts (keV). The peaks that form as a result are the spectrometric end-products of elements that produce radioisotopes.

Two irradiations were performed to acquire data on elements that produce short, medium and long-lived radioisotopes. In total, data on 32 different elements were acquired for each sample. Seven standard reference materials (SRMs) and control samples were run with each batch of archaeological materials. The SRMs used for this analysis included SRM 1632b Coal, SRM 1633b Fly Ash, SRM 688 Basalt, SRM 278 Obsidian Rock all issued by the National Institute of Standards and Technology (NIST), and Ohio Red Clay. Non-certified elemental concentrations from the Ohio Red Clay were taken from Glascock *et al.* (2007).

The samples were run through a pneumatic tube system and subjected to a 10-second thermal irradiation at a neutron flux of 5×10^{13} n cm^{-2} s^{-1}. Each sample was left to decay for 10 minutes and then measured by a HPGe detector for 5 minutes. The elements measured for the short-lived procedure include Al, Ba, Br, Ca, Co, Cl, Dy, K, Mg, Na, Ti and V. The samples were left to decay for approximately 24 hours, after which a second 5 minute count was performed to collect concentration data on Eu, K, La, Mn, Na and Sm. The same samples were repackaged into high-purity quartz vials and irradiated for 8 hours at a neutron flux of 5×10^{13} n cm^{-2} s^{-1}. The samples were left to decay for 7-10 days after which they were counted for 15 minutes to measure concentrations of Au, As, Ba, Br, Fe, La, Na, Nd, Sb, Sm and Th. Approximately 14-16 days after the long irradiation the samples were counted for another 15 minutes to measure concentrations of Ce, Co, Cr, Cs, Eu, Hf, Lu, Sc, Tb, and Yb. Other elements measured but not included in further

Table 3: Reported Elemental Concentrations of Standard Reference Materials

Element	SRM 1632b	SRM 1633b	SRM 688	SRM 278	Ohio Red Clay
Al (%)	0.87	15.05	8.95	7.18	6.86
Au	0.024	0.765	0.41	0.55	0.43
As	3.97	137	3.1	7.3	15.2
Ba	76.5	665	206	1250	605
Br	17.3	2.5	450	nm	nm
Ca (%)	0.2	1.51	6.2	0.768	0.352
Ce	9.5	209	9.6	63.4	116
Cl	1264	70	27.6	587	38
Co	2.26	46	48.4	3.3	23
Cr	11.3	198.2	330	6.5	82.8
Cs	0.64	10	0.36	7.1	13.7
Dy	1.125	17.2	4.2	6.6	5.7
Eu	0.187	4.1	1.2	0.88	1.6
Fe (%)	0.738	7.2	6.8	1.4	4.27
Hf	0.5	6.77	1.2	5.3	7.34
K (%)	0.082	1.75	0.23	3.45	2.96
La	4.5	94	5.1	33.4	49
Lu	0.054	1.1	0.4	0.6	0.68
Mg	330	5300	nm	1700	nm
Mn	12.2	131.8	1227	404	252
Na (%)	0.0409	0.202	1.62	3.52	0.1279
Nd	9.35	87	7.9	29.4	40.6
Sb	0.253	5.9	0.23	2.4	1.35
Sc	1.92	41	36.01	5.14	16.4
Sm	0.844	20.3	2.42	6.2	7.6
Sr	99.8	860	190	nm	70
Ta	0.243	2.4	0.34	1.25	2.4
Tb	0.169	2.8	0.36	0.6	1.63
Ti	548	8163	7700	1630	4700
Th	1.46	25.7	0.39	12.6	14.5
V	14.8	295.7	254	8.5	183
Yb	0.482	7.37	2.4	3.8	5.13

*nm = concentrations not measured. Concentrations are presented in ppm unless otherwise noted.

analyses include Ga, Pr, Rb and Zn. The raw data were calculated and calibrated using GammaVision™ and PEAK software, and bivariate statistical analyses were performed using JMP statistical software.

The elemental concentration data yielded from INAA are typically expressed as a percentage for major elements, such as Al, Na and Ca, and in parts per million (ppm) for minor and trace elements. Table 3 shows the average reported values for all SRMs used. See Appendix C for elemental data (ppm) on all ochre samples, and Appendix F for the summary data of the elemental concentrations for major geochemical groups. The Fe content of natural ochres can be highly variable (5-75 %), therefore, to compensate for this variability all element concentrations were calculated as a ratio to Fe for each sample (this is also referred to as Fe normalization). This transformation is necessary where high Fe content can potentially dilute the presence of other diagnostic elements, and also where low Fe content may amplify the presence of minerals that can substitute for Fe (Popelka-Filcoff et al. 2007). The values were then converted to a base-10 logarithmic format as part of standard statistical practice when the variability within a data set can be across several orders of magnitude (Baxter 1994:40). As argued by Baxter (1994:49), these transformations of scale are also necessary for data that are intended to be subjected to principal components analysis (PCA), as PCA is scale-dependent (see Appendix D for the elemental concentration data in $\log^{10}$ format). These Fe normalized, base-10 logarithmic values were then subjected to statistical analyses such as outlier calculations (Mahalanabois distance, Hotelling's T^2 distance and Jacknife distances), bivariate plotting

(to determine clustering within the data set), and PCA, all of which are described in more detail in the following chapter.

Chapter 4: Analytical Results

This chapter describes the results of the qualitative and INAA components of this study. First I describe the variability in ochre qualities within and between sites. Second, I discuss the geochemical results, beginning with a general summary and followed by a discussion of statistical analyses such as outlier calculations, bivariate correlations and principal components analysis. I finish with a discussion of these results in relation to their archaeological context.

On the Variable Qualities of Ochre

At each site, there is variability in the relative qualities of the ochre specimens, however the distribution of the ochre groups described in Table 2 varies between sites. For example, at Cockmi, there are differences in ochre qualities based on auger location. Location A is characterized primarily by Group 2 ochre, while location B by group 4 ochre. The ochre from Namu also follows a pattern of variable distribution with the exception of a large deposit of Group 3 ochres at auger location H. In contrast, Katit is characterized by Group 2 ochre, which is consistently similar at all auger locations and depths. In other words, there appears to be no consistent pattern in the distribution of these ochre groups within or between archaeological contexts. I hypothesized that variability in ochre qualities over space and time could be a result of either different ochre sources being accessed by site inhabitants, different methods of processing, or, ochre from different sources being stored, processed or used at different areas of the site for varying purposes. However, based on the geochemical results, none of these scenarios are the case. Despite the variability in spatial distribution of ochre qualities at any site,

the geochemical signatures of the mineral remain the same within each site. It was originally expected that the group classifications (i.e. Group 1, Group 2, see Table 2) would correspond with different source groups of ochre, however, through preliminary examination of bivariate plotting of elements such as Ti, V, Al, the chemical groups appeared to correspond with the archaeological sites from which the samples came (these are provided and described in further detail in the following section). It is for this reason that I chose to continue further statistical analyses, such as outlier calculations, with a focus on exploring and grouping based on this indicator.

Since ochre sources can vary in their physical and visual characteristics and still maintain a unique geochemical composition, these results suggest that despite the variability in visual characteristics, these sources were potentially accessed on the basis of their location rather than their quality. This concept will be discussed in more detail in the conclusion of this thesis. From a methodological standpoint, this result has significant implications for the classification of archaeological ochre based on visual characteristics alone, a problem also commonly reported in lithic characterization studies (Shackley 2008). While ochre qualities may be assessed based on their visual and tactile characteristics, these classifications are not necessarily diagnostic of different geochemical sources. Therefore, these results have nullified the hypothesis that ochre from different sources can be differentiated based on visual characteristics alone.

Results of Geochemical Analyses: Statistical Applications

To identify variability and geochemical trends in the ochre samples, the elemental concentration data yielded from the INAA must be explored through multivariate

statistics. In characterization studies, the most common practices include cluster and discriminant analyses, principal components analysis and correspondence analysis. Based on the complexity of the data set I had generated, I chose to do bivariate plotting, outlier calculations and PCA. Bivariate plotting of the elemental concentration data is useful for determining positive and negative correlations between elements, and for identifying potential outliers. PCA is a common exploratory method for analyzing a multivariate data set that is not readily discerned by simple visual characterization. It generates and integrates three categories of information: 1) obtains a two-dimensional picture that allows groups to be differentiated by their chemical composition; 2) obtains a two-dimensional picture showing how elements are associated, and 3) puts these two pictures together to see which elements affect the structure and how (Baxter 1994:48-49). Baxter also states that the results of a PCA will depend on how the data are scaled or transformed (1994:49). Therefore, because PCA is scale dependent, the data (in ppm) needed to be expressed as a ratio to Fe (in addition to the need to account for the variable Fe content that may dilute or amplify the presence of other minor or trace elements). All [EL]/Fe ratio values needed to be converted to base $\log^{10}$ format, which is standard statistical practice when the variability within a data set can be across several orders of magnitude, and where PCA will be applied (Baxter 1994:40). To test the efficacy of these transformations, I created bivariate plots of the data in three different forms: as ppm, as [EL] ppm/Fe, and as [EL] ppm/Fe $\log^{10}$ format, which illustrate how these transformations of scale can influence the appearance of the data when presented in this manner. These biplots are presented and described in more detail in the next section.

These two data transformations (Fe ratio and base $\log^{10}$ conversion) essentially bring what were once highly variable data to a format that can be subjected to scale-dependent multivariate discriminant analyses such as principal components.

During preliminary exploratory bivariate plotting of elements, I also identified a small number of outliers within the data set. The presence of outliers can dramatically influence the results of the PCA as they will drive the variance between the geochemical groups further than they actually are. In other words, outliers, if included in a PCA, will end up being the main feature of a component plot, therefore obscuring other useful structure in the data (Baxter 1994:79). I had anticipated the presence of outliers based on preliminary bivariate plotting, and for that reason, I performed Mahalanobis and Jacknife distance calculations and Hotelling's T^2 distribution tests to statistically identify and eliminate these outliers. In addition, to test and demonstrate the influence that these outliers had on the subsequent PCA, I have provided PCA plots both with and without the outliers included. Those PCA plots were also used to interpret the geochemical nature and archaeological distribution of different geochemical groups of ochre from this sample set. The following sections present and describe these statistical procedures in more detail.

Bivariate Correlations

The first step I took in exploring the data set was bivariate plotting of all elements. This was done for two reasons: 1) to see if any clustering or grouping would be evident based on any combinations of the 32 elements analyzed, and, 2) because bivariate plotting of selected elemental concentrations illustrates positive or negative correlations

between each variable. In other words, elemental groups such as first row transition metals (i.e. Sc, Ti, V, Cr, etc.) or lanthanide rare earths (Ce, Pr, Nd, Sm, Eu, etc.) are expected to behave similarly, therefore to measure the correlations between these variables, plotting them against each other demonstrates positive and negative correlations between them. These correlations also indicate if there are any outliers or erroneous results. Figures 3 and 4 show the correlations between concentrations of Sc/Fe and Al/Fe, and Ti/Fe and Al/Fe, respectively, which is a consistent pattern between other combinations of transition metals and lanthanide rare earth elements. What these figures demonstrate is that there are positive correlations between Al and the transition metals Sc and Ti, which is expected as Sc and Ti can substitute for Al in many minerals. The samples labelled by number are identified as potential outliers.

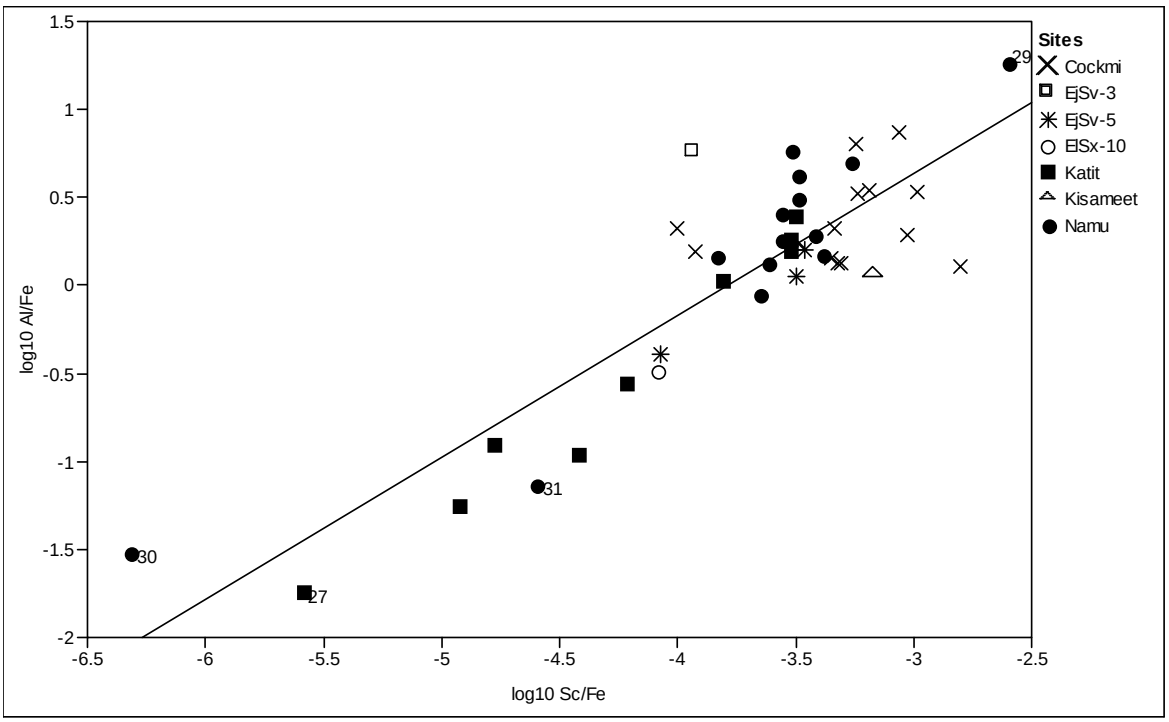

Figure 3: Biplot showing log^{10} correlation between Al/Fe and Sc/Fe

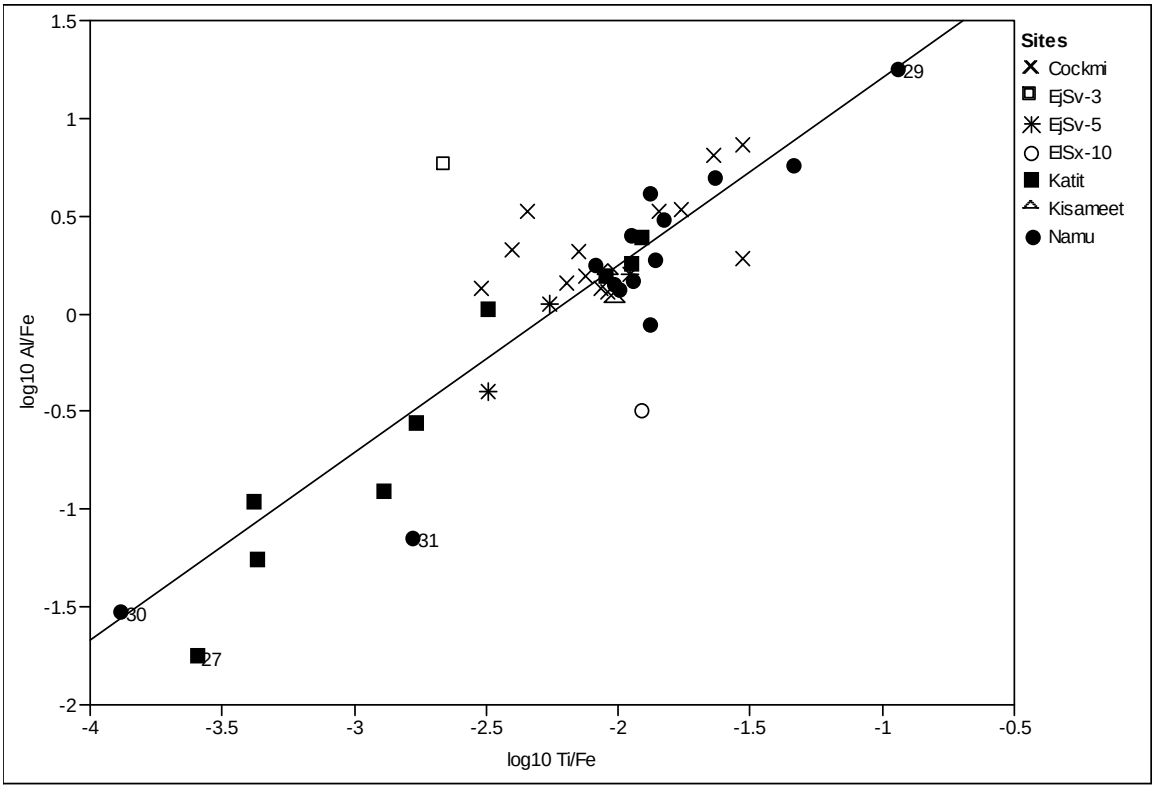

Figure 4: Biplot showing log^{10} correlation between Al/Fe and Ti/Fe

In addition to correlations and outlier identification, bivariate plotting was also performed to identify clustering of source groups and to show how the transformations of scale (Fe normalization and base log^{10}) are seen visually. Figures 5-7 illustrate these exercises. Other ochre studies have suggested that because the Fe content of ochre is highly variable (5-70%) it is necessary to normalize the concentrations of all other elements to Fe (Popelka-Filcoff et al. 2007). Once again, this transformation is necessary where high Fe content can potentially dilute the presence of other diagnostic elements, and also where low Fe content may amplify the presence of minerals that can substitute Fe. I decided to evaluate the usefulness of this transformation of scale for this data set by observing the patterns in bivariate elemental distribution and clustering between elements

plotted in ppm, elements plotted as ppm/Fe, and as ppm/Fe $\log^{10}$ format. In other words, Figures 5-7 are all composed of the same data, but in different stages of this transformation process. These plots illustrate how each of these transformations can modify the way the distribution appears through bivariate plotting, and how the apparent clustering of chemical groups can be affected by these transformations. These visual changes were critical to evaluate, as they are often what researchers use to differentiate and characterize chemical groups. (All ellipses are at 80% confidence.)

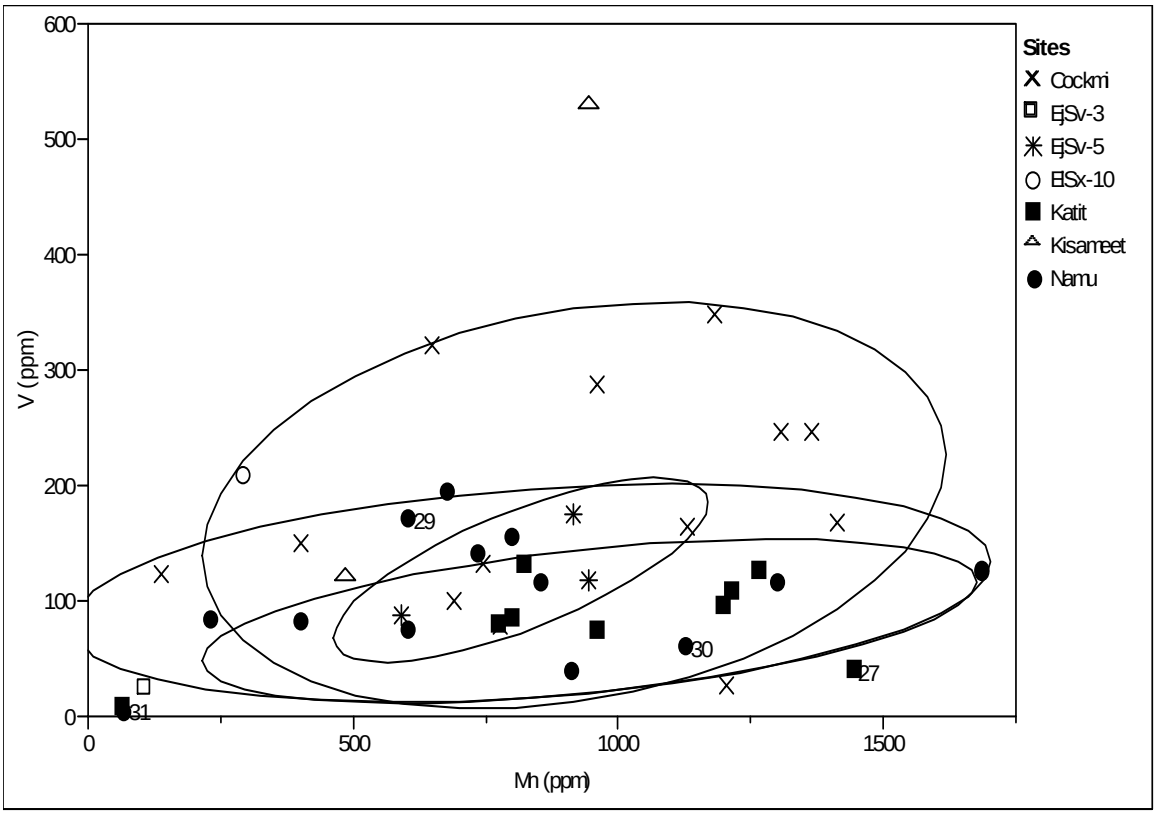

Figure 5: Bivariate fit of V and Mn

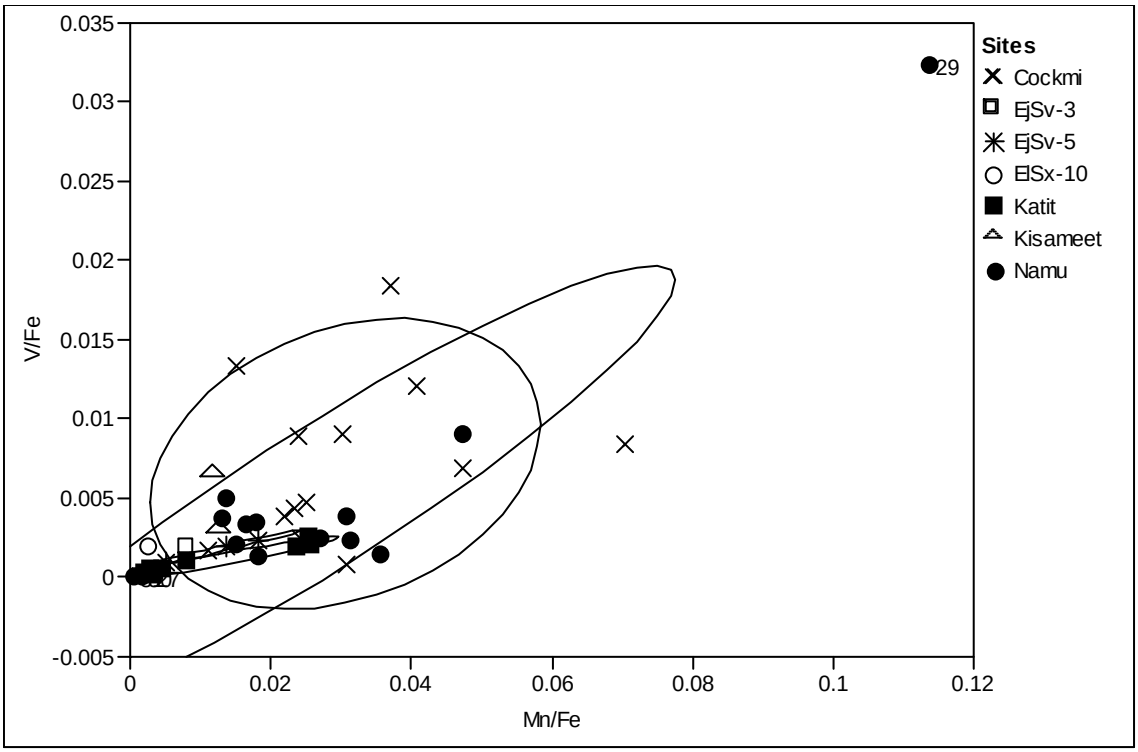

Figure 6: Bivariate Fit of V/Fe and Mn/Fe

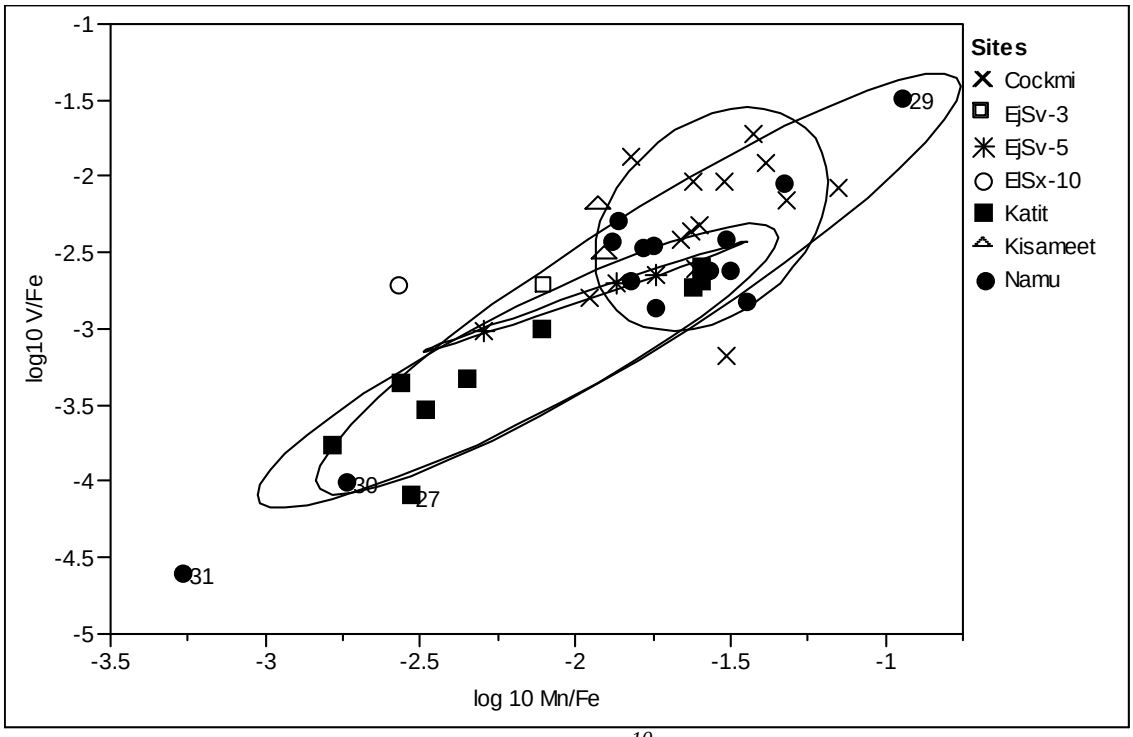

Figure 7: Bivariate fit of log^{10} V/Fe and Mn/Fe

The results show that by transforming the data as a ratio to Fe and to $\log^{10}$ format, the distributions of each geochemical group become more tightly clustered. Through each transformation of scale, the data are converted to more tightly clustered groups as they are converted to a common order of magnitude, and are therefore easier to interpret. This test demonstrates that converting the elemental concentrations as a ratio to Fe and to $\log^{10}$ format does not mask any potentially significant patterning in bivariate elemental distribution, and improves the visual clustering of groups. In addition, I subjectively identified potential outliers of each chemical group, indicated by number (i.e. 27, 29, 30, 31). Because outliers can potentially skew the results of a PCA, I decided to further test the statistical significance of these outliers by subjecting each of the geochemical groups to outlier calculations such as Mahalanobis distance, Jacknife distances and Hotelling's T^2 distribution.

Calculating Outliers

The identification and elimination of outliers is necessary to generate an accurate principal components analysis. As stated by Baxter (1994: 80), outliers can dramatically influence the results of a PCA as they will end up being the main feature of the component plot and obscure other useful structure in the data. To statistically identify outliers Mahalanobis distances, Jacknife distances and Hotelling's T^2 distribution values were calculated separately for each archaeological location (with the exception of Kisameet [ElSx-3] and all camp sites as the sample sizes were too small). I chose to calculate the outliers separately for each geochemical group because through bivariate plotting, these groups had already begun to emerge based on their archaeological context.

The three outlier calculations that were used all generate data in the form of distance values. Mahalanobis distance and Hotelling's T^2 distributions measure how far a multivariate point is from a multivariate mean, taking into account the covariance structure, while not being dependant on the scale of measurements. These measures generate scores that illustrate the dissimilarity of samples within a set and identify data points that have the most influence on the statistical spread of the sample set (Baxter 1994:80). Jacknife distance is a further refinement to the Mahalanobis and Hotelling's T^2 distribution; whereas the latter estimates the means, standard deviations and correlations of all points, 'Jacknifing' excludes the outlier points from those estimates. This computation in the JMP program then takes those excluded outlier points and puts them back into the distributional plot to illustrate where the sample would lie in relation to others, therefore making those outliers stand out more prominently. This proved to be effective in more accurately identifying the outliers from the Namu set of samples.

Because these three procedures generate similar scores, the plots are virtually identical. Figures 8-10 show the results for tests for three major village sites. The vertical distribution of icons in these plots is indicative of the distance scores for each sample. Samples with the highest scores, those situated closest to the horizontal line, are statistically identified as outliers and are labelled by number. A total of five outliers were identified in these data sets: one from Cockmi, three from Namu and one from Katit.

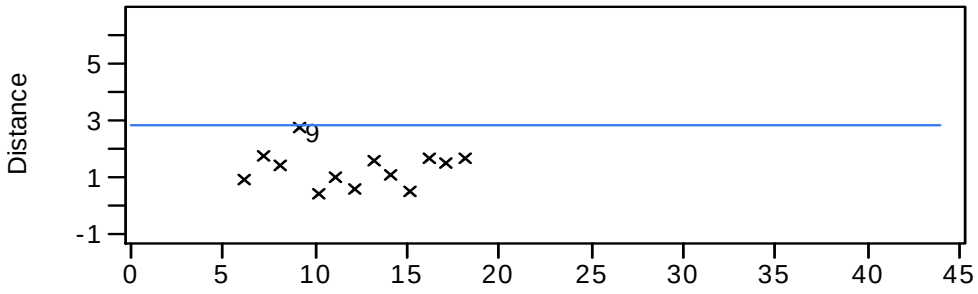

Figure 8: Mahalanobis distance scores for samples from Cockmi

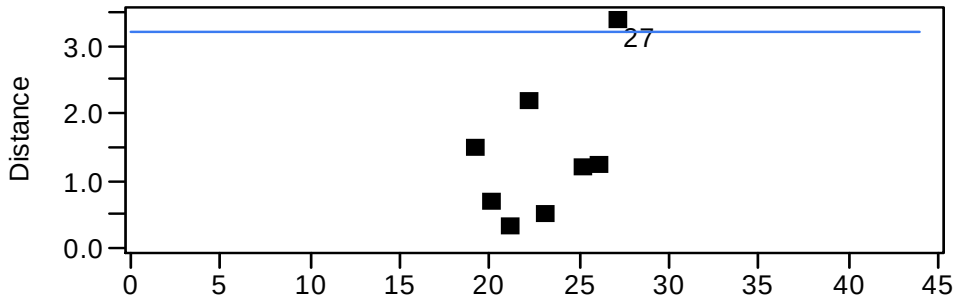

Figure 9: Hotelling's T^2 distance scores for samples from Katit

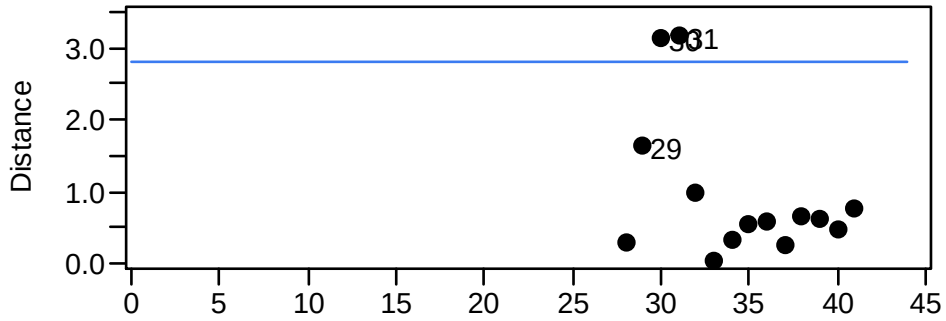

Figure 10: Jacknife distance scores for samples from Namu

While the omission of outliers will significantly affect a PCA analysis, it should not be considered a manipulation of data to get the results that one wants, as long as they are clearly identified and not simply discarded as erroneous results (Baxter 1994:80). On the contrary, these outliers could be potential sources of information. In the case of this project, these outliers could possibly represent different source groups altogether, which

itself warrants further exploration. For the purpose of this study I have not explored this possibility, however in future research these outliers will be more thoroughly addressed.

Principal Components Analysis: Outlier Tests

As stated, I chose to do PCA on these data because it is an effective way to explore patterns in a multivariate data set that are not readily discerned by simple visual characterization. To test Baxter's argument on the effect of outliers on a PCA, I ran the analysis twice, once including the outliers and once excluding them. For these, I used the Fe normalized, $\log^{10}$ elemental concentration values of all elements. Figures 11 and 12 are PCA biplots of principal components 1 (PC1) and PC 2, and PC1 and PC3, respectively. The outliers identified by outlier calculations are labelled by number. Figures 13 and 14 are biplots of the same data (i.e. PC1 and PC2; PC1 and PC3), however with the outliers excluded. The differences between Figures 11 and 12, and Figures 13 and 14 illustrate the influence that only five outliers can have on the results of a PCA. Therefore, this test supports the notion that outlier exclusion is critical to the results of a PCA.

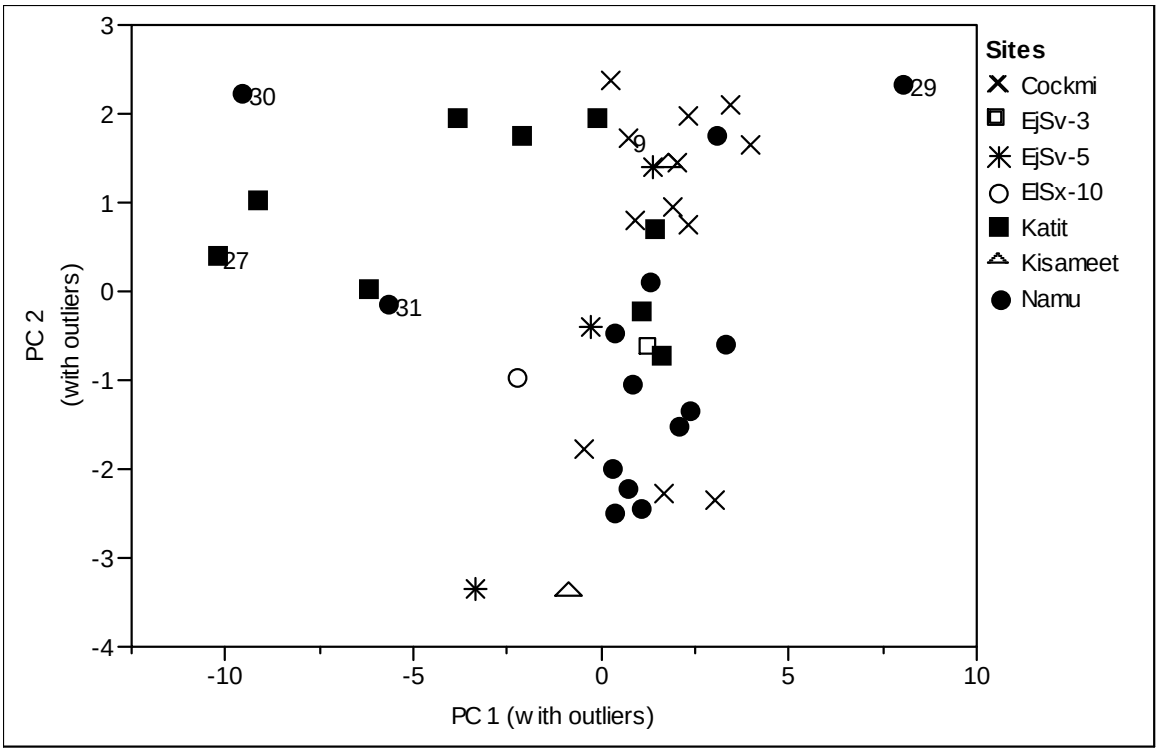

Figure 11: Biplot of PC1 and PC2, including outliers

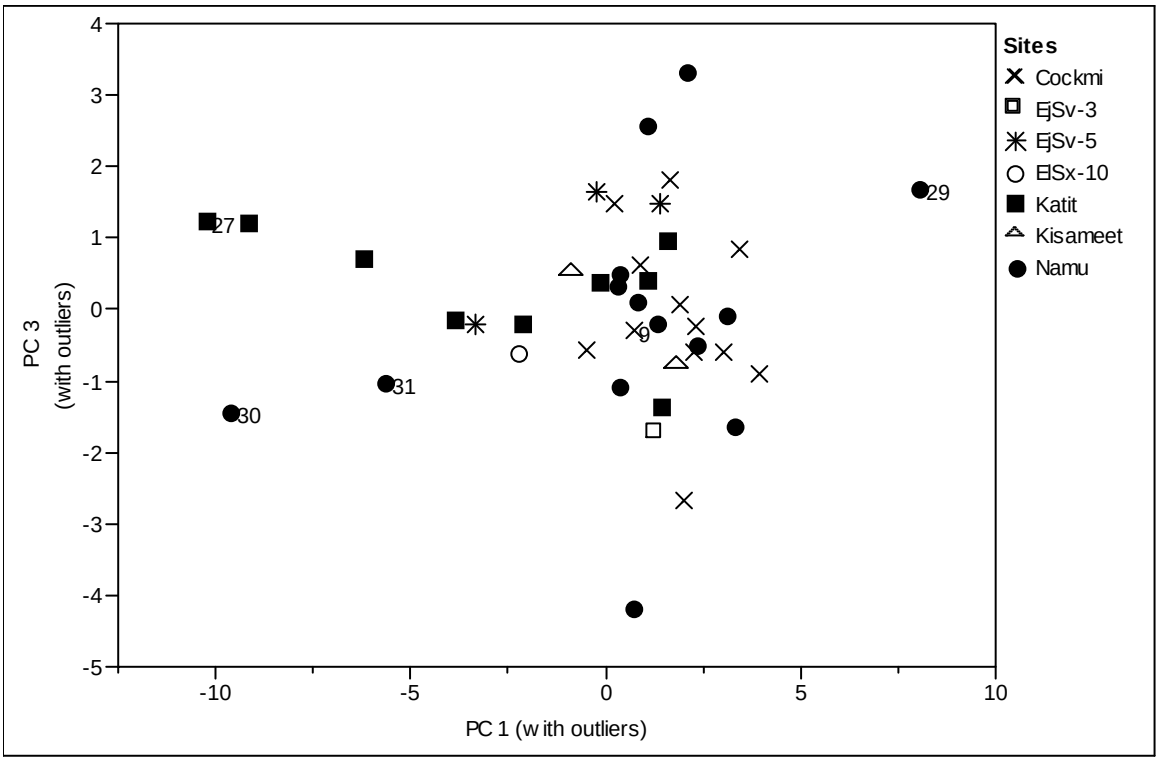

Figure 12: Biplot of PC1 and PC3, including outliers

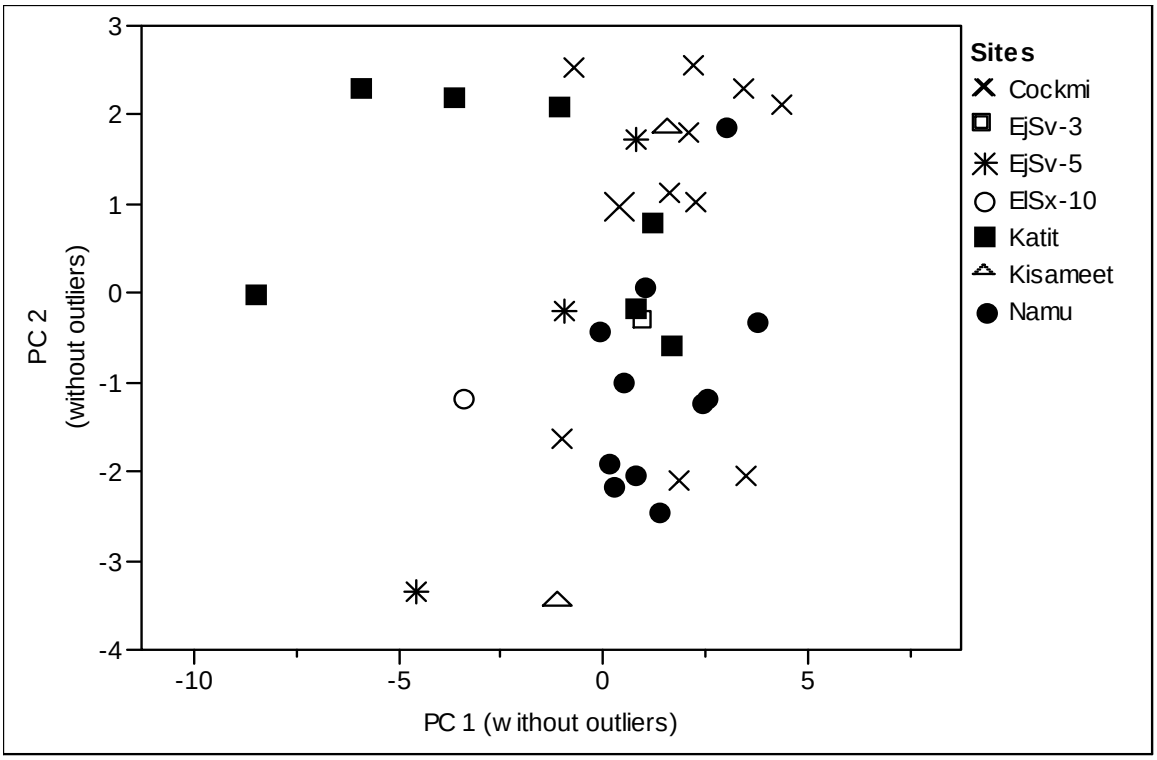

Figure 13: Biplot of PC1 and PC2, excluding outliers

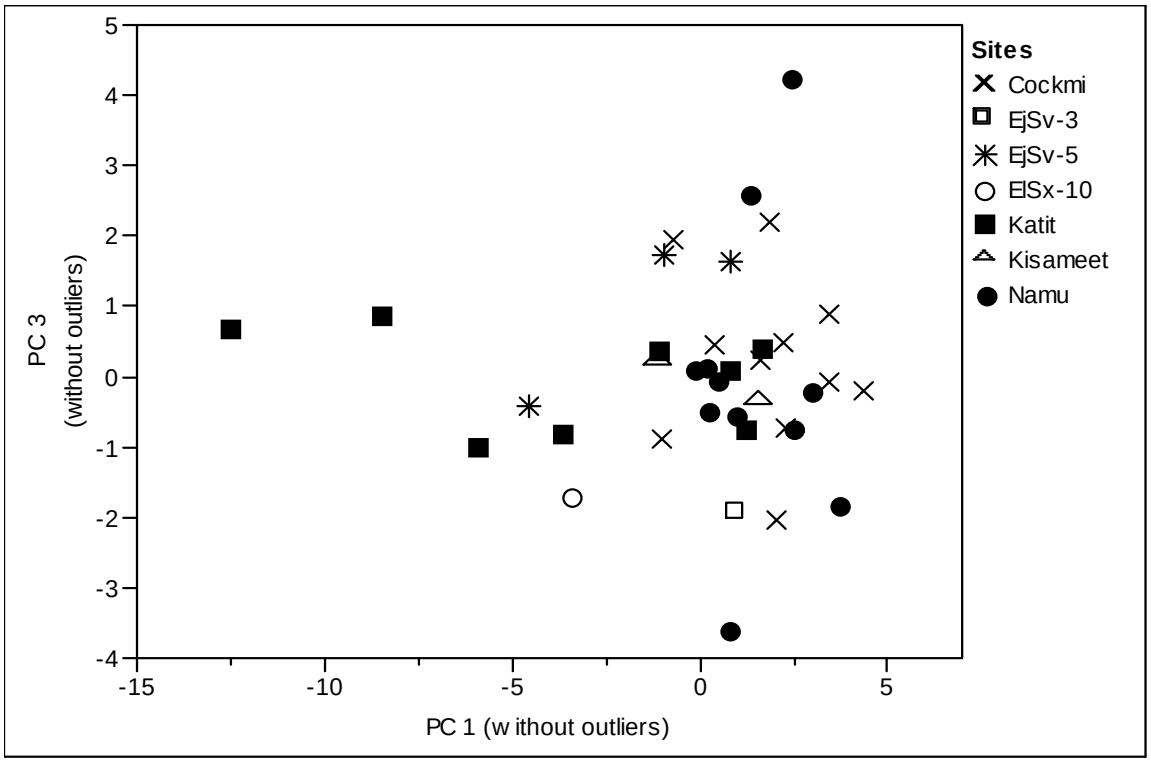

Figure 14: Biplot of PC1 and PC3, excluding outliers

Principal Components Analysis: Reading the Biplots

Figures 13 and 14 show the distribution of the archaeological samples when the first three principal components are plotted against each other (See below for a description of which elements comprise each principal component). The proper way to read these plots is to identify which samples are located in each of the four quadrants, with the quadrants being designated by the zero (0) marker on each axis. For example, in Figure 13, the positive values (>0, y-axis) for PC 2 are what separate most of the Katit geochemical group from the majority of the Namu and Cockmi geochemical group samples. The positive values for PC1 (>0, x-axis), are what separate the Cockmi and Namu samples from the Katit samples. Figure 14 shows that the negative values from PC 1 are what separate the Katit geochemical group from the Namu and Cockmi geochemical groups. In sum, the elements that negatively influence PC 1 pull the Katit geochemical group from the Namu and Cockmi groups, while the elements that positively and negatively influence PC 3 separate the Namu and Cockmi geochemical groups from each other.

To determine which elements comprise each principal components group, the statistical procedure generates eigenvector values for each variable for each PC. In other words, each element included in the analysis is assigned a score that reflects both the positive or negative influence each has on the principal components, as well as the strength of their influence. As a result, it is possible to identify which elements drive the variance between geochemical groups. The complete lists of eigenvector values for all three PCAs (including and excluding outliers) are in Appendix E. Table 4 shows by what

percentage each principal component drives the variance within the set. Overall, the first three principal components account for over 63% of the variability in the sample set.

Table 4: Percentage at Which Each PC Drives the Variance Within the Sample Set

Principal Component	Cumulative Percent
1	43.9
2	55.6
3	63.2

In sum, PC 1 is positively influenced by Ti, V, Al, Ca, Mn, Th, Sc, Eu, Sm, Ce and Nd. PC 2 is influenced most by Cr, Sb, Rb, Ba, Au and Cs. PC 3 is influenced most by Cl, Co, As, Sb and Lu. Therefore, the elements that appear to be most diagnostic in differentiating geochemical source groups of ochre are first row transition metals and lanthanide rare earth elements.

Principal Components Analysis: Archaeological Contexts

In combination, Figures 13 and 14 both show that a minimum of three major distinct geochemical groups are represented in this sample set. The samples from Katit are consistently distinctive from the rest, with a few potential exceptions that are distributed in the Namu and Cockmi geochemical groups. This pattern was anticipated based on where Katit was located geographically in relation to Namu and Cockmi, where one would expect less frequent interaction in comparison to the potential intensity of interaction between inhabitants of Namu and Cockmi. The samples from Namu and Cockmi are generally distinctive from each other, however a pattern has emerged where a small number of specimens that are typical of the Namu geochemical group came from Cockmi, and vice versa. In other words, there are two major geochemical groups of ochre

and they are both represented in variable proportion at Namu and Cockmi. This could be indicative of small-scale exchange of ochre, or shared access to a common ochre source. The two samples from Kisameet (ElSx-3) are shown to be geochemically similar in Figure 14, but separate in Figure 13. Based on Figure 14, the elements that influence PC 3 bring these two samples together, however in Figure 13, the elements that influence PC 2 drive the samples apart into two separate geochemical groups. This could be indicative of two different geochemical groups (one being shared with Namu), but this can only be verified with further sampling from this location.

To determine if there were any coarse patterns in the distribution of these materials at locations and depths within each site, I referred back to the locations and depths from where each sample came. I did this to determine if there were any changes over time in the mode of ochre procurement, or if variability in ochre procurement was evident at different areas of any given site. For example, I wanted to see if the evidence for shared access to a source between Namu and Cockmi began to occur at any specific time in the archaeological sequence, or if it was present at specific areas of either site. However, there was no pattern of such variability at any site. In other words, the locations from which the ochre was being accessed were being used (and potentially shared or exchanged) in the same manner for the entire period of occupation that was studied at each site.

Samples from the camp sites that were included in this study (EjSv-3, EjSv-5 and ElSx-10) yielded potentially interesting results. The reason for including these sites was to see if the ochres from them were geochemically similar to those from nearby villages.

Figure 13 shows that the elements that comprise PC 2 pull apart the three samples from EjSv-5. Figures 13 and 14 show that the sample from ElSx-10 is distinctive from almost all of the other samples. In Figures 13 and 14, the sample from EjSv-3 is wholly distinctive from the Katit geochemical group, but not quite distinguishable between the Cockmi and Namu geochemical groups. As it stands, there is no generalized pattern whereby the geochemistry of ochre from camp sites matches those from nearby village sites. In fact, some of these samples may represent ochre from different areas of one source, or different ochre sources altogether, however, more systematic and widespread sampling is needed to verify this.

Outliers as Potential Sources of Information

What is critical to remember about the outlier calculations is that they were considered as outliers to each site group, therefore adding a slight bias to the use of the calculations. Therefore, these specimens could in actuality be samples from one source that are present at multiple sites. In other words, one of the outliers from Cockmi or Namu or Katit could have easily matched with those from another site. For example, two of the three outliers from Cockmi could conceivably be from of the geochemical group represented at Katit (see Figures 3 and 4). More thorough statistical analyses would be needed to determine if this were the case. Regardless, the outliers should be considered as potential sources of information, as indicators of trade of raw materials or of an additional ochre source, which itself warrants further exploration. While I have not explored this possibility in great detail here, future research will address the significance of these outliers.

Discussion

The purpose of this study was to determine if it were possible to differentiate geochemically distinct ochre groups within an archaeological assemblage using INAA. Furthermore, if that were possible, could any patterns in the nature of procurement and distribution of ochre within and between archaeological sites on the central coast of British Columbia be identified? Prior to the geochemical characterization, I had anticipated, based on the degree of macroscopic variability in ochre qualities, that there would be multiple source groups represented in the ochre assemblage from any given site. I had hypothesized that a greater number of sources would indicate regional-scale exchange of ochre, more or less intensive trade activities, or at a minimum, access to and acquisition from multiple local sources. However, the results have indicated an alternative mode of procurement and distribution, where the general pattern of acquisition was limited to one or two sources, and that extensive trade was not predominant. The general mode of ochre procurement in this region involved localized acquisition, whereby village inhabitants were accessing ochre from a small number of local sources consistently over long periods of time, with little to no change in that behaviour. That there are two geochemical groups represented at both Namu and Cockmi provides some evidence for shared access to a common source, small-scale exchange. The temporal pattern of these behaviours also supports the notion that they were long-term practices, and the conspicuous lack of deviance from those practices also indicates that they were likely long-term, community-wide traditions.

Chapter 5: Conclusions and Future Research

Methodological Implications

This project demonstrates the potential for characterization studies of ochre, and the utility that these types of study can have to archaeologists. This study shows that ochre sources in this region, despite being geographically close, appear to be geochemically distinct from each other. Even without the use of ochre source material it is possible to determine the number and geochemical range of ochre sources present within a given archaeological assemblage. As the geochemical nature of ochre becomes better understood, the process of and problems associated with ochre characterization and sourcing become easier to overcome. Because ochre can be a geochemically heterogeneous mineral, the procedures for acquiring and interpreting elemental concentration data are not straightforward. The results of this research verify the need for specific research protocols as attested in current literature, such as the need for data on a wide range of elements, including transition metals and lanthanides (rare earth elements), and the need for statistical procedures such as PCA, normalization of elemental concentrations to Fe, and the identification and exclusion of geochemical outliers. Also important is that this study shows that visual characteristics of ochre should not be relied upon for differentiation of geochemical source groups. In some cases, relatively homogenous materials such as obsidian can be linked to their source based on distinctive visual characteristics. However, because of the variability in ochre formation processes and its geochemical heterogeneity, more intensive analytical and statistical techniques are required.

Archaeological Contexts: Conclusions and Future Research

The results of this study indicate a pattern of highly localized ochre acquisition within this region of central coastal British Columbia, and to a lesser extent, the potential for shared access to ochre sources or small-scale trade between villages. That these behaviours were established and maintained for long durations at these sites also suggests that the behaviours associated with ochre procurement and use were traditional, community-wide practices. Ochre acquisition and use in this region is known ethnographically to be associated with symbolic and ritual practice. This is also evident in the archaeological record where ochre is used as a component of mortuary ritual. What is also compelling is that there appears to be no correlation between geochemical ochre sources and their visual characteristics. In other words, raw materials from ochre sources weren't primarily sought after based on visual characteristics, but rather based on the place from which they came. All of these indicators: use contexts, long-term patterns of procurement, minimal exchange of materials, and lack of primary, selective preference for visual and tactile characteristics, support a mode of acquisition where ochre from specific places was more highly valued than others. There would have been no desire to get or use ochre from a different source, as it would not have carried the same symbols, meanings, ideas and stories associated with the more often used and desired source.

Now that evidence for these modes of procurement has been established, the groundwork has been laid for more thorough and contextual analyses of ochre procurement and use, toward exploring concepts such as landscape and place, resource use, long-term histories, and material culture and materiality. As this project

demonstrates, ochre-based research should be considered as an expansion of what is currently available to archaeologists as indicators of trade and exchange, cultural interaction, raw material economics and social and symbolic practices. The results from this analysis, and the patterns of behaviour we can infer from them, should be expanded, re-contextualised and reintegrated into the network of social interactions that they were once a part of.

Future Research

To expand this project, and to be able to address issues such as landscape perception, cultural interaction and materiality, several key areas will need to be considered: temporal resolution, the spatial extent of patterning, and the locations of ochre sources. The sites located in Rivers Inlet included in this study were examined in their entirety with reference to auger locations and depths. However, there are a number of sites in the Namu vicinity that still need to be analyzed for the distribution and geochemistry of ochre. All of the sites included in the geochemical component of this study were selected based on their general temporal contemporaneity. By examining the remaining auger locations at Namu and other villages and camps in the Namu vicinity I will be able to increase the spatial and temporal breadth and depth of these patterns in this region. For example, if there were significant differences in the ochre acquisition and distribution patterns at sites whose occupations date prior to the ones already analyzed, a period of transition in ochre-related behaviours could conceivably be identified. By expanding the spatial range of this study, I will be able to identify the extent of these ochre-related practices. It would be critical to know if there were more or less intensive

areas of ochre exchange between villages, or if shared or closed access to ochre sources could be further identified. In addition, more systematic sampling of ochre specimens from camp sites would further verify the extent of the movement of ochre materials, specifically between villages and nearby camp sites. Finally, a survey and geochemical study of ochre sources in the region would be critical to establish the geographical extent of ochre procurement. This would contribute to a further understanding of how far village inhabitants may have traveled to get ochre, and potentially the range of their resource catchments. Overall, by expanding and refining the spatial extent and chronology of ochre distribution, and through a systematic study of ochre sources and their geochemistry, a more comprehensive, long-term regional-scale history of ochre use can be generated.

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Appendix A: Distribution of Ochre Among Auger Samples Examined from Sites on the Central British Columbia Coast

Site and auger location	depth	# pieces	notes
ElSx10-B1	63	0	
ElSx10-B2	63-78	0	
ElSx10-B3	78-92	0	
ElSx10-B4	92-104	0	
ElSx10-B5	104-117	3	homogenous, bright orange with quartz and dark inclusions
ElSx10-B6	117-121	0	
Auger Total		**3**	
ElSx3-A1	0-47	5	
ElSx3-A2	47-83	51	
ElSx3-A3	83-101	4	
ElSx3-A4	101-119	13	
ElSx3-A5	119-134	28	looks like gritty type from EjSw-1
ElSx3-A6	134-151	6	
ElSx3-A7	151-166	17	gritty, burnt orange, medium quality
ElSx3-A8	166-170	5	
Auger Total		**129**	
ElSx3-B1	0-33	1	
ElSx3-B2	33-51	3	
ElSx3-B3	51-64	1	
ElSx3-B4	64-78	1	
ElSx3-B5	78-83	0	
ElSx3-B6	83-104	0	
ElSx3-B7	104-139	8	
ElSx3-B8	139-160	4	
ElSx3-B9	106-179	9	
ElSx3-B10	179-193	2	
ElSx3-B11	193-207	0	
ElSx3-B12	207-213	4	
ElSx3-B13	213-237	1	
ElSx3-B14	237-257	4	
ElSx3-B15	257-282	9	
ElSx3-B16	282-302	3	
ElSx3-B17	302-320	14	
Auger Total		**64**	
ElSx3-D1	0-22	0	
ElSx3-D2	22-44	0	
ElSx3-D3	44-69	4	
ElSx3-D4	69-90	0	
ElSx3-D5	90-100	0	
ElSx3-D6	100-112	8	
ElSx3-D7	112-129	0	
ElSx3-D8	129-146	14	

Site and auger location	depth	# pieces	notes
ElSx3-D9	146-160	10	
ElSx3-D10	160-173	1	
ElSx3-D11	173-189	3	
ElSx3-D12	189-205	0	
ElSx3-D13	205-219	6	
ElSx3-D14	219-239	0	
ElSx3-D15	239-253	3	
ElSx3-D16	253-263	0	
ElSx3-D17	263-279	0	
ElSx3-D18	279-291	0	
ElSx3-D19	291-318	4	
ElSx3-D20	318-321	0	
ElSx3-D21	321-322	7	
ElSx3-D22	322-326	1	
ElSx3-D23	326-333	11	
ElSx3-D24	333-330	2	
Auger Total		**74**	Primarily micaceous ochres, Groups 2 and 4
ElSx3-E1	0-65	0	
ElSx3-E2	65-82	0	
ElSx3-E3	82-97	0	
ElSx3-E4	79-110	5	
ElSx3-E5	110-118	2	
ElSx3-E6	118-130	0	
ElSx3-E7	130-141	0	
ElSx3-E8	141-150	0	
ElSx3-E9	150-158	0	
ElSx3-E10	158-178	0	
ElSx3-E11	178-192	1	
ElSx3-E12	192-204	2	
ElSx3-E13	204-215	0	
ElSx3-E14	215-233	1	
ElSx3-E15	233-236	6	
ElSx3-E16	236-250	13	
ElSx3-E17	250-262	9	
ElSx3-E18	262-271	1	
ElSx3-E19	271-277	0	
ElSx3-E20	277-291	2	
Auger Total		**42**	
ElSx1-H1	0-19	0	
ElSx1-H2	19-26	0	
ElSx1-H3	26-36	1	homogenous, bright orange, high quality
ElSx1-H4	36-44	13	all purple-red siltstone, fine-grained, dense, homogenous, hard
ElSx1-H5	44-56	61	all purple-red siltstone, fine-grained, dense, homogenous, hard

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Site and auger location	depth	# pieces	notes
ElSx1-H6	56-64	1	
ElSx1-H7	64-80	1	
ElSx1-H8	80-89	10	yellow, fine-grained clay, no inclusions, good quality
ElSx1-H9	89-108	5	
ElSx1-H10	108-123	7	
ElSx1-H11	123-146	25	yellow, blocky, jagged
ElSx1-H12	146-157	12	all purple-red siltstone, fine-grained, dense, homogenous, hard
Auer Total		**136**	Group 2 and 3 ochres
ElSx-1 I1	0-43	0	
ElSx-1 I2	43-69	0	
ElSx-1 I3	69-89	1	
ElSx-1 I4	89-114	6	yellow-orange, coarse-grained, medium quality
ElSx-1 I5	114-135	0	
ElSx-1 I6	135-149	6	
ElSx-1 I7	149-167	5	yellow-orange, coarse-grained, medium quality
ElSx-1 I8	167-189	0	
ElSx-1 I9	189-203	0	
ElSx-1 I10	203-216	0	
ElSx-1 I11	216-232	3	yellow-orange, coarse-grained, medium quality
ElSx-1 I12	232-259	0	
ElSx-1 I13	259-270	3	
ElSx-1 I14	270-281	1	
ElSx-1 I15	281-300	2	
ElSx-1 I16	300-308	1	
ElSx-1 I17	308-330	4	
ElSx-1 I18	330-340	19	fine-grained, homogenous, hard; and orange-red-purple, homogenous; and silicified w/dark inclusions
ElSx-1 I19	340-353	5	
ElSx-1 I20	353-363	1	
ElSx-1 I21	363-376	6	dark red, dense, solid, fine-grained
ElSx-1 I22	376-390	1	
ElSx-1 I23	390-402	0	
ElSx-1 I24	402-407	1	
Auger Total		**65**	Primarily Groups 1 and 5
ElSx1-J1	0-37	0	
ElSx1-J2	37-62	3	
ElSx1-J3	63-73	1	
ElSx1-J4	73-86	18	
ElSx1-J5	86-107	22	
ElSx1-J6	107-125	19	
ElSx1-J7	125-154	7	
ElSx1-J8	154-176	27	
ElSx1-J9	176-200	3	

Appendix A: Distribution of Ochre Among Auger Samples Examined from Sites on the Central British Columbia Coast

Site and auger location	depth	# pieces	notes
ElSx1-J10	200-212	25	high-quality, deep red ochre, fine-grained, no inclusions, hard
ElSx1-J11	212-235	15	
ElSx1-J12	235-244	2	
ElSx1-J13	244-261	4	
ElSx1-J14	261-274	2	
ElSx1-J15	274-285	3	
ElSx1-J16	285-303	0	
ElSx1-J17	303-315	0	
ElSx1-J18	315-324	5	
ElSx1-J19	324-342	3	bright red with some silica inclusions, banding
ElSx1-J20	342-364	2	
ElSx1-J21	354-378	4	
ElSx1-J22	378-397	0	
ElSx1-J23	397-405	0	
ElSx1-J24	405-420	2	
ElSx1-J25	420-430	0	
ElSx1-J26	430-440	0	
ElSx1-J27	440-449	0	
ElSx1-J28	449-457	0	
ElSx1-J29	457-474	0	
ElSx1-J30	474-485	2	
ElSx1-J31	485-500	0	
ElSx1-J32	500-510	0	
Auger Total		**169**	Primarily Groups 1 and 4
EjSw-1 A1	0-22	0	
EjSw-1 A2	22-39	0	
EjSw-1 A3	39-56	0	
EjSw-1 A4	56-70	0	
EjSw-1 A5	70-82	80	
EjSw-1 A6	82-92	9	
EjSw-1 A7	92-105	2	blocky with dark mineral inclusion, powdery inside
EjSw-1 A8	105-115	8	
EjSw-1 A9	115-129	0	
EjSw-1 A10	129-144	7	
EjSw-1 A11	144-160	12	
EjSw-1 A12	160-176	1	
EjSw-1 A13	176-188	0	
EjSw-1 A14	188-207	5	
EjSw-1 A15	207-218	0	
EjSw-1 A16	218-231	0	
EjSw-1 A17	231-242	6	
EjSw-1 A18	242-255	10	
EjSw-1 A19	255-268	3	
EjSw-1 A20	268-282	5	

Site and auger location	depth	# pieces	notes
EjSw-1 A21	282-290	0	
EjSw-1 A22	290-305	2	
EjSw-1 A23	305-311	4	
EjSw-1 A24	311-319	9	
EjSw-1 A25	319-333	8	
EjSw-1 A26	333-346	8	
EjSw-1 A27	346-358	0	
EjSw-1 A28	358-372	8	
EjSw-1 A29	372-378	1	
EjSw-1 A30	378-384	0	
EjSw-1 A31	384-396	0	
EjSw-1 A32	396-404	0	
EjSw-1 A33	404-410	4	sandy and gritty with dark inclusions
EjSw-1 A34	410-416	0	
EjSw-1 A35	416-421	0	
Auger Total		**192**	Primarily Group 4
EjSw-1 B1	0-24	0	
EjSw-1 B2	24-43	3	
EjSw-1 B3	43-66	10	
EjSw-1 B4	66-77	12	
EjSw-1 B5	77-84	2	
EjSw-1 B6	84-94	0	
EjSw-1 B7	94-106	20	
EjSw-1 B8	106-120	5	
EjSw-1 B9	120-128	0	
EjSw-1 B10	128-140	9	
EjSw-1 B11	140-150	0	
EjSw-1 B12	150-159	25	gritty, blocky, sandy grain size
EjSw-1 B13	159-170	6	
EjSw-1 B14	170-180	6	
EjSw-1 B15	180-187	5	greasy, shiny
EjSw-1 B16	187-200	9	
EjSw-1 B17	200-210	4	
EjSw-1 B18	210-217	3	
EjSw-1 B19	217-224	5	
EjSw-1 B20	224-233	20	small limonite; and brighter, greasier samples
EjSw-1 B21	233-240	3	
EjSw-1 B22	240-252	5	
EjSw-1 B23	252-267	2	
EjSw-1 B24	267-280	1	
EjSw-1 B25	280-295	0	
EjSw-1 B26	295-305	0	
EjSw-1 B27	305-310	0	
EjSw-1 B28	310-316	0	

Site and auger location	depth	# pieces	notes
EjSw-1 B29	316-325	2	
EjSw-1 B30	325-330	3	
EjSw-1 B31	330-336	2	
EjSw-1 B32	336-344	0	
EjSw-1 B33	344-349	0	
EjSw-1 B34	349-357	2	
EjSw-1 B35	357-364	7	
EjSw-1 B36	364-372	0	
EjSw-1 B37	372-378	4	
EjSw-1 B38	378-388	0	
EjSw-1 B39	388-398	13	
EjSw-1 B40	398-403	17	
EjSw-1 B41	403-412	1	
EjSw-1 B42	412-418	5	
EjSw-1 B43	418-432	0	
EjSw-1 B44	432-438	7	
Auger Total		**218**	
EjSw-1 C1	0-38	0	
EjSw-1 C2	38-67	4	
EjSw-1 C3	67-84	1	
EjSw-1 C4	84-113	6	
EjSw-1 C5	113-130	15	
EjSw-1 C6	130-147	20	
EjSw-1 C7	147-163	10	
EjSw-1 C8	163-174	5	
EjSw-1 C9	174-186	0	
EjSw-1 C10	186-194	0	
EjSw-1 C11	194-202	5	
EjSw-1 C12	202-215	10	
EjSw-1 C13	215-225	6	
EjSw-1 C14	225-238	8	
EjSw-1 C15	238-251	0	
EjSw-1 C16	251-263	2	
EjSw-1 C17	263-271	4	
EjSw-1 C18	271-287	3	
EjSw-1 C19	287-304	0	
EjSw-1 C20	304-318	0	
EjSw-1 C21	318-328	0	
EjSw-1 C22	328-338	6	
EjSw-1 C23	338-353	0	
EjSw-1 C24	353-363	15	
EjSw-1 C25	363-381	4	
EjSw-1 C26	381-392	0	
EjSw-1 C27	392-399	1	

Site and auger location	depth	# pieces	notes
EjSw-1 C28	399-406	0	
EjSw-1 C29	406-415	9	
EjSw-1 C30	415-422	6	
EjSw-1 C31	422-431	19	
EjSw-1 C32	431-440	6	
EjSw-1 C33	440-450	20	
EjSw-1 C34	450-457	8	
EjSw-1 C35	457-470	0	
EjSw-1 C36	470-477	0	
EjSw-1 C37	477-485	0	
EjSw-1 C38	485-494	4	
EjSw-1 C39	494-500	3	
EjSw-1 C40	500-506	0	
EjSw-1 C41	506-510	0	
EjSw-1 C42	510-519	0	
EjSw-1 C43	519-527	0	
EjSw-1 C44	527-536	0	
Auger Total		**200**	
EjSw-1 D1	0-40	2	
EjSw-1 D2	40-60	1	
EjSw-1 D3	60-88	1	
EjSw-1 D4	88-108	0	
EjSw-1 D5	108-111	1	
EjSw-1 D6	111-123	2	
EjSw-1 D7	123-142	11	
EjSw-1 D8	142-157	2	
EjSw-1 D9	157-175	0	
EjSw-1 D10	175-190	6	
EjSw-1 D11	190-201	16	
EjSw-1 D12	201-216	12	
EjSw-1 D13	216-226	7	
EjSw-1 D14	226-240	2	
EjSw-1 D15	240-264	0	
EjSw-1 D16	264-273	34	
EjSw-1 D17	273-283	5	
EjSw-1 D18	283-295	4	
EjSw-1 D19	295-315	5	
EjSw-1 D20	315-330	2	
EjSw-1 D21	330-349	3	
EjSw-1 D22	349-379	3	
EjSw-1 D23	379-412	9	
EjSw-1 D24	?	2	
Auger Total		**130**	

Appendix A: Distribution of Ochre Among Auger Samples Examined from Sites on the Central British Columbia Coast

Site and auger location	depth	# pieces	notes
EkSt-1 A1	0-25	4	
EkSt-1 A2	25-39	7	
EkSt-1 A3	39-47	1	
Auger Total		**12**	
EkSt-1 B1	0-20	2	
EkSt-1 B2	20-36	12	
EkSt-1 B3	36-61	6	
EkSt-1 B4	61-75	20	Group 2-looking
EkSt-1 B5	75-90	15	
EkSt-1 B6	90-112	6	
EkSt-1 B7	112-128	5	
EkSt-1 B8	128-143	1	
EkSt-1 B9	143-157	1	
EkSt-1 B10	157-158	3	
EkSt-1 B11	158-172	2	
EkSt-1 B12	172-180	0	
EkSt-1 B13	180-203	0	
Auger Total		**73**	Primarily Group 2
EkSt-1 C1	0-25	0	
EkSt-1 C2	25-45	1	
EkSt-1 C3	45-74	3	sandy, grainy and friable
EkSt-1 C4	74-93	0	
EkSt-1 C5	93-112	0	
EkSt-1 C6	112-124	0	
EkSt-1 C7	124-140	1	yellow limonite
EkSt-1 C8	140-152	0	
EkSt-1 C9	152-166	0	
EkSt-1 C10	166-178	0	
EkSt-1 C11	178-184	0	
EkSt-1 C12	184-194	0	
EkSt-1 C13	194-204	0	
Auger Total		**5**	Primarily Group 4
EkSt-1 D1	0-29	8	rusty-looking, orange and black, heterogenous
EkSt-1 D2	29-57	4	
EkSt-1 D3	57-77	0	
EkSt-1 D4	77-87	0	
EkSt-1 D5	87-98	0	
EkSt-1 D6	98-118	0	
EkSt-1 D7	118-147	1	
EkSt-1 D8	147-154	6	
EkSt-1 D9	154-169	0	
EkSt-1 D10	169-173	0	

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Site and auger location	depth	# pieces	notes
EkSt-1 D11	173-183	0	
EkSt-1 D12	183-193	6	
Auger Total		**25**	Primarily Group 2
EkSt-5 A1	0-22	0	
EkSt-5 A2	22-39	0	
EkSt-5 A3	39-47	1	fine grained, yellow-orange
EkSt-5 A4	47-59	0	
Auger Total		**1**	Group 1
EjSv-5 A1	0-44	0	
EjSv-5 A2	44-68	5	medium grained, bright orange, few dark inclusions
EjSv-5 A3	68-84	0	
EjSv-5 A4	84-94	0	
EjSv-5 A5	94-100	0	
EjSv-5 A6	100-107	1	
EjSv-5 A7	107-114	0	
EjSv-5 A8	114-124	0	
EjSv-5 A9	124-130	0	
EjSv-5 A10	130-137	0	
EjSv-5 A11	137-144	0	
EjSv-5 A12	144-153	1	
EjSv-5 A13	153-158	0	
EjSv-5 A14	158-164	2	
EjSv-5 A15	164-170	1	
EjSv-5 A16	170-178	0	
EjSv-5 A17	178-184	0	
EjSv-5 A18	184-191	0	
EjSv-5 A19	191-202	2	
EjSv-5 A20	202-209	5	high quality, red, fine-grained, homogenous
Auger Total		**17**	Primarily Groups 1 and 2
EjSv-4 A1	0-43	0	
EjSv-4 A2	43-56	0	
EjSv-4 A3	56-69	0	
EjSv-4 A4	69-79	0	
EjSv-4 A5	79-87	0	
EjSv-4 A6	87-94	0	
EjSv-4 A7	94-110	0	
EjSv-4 A8	110-131	8	
EjSv-4 A9	131-150	0	
Auger Total		**8**	
EjSv-4 B1	0-35	0	
EjSv-4 B2	35-68	0	

Appendix A: Distribution of Ochre Among Auger Samples Examined from Sites on the Central British Columbia Coast

Site and auger location	depth	# pieces	notes
EjSv-4 B3	68-70	1	
Auger Total		**1**	
EjSv-1 A1	0-61	0	
EjSv-1 A2	61-72	8	
EjSv-1 A3	72-93	41	
EjSv-1 A4	93-105	0	
EjSv-1 A5	105-121	0	
EjSv-1 A6	121-136	1	
EjSv-1 A7	?	8	
Auger Total		**58**	
EjSv-2 A1	0-58	0	
EjSv-2 A2	58-79	3	
EjSv-2 A3	79-102	8	
EjSv-2 A4	102-120	1	
EjSv-2 A5	120-136	5	
EjSv-2 A6	136-149	0	
EjSv-2 A7	149-158	3	
EjSv-2 A8	158-169	5	
EjSv-2 A9	169-186	1	
EjSv-2 A10	186-196	1	
EjSv-2 A11	196-209	0	
EjSv-2 A12	209-217	0	
EjSv-2 A13	217-225	5	
EjSv-2 A14	225-236	0	
EjSv-2 A15	236-250	0	
EjSv-2 A16	250-263	0	
EjSv-2 A17	263-278	2	
EjSv-2 A18	278-289	0	
EjSv-2 A19	289-300	2	orangey clay
Auger Total		**36**	
EjSv-3 A1	0-46	0	
EjSv-3 A2	46-76	1	plus 8 trace
EjSv-3 A3	76-102	5	
EjSv-3 A4	102-117	0	
EjSv-3 A5	117-134	25	pinky silica, blocky and hard
EjSv-3 A6	134-152	7	
EjSv-3 A7	152-176	0	
Auger Total		**38**	Primarily Group 4
EjSv-8 A1	?	0	
EjSv-8 A2	85	2	
EjSv-8 A3	85-90	trace	

Site and auger location	depth	# pieces	notes
EjSv-8 A4	90-106	1	
EjSv-8 A5	106-120	1	
EjSv-8 A6	120-123	12	
EjSv-8 A7	123-133	5	
EjSv-8 A8	133-158	8	
EjSv-8 A9	158-174	6	
EjSv-8 A10	174-187	2	
EjSv-8 A11	187-177	0	
EjSv-8 A12	177-187	15	
EjSv-8 A13	187-180	0	
EjSv-8 A14	180-183	3	
EjSv-8 A15	183-187	6	
EjSv-8 A16	187-195	3	
EjSv-8 A17	195-210	1	
EjSv-8 A18	210-216	1	
EjSv-8 A19	216-224	0	
EjSv-8 A20	224-230	2	
EjSv-8 A21	230-243	0	
EjSv-8 A22			
Auger Total		**68**	
EjSv-9 A1	0-15	0	
EjSv-9 A2	15-37	0	
EjSv-9 A3	37-57	0	
EjSv-9 A4	57-81	0	
EjSv-9 A5	81-105	0	
EjSv-9 A6	105-114	0	
EjSv-9 A7	114-126	0	
EjSv-9 A8	126-138	0	
EjSv-9 A9	138-153	0	
EjSv-9 A10	153-173	0	
EjSv-9 A11	173-205	0	
EjSv-9 A12	205-221	0	
EjSv-9 A13	221-	0	
Auger Total		**0**	
EjSv-9 B1		1	
EjSv-9 B2	0-77	0	
EjSv-9 B3	77-88	0	
EjSv-9 B4	88-97	0	
EjSv-9 B5	97-	0	
Auger Total		**1**	
EjSv-10 A1		0	
EjSv-10 A2	65	0	

Site and auger location	depth	# pieces	notes
EjSv-10 A3	65-78	0	
EjSv-10 A4	78-83	0	
EjSv-10 A5	83-95	0	
EjSv-10 A6	95-104	3	
EjSv-10 A7	104-110	0	
EjSv-10 A8	110-128	0	
EjSv-10 A9	128-140	0	
EjSv-10 A10	140-150	0	
EjSv-10 A11	150-167	0	
EjSv-10 A12	167-177	0	
EjSv-10 A13	177-183	0	
EjSv-10 A14	183-195	0	
EjSv-10 A15	195-202	0	
EjSv-10 A16	202-210	0	
EjSv-10 A17	210-220	0	
EjSv-10 A18	220-224	0	
EjSv-10 A19	224-233	0	
EjSv-10 A20	233-244	0	
EjSv-10 A21	244-253	0	
EjSv-10 A22	253-260	0	
EjSv-10 A23	260-270	0	
EjSv-10 A24	270-280	0	
EjSv-10 A25	280-289	0	
Auger Total		**3**	
EjSv-10 B1	0-66	0	
EjSv-10 B2	66-88	0	
EjSv-10 B3	88-103	0	
EjSv-10 B4	103-113	0	
EjSv-10 B5	113-125	0	
EjSv-10 B6	125-141	0	
EjSv-10 B7	141-148	0	
EjSv-10 B8	148-158	0	
EjSv-10 B9	158-176	0	
EjSv-10 B10	176-185	1	
EjSv-10 B11	185-195	0	
EjSv-10 B12	195-207	0	
EjSv-10 B13	207-227	0	
EjSv-10 B14	227-234	0	
EjSv-10 B15	234-245	0	
EjSv-10 B16	245-255	0	
EjSv-10 B17	255-264	0	
EjSv-10 B18	264-271	0	
EjSv-10 B19	271-283	0	
EjSv-10 B20	283-	0	

Site and auger location	depth	# pieces	notes
Auger Total		**1**	
EjSv-10 C1	0-60	0	
EjSv-10 C2	60-75	0	
EjSv-10 C3	75-88	0	
EjSv-10 C4	88-98	0	
EjSv-10 C5	98-111	0	
EjSv-10 C6	111-125	0	
EjSv-10 C7	125-142	0	
EjSv-10 C8	142-149	0	
EjSv-10 C9	149-170	0	
EjSv-10 C10	170-181	0	
EjSv-10 C11	181-192	0	
EjSv-10 C12	192-203	0	
EjSv-10 C13	203-219	0	
EjSv-10 C14	219-229	0	
EjSv-10 C15	229-242	0	
EjSv-10 C16	242-255	0	
EjSv-10 C17	255-264	0	
EjSv-10 C18	264-287	0	
EjSv-10 C19	287-314	0	
EjSv-10 C20	314-348	0	
EjSv-10 C21	348-370	0	
EjSv-10 C22	370-	0	
Auger Total		**0**	
EjSv-10 D1	0-84	0	
EjSv-10 D2	84-83	0	
EjSv-10 D3	83-104	0	
EjSv-10 D4	104-115	0	
EjSv-10 D5	115-127	0	
EjSv-10 D6	127-138	0	
EjSv-10 D7	138-150	0	
EjSv-10 D8	150-165	0	
EjSv-10 D9	165-178	0	
EjSv-10 D10	178-190	0	
EjSv-10 D11	190-206	0	
EjSv-10 D12	206-214	0	
EjSv-10 D13	214-229	1	
EjSv-10 D14	229-240	1	
EjSv-10 D15	240-254	1	
EjSv-10 D16	254-265	0	
EjSv-10 D17	265-	0	
Auger Total		**3**	

Appendix A: Distribution of Ochre Among Auger Samples Examined from Sites on the Central British Columbia Coast

Site and auger location	**depth**	**# pieces**	**notes**
EjSv-11 A1	0-51	0	
EjSv-11 A2	51-78	0	
EjSv-11 A3	78-92	2	
EjSv-11 A4	92-104	6	yellowy clay
EjSv-11 A5	104-110	4	yellowy clay
EjSv-11 A6	110-127	4	yellowy clay
EjSv-11 A7	127-138	5	yellowy clay
EjSv-11 A8	138-146	2	yellowy clay
EjSv-11 A9	146-154	4	
EjSv-11 A10	154-164	1	
EjSv-11 A11	164-170	0	
EjSv-11 A12	170-180	2	yellowy clay
Auger Total		**30**	Primarily group 1 in texture, but yellow in color

	MNR CODE	Site, Auger, Depth	Description
1	NWCO 5-10	EjSv-3 A5: 117-134	11 pieces, pinky silica, blocky and hard
2	NWCO 4-9	EjSv-5 A2a: 44-68	2 pieces, medium grained, orange, few dark inclusions
3	NWCO 3-2	EjSvt-5 A2b: 44-68	one piece, fine grained, yellow-orange
4	NWCO 4-2	EjSv-5 A20: 202-209	4-5 pieces high quality, red, fine-grained, homogenous
5	NWCO 2-1	EjSw-1 A33: 404-410	4 pieces, sandy and gritty with quartz inclusions
6	NWCO 1-3	EjSw-1 A5: 70-82	8 pieces
7	NWCO 2-4	EjSw-1 A7: 92-105	one piece, blocky with dark mineral inclusion, powdery
8	NWCO 1-6	EjSw-1 B12: 150-159	11 pieces, gritty, blocky, sandy grain size
9	NWCO 2-3	EjSw-1 B15: 180-187	3 pieces, greasy, shiny. Different than gritty type
10	NWCO 2-2	EjSw-1 B20-a: 224-233	3 pieces of small limonite
11	NWCO 1-4	EjSw-1 B20-b: 224-233	7 pieces of the brighter, greasier samples
12	NWCO 5-6	EjSw-1 BS-a	bulk sample A, dense, rich colour, NE and near auger A
13	NWCO 5-7	EjSw-1 BSB-a	beach/bulk sample, white, black and pink
14	NWCO 5-8	EjSw-1 BSB-b	beach/bulk sample, dense, rich, red
15	NWCO 2-7	EjSw-1 C12: 202-215	10 pieces, blocky, greasy, shiny type; large dark inclusions
16	NWCO 1-1	EjSw-1 C6-a: 130-147	19 pieces limonite
17	NWCO 1-2	EjSw-1 C6-b: 130-147	8 pieces orangey yellow
18	NWCO 2-8	EkSt-1 A2a: 25-37	9 pieces, light orange, clay-looking
19	NWCO 3-8	EkSt-1 A2b: 25-37	yellow-orange powder
20	NWCO 3-3	EkSt-1 B10-a: 157-158	1 piece good quality, deep red-purple
21	NWCO 3-1	EkSt-1 B4-a: 61-75	6 tiny pieces, dark
22	NWCO 3-5	EkSt-1 B7-a: 112-128	bright orange, high quality
23	NWCO 3-6	EkSt-1 B7-b: 112-128	dark red, high quality
24	NWCO 3-4	EkSt-1 C3-a: 45-74	3 pieces, sandy grainy and friable
25	NWCO 3-7	EkSt-1 C7: 124-140	2 pieces yellow limonite
26	NWCO 5-9	EkSt-1 D1: 0-29	5 pieces, rusty-looking, orange and black, heterogeneous
27	NWCO 5-3	ElSx-1 H11: 123-146	3 pieces
28	NWCO 4-5	ElSx-1 H3: 26-36	1 piece, homogenous, bright orange, high quality
29	NWCO 5-5	ElSx-1 H5: 44-56	5 pieces purple-red siltstone, fine-grained, dense, hard
30	NWCO 5-4	ElSx-1 H8: 80-89	3 pieces, yellow, fine-grained, no inclusions, good quality
31	NWCO 4-6	ElSx-1 I11: 216-232	2 pieces, yellow-orange, coarse-grained, medium quality
32	NWCO 4-7	ElSx-1 I18-a: 330-340	1 piece, fine-grained, medium red, homogenous, hard
33	NWCO 4-8	ElSx-1 I18-b: 330-340	2 pieces, orange-red-purple, homogenous
34	NWCO 4-1	ElSx-1 I18-c: 330-340	2 pieces, silicified with dark inclusions, medium quality
35	NWCO 4-3	ElSx-1 I21: 363-376	1 piece, dark red, dense, solid, fine-grained, high quality
36	NWCO 5-1	ElSx-1 J10: 200-212	1 piece high-quality, deep red, fine-grained, no inclusions
37	NWCO 5-2	ElSx-1 J19: 324-342	2 pieces, bright red with some silica inclusions, banding
38	NWCO 2-5	ElSx-1 J5-a: 86-107	6 small pieces
39	NWCO 2-6	ElSx-1 J5-b: 86-107	red, orange and yellow swirled
40	NWCO 1-5	ElSx-1 J8: 154-176	3 pieces
41	NWCO 4-4	ElSx-10 B5: 104-117	2 pieces, homogenous, orange, quartz and dark inclusions,
42	NWCO 2-9	ElSx-3 A5: 119-134	one piece, looks like gritty type from EjSw-1
43	NWCO 4-10	ElSx-3 A7: 151-166	3 pieces, gritty, burnt orange, medium quality

MNR CODE	Site	Ti ppm	V ppm	Al %	Cl ppm	Ca %	Mn ppm	Th ppm	Cr ppm	Sc ppm	Zn ppm	Co ppm	Fe %
1-1	EjSw-1	203	162	3.1	172	6.1	1126	1.30	19	11.2	4085	3.2	2.39
1-2	EjSw-1	841	347	5.4	162	9.3	1177	2.28	28	26.8	1142	4.3	2.90
1-3	EjSw-1	286	286	4.0	87.71	4.8	955	1.97	60	49.6	BDL	2.5	3.20
1-4	EjSw-1	154	25	8.2	180	6.7	1200	2.39	6	3.8	6920	4.6	3.94
1-5	ElSx-1	361	82	7.3	361	4.3	402	4.35	11	7.9	BDL	6.1	2.41
1-6	EjSw-1	437	245	9.0	154	8.5	1360	0.18	104	6.8	2090	11.6	5.86
2-1	EjSw-1	330	245	7.4	225	7.5	1303	1.43	39	23.2	BDL	7.0	5.27
2-2	EjSw-1	285	166	6.6	369	5.7	1410	3.33	22	11.6	92.4	2.0	2.01
2-3	EjSw-1	300	320	5.9	97.13	5.5	646	1.51	46	11.1	268	BDL	1.75
2-4	EjSw-1	145	78	10.7	BDL	6.2	775	1.10	19	33.0	396	5.0	3.25
2-5	ElSx-1	612	172	9.5	115	7.7	604	3.46	7	13.5	BDL	49.2	0.53
2-6	ElSx-1	81	61	1.8	564	1.0	1127	1.01	32	0.3	BDL	17.7	61.51
2-7	EjSw-1	241	130	7.1	304	4.1	742	7.04	15	15.6	205	4.6	3.43
2-8	EkSt-1	561	126	8.9	78	5.2	1261	3.55	35	15.1	79.7	15.9	5.04
2-9	ElSx-3	356	121	6.5	168	1.4	485	6.16	19	12.5	499	5.9	3.91
3-1	EkSt-1	25	8	0.8	34	0.4	61	0.25	4	1.2	114	1.6	0.79
3-2	EjSv-5	477	87	6.9	62	1.5	589	5.27	67	15.03	522	14.0	4.33
3-3	EkSt-1	388	130	3.7	69	1.8	820	0.14	5	5.045	165	17.0	30.31
3-4	EkSt-1	494	74	9.7	54	5.0	956	10.7	25	12.7	335	3.8	4.07
3-5	EkSt-1	304	83	4.9	726	3.6	795	0.49	26	10.9	BDL	5.4	18.00
3-6	EkSt-1	155	108	4.0	835	1.9	1210	2.36	83	14.1	309	13.5	37.45
3-7	EkSt-1	203	79	2.6	343	1.8	770	1.64	39	5.6	39.2	4.8	47.67
3-8	EkSt-1	416	95	7.2	426	6.0	1194	3.68	37	14.2	486	13.1	4.71
4-1	ElSx-1	210	3	0.9	97	0.6	68	0.74	BDL	3.24	BDL	8.01	12.65
4-10	ElSx-3	777	530	9.5	816	6.1	943	1.20	BDL	53.56	397	13.8	8.03
4-2	EjSv-5	585	174	7.3	742	2.9	915	20.1	BDL	15.37	BDL	10.6	18.11
4-3	ElSx-1	720	141	8.8	213	2.2	736	2.63	BDL	4.82	BDL	4.25	1.56
4-4	ElSx-10	1338	208	3.5	361	0.3	293	9.58	2	9.17	66.1	1.64	10.93
4-5	ElSx-1	570	116	7.4	392	3.2	853	3.07	5	13.77	95.3	8.40	5.63
4-6	ElSx-1	619	155	8.4	372	4.4	799	2.23	4	17.47	115	7.35	4.48

MNR CODE	Site	Ti ppm	V ppm	Al %	Cl ppm	Ca %	Mn ppm	Th ppm	Cr ppm	Sc ppm	Zn ppm	Co ppm	Fe %
4-7	ElSx-1	393	85	8.2	222	3.1	231	4.88	1	9.21	63.5	0.49	1.68
4-8	ElSx-1	591	195	7.5	BDL	5.0	677	3.26	BDL	21.64	167	6.62	5.18
4-9	EjSv-5	286	119	5.8	192	11.1	943	1.77	1	16.40	120	9.22	5.18
5-1	ElSx-1	517	127	7.6	190	17.1	1687	10	BDL	7.96	274	2.74	5.36
5-10	EjSv-3	29	26	7.7	63.4	1.0	104	11.6	BDL	1.51	BDL	1.17	1.33
5-2	ElSx-1	338	39	10.5	292	6.9	912	3.16	BDL	8.37	61.0	4.17	2.56
5-3	ElSx-1	221	75	5.0	160	3.5	602	2.97	BDL	5.50	40.7	3.15	1.96
5-4	ElSx-1	395	116	8.6	254	4.0	1301	2.73	BDL	13.44	88.6	10.8	4.81
5-5	ElSx-1	1230	124	8.0	157	4.3	1685	0.57	BDL	21.10	735	16	9.22
5-6	EjSw-1	187	99	8.3	584	3.5	687	4.1	BDL	30.42	BDL	8.54	6.27
5-7	EjSw-1	380	148	10.5	906	7.4	398	BDL	BDL	9.355	326	0.46	1.68
5-8	EjSw-1	269	121	6.6	150	2.1	136	0.47	BDL	7.841	274	1	0.92
5-9	EkSt-1	123	39	0.9	283	0.9	1441	0.07	6	1.28	7.70	11.0	49.23

	aver	405	136	6.6	293	4.5	846	3.6	26	14	643	8.2	9.6
	stdev	276	99	2.7	234	3.2	421	3.9	26	11	1384	8.1	14.1
	% err	68	72	41	80	71	50	109	97	82	215	100	148

MNR CODE	**Site**	**Sm ppm**	**Br ppm**	**As ppm**	**Eu ppm**	**Nd ppm**	**Sb ppm**	**Rb ppm**	**Na %**	**La ppm**	**Ba ppm**
1-1	EjSw-1	2.6	6.9	BDL	4.27	6.5	0.376	2.2	0.07	7.2	50
1-2	EjSw-1	8.4	4.1	BDL	4.20	28.3	0.425	16.0	0.77	24.1	660
1-3	EjSw-1	5.9	2.2	1.7	1.090	23.6	0.052	BDL	0.67	19.1	850
1-4	EjSw-1	2.7	2.3	1.6	1.100	11.7	0.322	3.3	1.87	9.3	330
1-5	ElSx-1	4.6	0.9	6.5	1.480	18.6	0.236	19.8	3.39	14.8	1100
1-6	EjSw-1	0.4	12.3	26.6	0.900	140.6	1.866	95.2	0.17	12.1	350
2-1	EjSw-1	3.80	2.7	2.7	1.51	9.5	0.410	BDL	3.98	9.6	370
2-2	EjSw-1	3.41	4.6	5.1	1.19	13.4	0.625	14.7	1.50	10.4	460
2-3	EjSw-1	2.03	0.4	2.5	0.905	-3.7	0.534	100.2	0.21	5.8	4220
2-4	EjSw-1	5.42	7.6	BDL	1.35	9.7	0.289	1.5	4.17	9.4	310
2-5	ElSx-1	6.71	0.6	5.3	2.30	24.9	0.612	2.7	3.25	26.7	211
2-6	ElSx-1	BDL	3.1	1.5	0.687	BDL	0.354	31.7	0.14	0.6	370
2-7	EjSw-1	3.74	1.1	1.1	1.06	15.0	0.150	10.3	2.47	20.6	321
2-8	EkSt-1	4.35	5.6	BDL	1.01	18.4	0.113	94.4	2.65	20.7	890
2-9	ElSx-3	5.51	8.5	BDL	2.64	13.9	0.987	74.2	2.41	29.0	510
3-1	EkSt-1	0.34	0.7	0.2	0.19	0.9	0.120	4.1	0.42	1.5	56
3-2	EjSv-5	2.55	9.6	6.9	2.213	4.5	1.062	0.057	2.94	16.6	480
3-3	EkSt-1	0.87	2.8	3.2	0.909	5	0.498	20.0	0.63	5.1	380
3-4	EkSt-1	8.73	4.1	3.1	2.79	45.9	0.798	BDL	4.10	79.6	180
3-5	EkSt-1	3.01	37.0	7.5	7.97	54.6	2.434	BDL	0.50	12.2	2400
3-6	EkSt-1	4.07	53.9	22.9	5.65	31.1	2.793	BDL	0.94	8.5	400
3-7	EkSt-1	1.47	19.4	12.2	3.23	0.0	0.897	BDL	0.15	5.2	1100
3-8	EkSt-1	5.49	4.6	1.4	1.51	19.6	0.214	0.06	3.88	21.9	980
4-1	ElSx-1	1.02	0.015	3.09	17.9	2.67	0.170	1.52	0.05	2.8	104
4-10	ElSx-3	4.40	0.655	2.30	1.04	23.45	0.108	0.014	2.87	15.8	83
4-2	EjSv-5	1.20	19.5	0.898	2.43	3.60	0.324	0.1	1.54	18.0	779.2
4-3	ElSx-1	4.33	0.8	BDL	1.22	0.557	3.053	BDL	0.74	19.8	BDL
4-4	ElSx-10	2.24	2.81	18.82	1.001	9.26	0.261	0.082	1.34	13.8	819
4-5	ElSx-1	3.67	3.24	1.78	1.287	32.23	0.285	0.071	2.87	20.1	786
4-6	ElSx-1	3.91	1.68	4.64	1.389	5.49	0.125	0.080	5.09	11.3	384
4-7	ElSx-1	1.06	1.09	BDL	0.726	2.4	0.099	0.105	5.18	32.4	9194
4-8	ElSx-1	0.288	4.37	43.5	0.178	BDL	BDL	0.074	2.90	21.0	2359
4-9	EjSv-5	8.80	3.58	BDL	1.123	52.47	0.689	0.02	0.75	6.8	410
5-1	ElSx-1	6.31	0.19	BDL	1.03	14.55	0.309	BDL	0.57	27.5	19

MNR CODE	Site	Sm ppm	Br ppm	As ppm	Eu ppm	Nd ppm	Sb ppm	Rb ppm	Na %	La ppm	Ba ppm
5-10	EjSv-3	2.25	0.73	1.29	0.69	16.17	0.040	0.112	3.29	4.7	2268
5-2	ElSx-1	4.07	0.77	0.75	1.9755	10	0.186	0.016	3.58	14.1	1631
5-3	ElSx-1	1.24	0.495	BDL	2.91	1.69	0.095	0.04	2.81	17.4	BDL
5-4	ElSx-1	5.34	0.165	0.26	1.28	14.01	0.181	0.09	2.25	16.5	630
5-5	ElSx-1	2.28	2.335	2.21	0.88	16.98	0.07	0.025	4.11	50.3	660
5-6	EjSw-1	3.57	2.165	2.98	0.73	26.14	0.023	0.03	2.32	18.5	1356
5-7	EjSw-1	9.3	BDL	BDL	3.162	26.2	0.169	0.01	6.40	14.6	205
5-8	EjSw-1	4.39	3.52	1.797	1.81	5.07	0.008	0.013	3.66	10.4	750
5-9	EkSt-1	1.25	3.33	0.3	0.591	4.7	5.20	0.008	0.17	1.5	95
	aver	3.7	5.9	6.1	2.2	19	0.7	14	2.18	16.5	964
	stdev	2.4	10.2	9.4	2.9	24	1.0	29	1.66	13.7	1549.4
	% err	64	173	153	132	129	155	207	76	83.3	161

MNR CODE	Site	Ce ppm	Cs ppm	Tb ppm	Yb ppm	Lu ppm	Hf ppm	Ta ppm	Au ppm
1-1	EjSw-1	11.8	4.45	0.36	0.55	0.161	1.60	1.59	1.16
1-2	EjSw-1	57.5	5.40	0.65	1.67	0.238	4.22	2.30	1.15
1-3	EjSw-1	33.1	2.88	0.87	1.29	0.400	2.11	1.30	0.68
1-4	EjSw-1	20.8	4.46	0.21	0.70	BDL	1.89	1.10	0.86
1-5	ElSx-1	38.9	2.25	0.94	1.09	0.086	2.94	0.78	0.71
1-6	EjSw-1	8.0	5.29	0.06	0.46	0.850	1.28	1.17	0.58
2-1	EjSw-1	12.2	3.70	0.32	0.32	0.164	1.76	0.79	0.69
2-2	EjSw-1	16.3	5.20	0.35	0.47	0.106	2.28	0.80	0.42
2-3	EjSw-1	8.6	9.70	0.24	0.38	0.242	1.76	1.80	0.42
2-4	EjSw-1	12.5	6.90	1.06	0.85	0.097	4.08	1.53	0.50
2-5	ElSx-1	37.8	2.38	0.67	0.71	0.042	1.89	0.26	0.40
2-6	ElSx-1	26.0	13.10	1.30	0.73	0.170	0.82	1.18	2.50
2-7	EjSw-1	43.0	2.81	0.22	0.62	0.840	0.75	0.54	0.34
2-8	EkSt-1	1.9	1.69	0.31	0.53	0.167	1.89	0.89	0.27
2-9	ElSx-3	31.6	2.86	BDL	1.10	0.227	1.77	5.00	1.38
3-1	EkSt-1	7.6	0.97	0.03	BDL	0.018	0.19	0.11	0.11
3-2	EjSv-5	45.5	2.533	0.561	BDL	4.537	5.24	0.10	4.8
3-3	EkSt-1	54.7	3.482	0.100	BDL	0.893	1.03	BDL	0.5
3-4	EkSt-1	20.0	0.3	0.568	0.44	0.042	4.88	BDL	0.08
3-5	EkSt-1	BDL	27.00	0.13	2.60	0.260	5.00	9.20	4.70
3-6	EkSt-1	12.2	79.00	0.60	6.10	0.530	5.30	4.50	5.60
3-7	EkSt-1	14.3	30.40	0.00	0.00	0.255	0.10	BDL	3.00
3-8	EkSt-1	27.2	0.63	0.209	0.49	0.085	2.62	0.10	0.07
4-1	ElSx-1	13.9	1.60	0.48	0.20	0.020	0.29	0.02	0.139
4-10	ElSx-3	4.2	0.021	BDL	2.63	0.073	1.30	0.11	0.04
4-2	EjSv-5	20.7	BDL	0.13	0.23	0.455	1.27	0.49	0.032
4-3	ElSx-1	28.9	0.132	0.05	0.02	0.476	0.84	0.05	0.133
4-4	ElSx-10	18.3	1.98	0.641	0.52	0.032	11.12	2.99	BDL

MNR CODE	Site	Ce ppm	Cs ppm	Tb ppm	Yb ppm	Lu ppm	Hf ppm	Ta ppm	Au ppm
4-5	ElSx-1	40.2	4.68	0.213	0.62	0.148	3.94	BDL	0.03
4-6	ElSx-1	40.2	4.04	0.715	2.48	0.075	2.94	1.99	0.06
4-7	ElSx-1	18.4	0.77	0.465	1.15	0.056	2.35	0.18	0.06
4-8	ElSx-1	17.1	0.322	0.934	5.99	0.456	3.38	0.33	0.11
4-9	EjSv-5	5.6	6.06	0.174	BDL	1.140	1.81	BDL	0.06
5-1	ElSx-1	38.8	0.31	0.51	0.43	0.0299	5.74	0.56	0.03
5-10	EjSv-3	28.1	0.676	0.087	0.08	0.0141	1.84	0.09	0.053
5-2	ElSx-1	29.1	0.355	0.261	1.46	0.054	6.73	0.45	0.052
5-3	ElSx-1	70.7	0.365	0.07	BDL	0.108	1.44	0.22	0.003
5-4	ElSx-1	24.3	2.07	0.22	1.02	0.212	3.06	0.32	0.063
5-5	ElSx-1	20.4	0.803	0.741	0.14	7.170	8.28	2.60	0.108
5-6	EjSw-1	24.4	1.04	0.00	0.56	0.264	2.00	0.62	0.174
5-7	EjSw-1	15.8	0.393	0.033	0.01	2.609	3.02	0.08	BDL
5-8	EjSw-1		0.230	0.006	0.09	2.750	3.18	0.49	0.02
5-9	EkSt-1	64	1.92	0.298	0.31	0.170	0.42	0.78	0.053
	aver		5.8	0.38	1.0	0.64	2.8	1.2	0.78
	stdev		13.1	0.33	1.4	1.35	2.2	1.8	1.37
	% err		225	85	134	212	80	141	175

Appendix D: Elemental Concentrations in Log^{10} /Fe Format

MNR	Sites	Ti	V	Al	Cl	Ca	Mn	Th	Cr
CODE		ppm	ppm	%	ppm	%	ppm	ppm	ppm
1-1	EjSw-1	-2.07119	-2.16957	-3.88132	-2.14184	-3.59621	-1.32668	-4.2641	-3.10775
1-2	EjSw-1	-1.5378	-1.92166	-3.72696	-2.25349	-3.49227	-1.3915	-4.1049	-3.00841
1-3	EjSw-1	-2.04869	-2.0486	-3.89882	-2.56178	-3.81986	-1.52463	-4.20984	-2.7276
1-4	EjSw-1	-2.40768	-3.19143	-3.68334	-2.3401	-3.76867	-1.51668	-4.2182	-3.7995
1-5	ElSx-1	-1.82509	-2.47094	-3.51622	-1.8244	-3.75195	-1.77812	-3.74408	-3.32888
1-6	EjSw-1	-2.12755	-2.37886	-3.81355	-2.58196	-3.83918	-1.63475	-5.52147	-2.75297
2-1	EjSw-1	-2.20236	-2.33185	-3.85079	-2.36908	-3.84681	-1.60645	-4.56555	-3.13249
2-2	EjSw-1	-1.84928	-2.08406	-3.48761	-1.73711	-3.5463	-1.15503	-3.78138	-2.95464
2-3	EjSw-1	-1.76698	-1.73849	-3.47291	-2.25627	-3.50614	-1.43322	-4.0649	-2.58199
2-4	EjSw-1	-2.35107	-2.62186	-3.48067	-6.51173	-3.72126	-1.62224	-4.47088	-3.22252
2-5	ElSx-1	-0.93845	-1.49048	-2.74712	-1.66636	-2.83694	-0.94434	-3.18678	-2.90061
2-6	ElSx-1	-3.88179	-4.00148	-5.5296	-3.03742	-5.77806	-2.73691	-5.7831	-4.27792
2-7	EjSw-1	-2.15314	-2.42277	-3.68725	-2.05236	-3.92697	-1.66555	-3.68793	-3.36826
2-8	EkSt-1	-1.95329	-2.60238	-3.75346	-2.80838	-3.99027	-1.60153	-4.15222	-3.15398
2-9	ElSx-3	-2.04053	-2.50951	-3.77811	-2.36668	-4.45407	-1.906	-3.80234	-3.31066
3-1	EkSt-1	-2.4998	-3.01584	-3.98391	-2.36248	-4.25214	-2.11515	-4.4928	-3.25805
3-2	EjSv-5	-1.95809	-2.69892	-3.80059	-2.84531	-4.45731	-1.86616	-3.91514	-2.80915
3-3	EkSt-1	-2.89284	-3.36654	-4.91674	-3.64536	-5.22955	-2.5678	-6.32535	-4.81471
3-4	EkSt-1	-1.9157	-2.74023	-3.62093	-2.87329	-3.91021	-1.62884	-3.57707	-3.21812
3-5	EkSt-1	-2.77209	-3.33393	-4.56764	-2.39428	-4.69492	-2.3548	-5.56149	-3.84693
3-6	EkSt-1	-3.38421	-3.54028	-4.97198	-2.65178	-5.30428	-2.49077	-5.19993	-3.65451
3-7	EkSt-1	-3.3711	-3.77855	-5.26765	-3.14305	-5.4142	-2.79201	-5.46281	-4.08186
3-8	EkSt-1	-2.05468	-2.6954	-3.81627	-2.04402	-3.89654	-1.59642	-4.10723	-3.10797
4-1	ElSx-1	-2.77994	-4.60727	-5.14747	-3.11618	-5.33161	-3.26901	-5.23293	-7.10216
4-10	ElSx-3	-2.01456	-2.18071	-3.92634	-1.99351	-4.1179	-1.93046	-4.82627	-6.90498
4-2	EjSv-5	-2.49079	-3.01621	-4.39452	-2.38779	-4.7918	-2.29652	-3.95475	-7.25794
4-3	ElSx-1	-1.33449	-2.04328	-3.24645	-1.86309	-3.85588	-1.32494	-3.77187	-6.19182
4-4	ElSx-10	-1.91213	-2.71969	-4.49819	-2.48137	-5.53222	-2.57172	-4.0571	-4.74299
4-5	ElSx-1	-1.99443	-2.68654	-3.88006	-2.1575	-4.24529	-1.81935	-4.26366	-4.08008
4-6	ElSx-1	-1.85996	-2.46059	-3.72689	-2.08093	-4.00579	-1.7491	-4.3041	-4.04527
4-7	ElSx-1	-1.62977	-2.29642	-3.30963	-1.87699	-3.73491	-1.86055	-3.53576	-4.33523
4-8	ElSx-1	-1.94239	-2.42296	-3.83619	-6.71397	-4.01082	-1.88338	-4.20055	-6.71397
4-9	EjSv-5	-2.25771	-2.63959	-3.95123	-2.43081	-3.67028	-1.73957	-4.46721	-4.88157
5-1	ElSx-1	-2.01515	-2.62488	-3.84849	-2.45023	-3.49703	-1.50193	-3.72899	-6.72899
5-10	EjSv-3	-2.66534	-2.71532	-3.2367	-2.32285	-4.11302	-2.10806	-3.06048	-6.12494
5-2	ElSx-1	-1.87906	-2.82019	-3.38534	-1.94193	-3.56661	-1.44769	-3.9083	-6.4079
5-3	ElSx-1	-1.94824	-2.41944	-3.5975	-2.08879	-3.74441	-1.51347	-3.81996	-6.29323
5-4	ElSx-1	-2.08499	-2.61706	-3.74882	-2.27762	-4.07482	-1.56732	-4.24529	-6.68176
5-5	ElSx-1	-1.87478	-2.87048	-4.0598	-2.76925	-4.33514	-1.73816	-5.21121	-6.96479
5-6	EjSw-1	-2.52535	-2.80363	-3.87977	-2.03092	-4.2593	-1.96075	-4.1848	-6.79759
5-7	EjSw-1	-1.64515	-2.05428	-3.202	-1.2675	-3.35702	-1.62479	-6.22456	-6.22456
5-8	EjSw-1	-1.53226	-1.88034	-3.14285	-1.78628	-3.64062	-1.82796	-4.28797	-5.96237
5-9	EkSt-1	-3.60171	-4.10334	-5.75776	-3.24029	-5.75091	-2.53353	-6.82464	-4.90971

Appendix D: Elemental Concentrations in Log^{10} /Fe Format

MNR	Sites	Sc	Co	Eu	Nd	Sm	Br	As	Sb
CODE		ppm	ppm	ppm	ppm	ppm	ppm	0.00	ppm
1-1	EjSw-1	-3.32895	-3.87335	-3.74766	-3.56494	-3.95556	-3.54111	-6.37809	-4.80282
1-2	EjSw-1	-3.03378	-3.82653	-3.8391	-3.01082	-3.54001	-3.8525	-6.46235	-4.83365
1-3	EjSw-1	-2.80901	-4.106	-4.46739	-3.13167	-3.73509	-4.16088	-4.2767	-5.78703
1-4	EjSw-1	-4.01205	-3.93291	-4.5546	-3.52708	-4.16739	-4.24047	-4.38824	-5.08824
1-5	ElSx-1	-3.48369	-3.5952	-4.21217	-3.11193	-3.71529	-4.42265	-3.56736	-5.00872
1-6	EjSw-1	-3.9332	-3.70258	-4.81401	-2.62024	-5.1662	-3.67852	-3.34298	-4.49735
2-1	EjSw-1	-3.35579	-3.87405	-4.5411	-3.74501	-4.14214	-4.29656	-4.28747	-5.10924
2-2	EjSw-1	-3.24048	-4.00607	-4.22959	-3.17585	-3.77126	-3.63826	-3.59296	-4.5081
2-3	EjSw-1	-3.19769	-6.24363	-4.28706	-6.24363	-3.93699	-4.60032	-3.85	-4.51609
2-4	EjSw-1	-2.99345	-3.81141	-4.38197	-3.5238	-3.77812	-3.62873	-6.51173	-5.05047
2-5	ElSx-1	-2.59356	-2.03321	-3.36377	-2.32946	-2.89845	-3.94248	-3.00155	-3.93871
2-6	ElSx-1	-6.31184	-4.53978	-5.95196	-7.78896	-7.78896	-5.29219	-5.60998	-6.23996
2-7	EjSw-1	-3.34126	-3.87468	-4.51056	-3.35882	-3.96281	-4.50016	-4.50951	-5.35952
2-8	EkSt-1	-3.52342	-3.50114	-4.69687	-3.43684	-4.06351	-3.95587	-6.7021	-5.64908
2-9	ElSx-3	-3.49676	-3.82061	-4.17063	-3.44818	-3.85098	-3.6627	-6.59199	-4.59763
3-1	EkSt-1	-3.81049	-3.68422	-4.62187	-3.94597	-4.36885	-4.08328	-4.69011	-4.82053
3-2	EjSv-5	-3.45953	-3.49048	-4.2916	-3.9834	-4.23007	-3.65573	-3.79776	-4.6104
3-3	EkSt-1	-4.7788	-4.25118	-5.52308	-4.78266	-5.54211	-5.03944	-4.97648	-5.78422
3-4	EkSt-1	-3.50537	-4.02792	-4.16433	-2.94748	-3.66837	-3.99609	-4.12272	-4.70747
3-5	EkSt-1	-4.21663	-4.52347	-4.35403	-3.51779	-4.77652	-3.68727	-4.38213	-4.86901
3-6	EkSt-1	-4.42499	-4.44439	-4.82115	-4.08113	-4.96404	-3.84191	-4.21388	-5.12734
3-7	EkSt-1	-4.93069	-5.00129	-5.1695	-7.67829	-5.51185	-4.39092	-4.59164	-5.72559
3-8	EkSt-1	-3.5215	-3.55719	-4.49578	-3.38068	-3.93397	-4.0067	-4.51609	-5.34387
4-1	ElSx-1	-4.59119	-4.19826	-3.84931	-4.67589	-5.0943	-6.92607	-4.61212	-5.87216
4-10	ElSx-3	-3.17615	-3.76501	-4.88794	-3.53489	-4.26112	-5.08873	-4.54414	-5.87021
4-2	EjSv-5	-4.07138	-4.23034	-4.87234	-4.70134	-5.17876	-3.96791	-5.30447	-5.74688
4-3	ElSx-1	-3.50873	-3.56349	-4.10546	-4.44592	-3.55489	-4.28873	-6.19182	-3.70709
4-4	ElSx-10	-4.07617	-4.82411	-5.03823	-4.07203	-4.68843	-4.58957	-3.76401	-5.62179
4-5	ElSx-1	-3.61135	-3.82606	-4.6408	-3.24198	-4.18603	-4.23977	-4.50091	-5.29556
4-6	ElSx-1	-3.40942	-3.78546	-4.50898	-3.91233	-4.05967	-4.42606	-3.9853	-5.55519
4-7	ElSx-1	-3.25967	-4.53211	-4.17364	-2.50427	-3.27945	-3.67074	-6.22416	-5.22957
4-8	ElSx-1	-3.37876	-3.8932	-4.70114	-3.55101	-3.91383	-5.43522	-6.71397	-6.71397
4-9	EjSv-5	-3.49925	-3.74954	-4.87523	-3.50536	-4.36127	-4.85075	-4.60248	-4.87605
5-1	ElSx-1	-3.828	-4.2905	-4.43331	-3.72899	-4.11939	-4.8425	-4.85393	-5.23903
5-10	EjSv-3	-3.94488	-4.0562	-3.66104	-3.89589	-4.03145	-4.43033	-6.12494	-5.5221
5-2	ElSx-1	-3.48513	-3.78771	-4.30069	-3.26133	-3.68047	-5.19042	-4.99271	-5.13906
5-3	ElSx-1	-3.55285	-3.79447	-4.34875	-3.06333	-3.93551	-3.92495	-3.94862	-5.31469
5-4	ElSx-1	-3.55342	-3.64835	-4.81843	-3.26442	-4.12885	-4.3463	-4.20809	-5.42391
5-5	ElSx-1	-3.64047	-3.76067	-4.46488	-3.54649	-3.99631	-6.96479	-6.96479	-6.11969
5-6	EjSw-1	-3.31446	-3.86634	-4.5393	-4.09256	-4.15548	-4.25105	-4.54308	-6.43779
5-7	EjSw-1	-3.25354	-4.56086	-4.45261	-3.55246	-4.12765	-3.70211	-4.74744	-4.99667
5-8	EjSw-1	-3.06799	-3.96237	-4.10152	-3.58216	-3.93706	-3.92494	-5.96237	-6.05928
5-9	EkSt-1	-5.58555	-4.65026	-6.44251	-7.69219	-6.23335	-5.05162	-4.0537	-4.97618

MNR	Rb	Na	La	Ba	Au
CODE	**ppm**	**%**	**ppm**	**ppm**	**ppm**
1-1	-4.03182	-5.54378	-3.5197	-2.67912	-4.31363
1-2	-3.25887	-4.57603	-3.07962	-1.6428	-4.40165
1-3	-6.50482	-4.67736	-3.22419	-1.5754	-4.67231
1-4	-4.07519	-4.32342	-3.62903	-2.07748	-4.6615
1-5	-3.08541	-3.85197	-3.21115	-1.34104	-4.53118
1-6	-2.78957	-5.54528	-3.68547	-2.22419	-5.00483
2-1	-6.72151	-4.12196	-3.73927	-2.1533	-4.88266
2-2	-3.13661	-4.12735	-3.28846	-1.64134	-4.68085
2-3	-2.24274	-4.91281	-3.47891	-0.61832	-4.62038
2-4	-4.3442	-3.89201	-3.53884	-2.02037	-4.81276
2-5	-3.28934	-3.21406	-2.29843	-1.40115	-4.12337
2-6	-4.28845	-6.6294	-5.99631	-3.22076	-5.39102
2-7	-3.52341	-4.14318	-3.22185	-2.0292	-5.00423
2-8	-2.72721	-4.279	-3.3863	-1.75271	-5.27074
2-9	-2.72143	-4.20952	-3.12962	-1.88442	-4.45211
3-1	-3.28733	-4.28012	-3.71809	-2.15058	-4.85738
3-2	-5.88073	-4.16826	-3.41572	-1.95537	-3.95537
3-3	-4.18024	-5.68229	-4.77236	-2.90185	-5.78266
3-4	-6.60951	-3.99672	-2.70859	-2.35423	-5.70642
3-5	-7.25537	-5.55989	-4.16725	-1.87516	-4.58327
3-6	-7.57348	-5.59857	-4.64261	-2.97142	-4.82529
3-7	-7.67829	-6.48872	-4.96384	-2.6369	-5.20117
3-8	-5.88093	-4.08449	-3.33288	-1.6821	-5.82823
4-1	-4.92032	-6.36639	-4.65954	-3.08697	-5.95768
4-10	-6.75885	-4.4472	-3.70763	-2.9859	-6.30292
4-2	-6.17516	-5.06941	-4.00169	-2.36631	-6.75856
4-3	-6.19182	-4.32019	-2.89444	-6.19182	-5.06918
4-4	-6.12477	-4.91089	-3.89945	-2.12525	-7.03859
4-5	-5.89904	-4.29261	-3.44804	-1.85506	-6.27318
4-6	-5.74856	-3.94496	-3.60015	-2.06678	-5.8735
4-7	-5.20256	-3.50965	-2.71326	-0.26066	-5.44601
4-8	-5.84474	-4.25205	-3.39129	-1.34134	-5.67258
4-9	-6.41305	-4.83901	-3.88476	-2.10129	-5.93593
5-1	-6.72899	-4.97235	-3.28965	-3.45023	-6.25187
5-10	-5.07688	-3.60839	-3.45116	-0.7692	-5.4037
5-2	-6.20378	-3.85342	-3.25883	-1.19553	-5.6919
5-3	-5.69117	-3.84493	-3.05257	-6.29323	-6.81611
5-4	-5.72751	-4.32957	-3.46387	-1.88241	-5.88241
5-5	-6.56339	-4.35095	-3.26297	-2.14525	-5.93137
5-6	-6.29244	-4.43296	-3.53144	-1.66528	-5.55784
5-7	-6.22892	-3.41838	-3.06021	-1.91281	-6.22456
5-8	-5.862	-3.39889	-2.94367	-1.08731	-5.66134
5-9	-7.7891	-6.4646	-5.51397	-3.71317	-6.96791

MNR	Sites	Ce	Cs	Tb	Yb	Lu	Hf	Ta
CODE		ppm	ppm	ppm	ppm	ppm	ppm	ppm
1-1	EjSw-1	-3.30621	-3.72973	-4.82179	-4.63773	-5.17126	-4.17397	-4.17669
1-2	EjSw-1	-2.70268	-3.72995	-4.64943	-4.23963	-5.08577	-3.83703	-4.10062
1-3	EjSw-1	-2.98499	-4.04542	-4.5653	-4.39423	-4.90276	-4.18053	-4.39087
1-4	EjSw-1	-3.27793	-3.94666	-5.27378	-4.7509	-6.596	-4.31954	-4.5546
1-5	ElSx-1	-2.79249	-4.03025	-4.40931	-4.34501	-5.44794	-3.91409	-4.49034
1-6	EjSw-1	-3.86517	-4.0448	-5.99011	-5.1055	-4.83884	-4.66105	-4.70007
2-1	EjSw-1	-3.63515	-4.1533	-5.21636	-5.21636	-5.50666	-4.47599	-4.82388
2-2	EjSw-1	-3.09191	-3.5881	-4.76003	-4.632	-5.27879	-3.94616	-4.40101
2-3	EjSw-1	-3.30913	-3.25686	-4.86342	-4.66385	-4.85982	-3.99812	-3.98836
2-4	EjSw-1	-3.41482	-3.67288	-4.48642	-4.58231	-5.52496	-3.90107	-4.32704
2-5	ElSx-1	-2.14794	-3.34885	-3.89936	-3.87417	-5.10218	-3.44897	-4.31046
2-6	ElSx-1	-5.22076	-4.67169	-5.67502	-5.92564	-6.55851	-5.87515	-5.71708
2-7	EjSw-1	-3.14832	-4.087	-5.19328	-4.74332	-4.61143	-4.66065	-4.80331
2-8	EkSt-1	-3.28713	-4.47422	-5.21074	-4.97783	-5.47939	-4.42564	-4.75271
2-9	ElSx-3	-2.95852	-4.13562	-6.59199	-4.5506	-5.23596	-4.34402	-3.89302
3-1	EkSt-1	-3.6316	-3.912	-5.40741	-5.89877	-5.65326	-4.62693	-4.86938
3-2	EjSv-5	-3.13637	-4.23304	-4.88785	-6.63661	-3.97983	-3.91708	-5.63661
3-3	EkSt-1	-4.60253	-4.93976	-6.48106	-7.48163	-5.53063	-5.46788	-8.48163
3-4	EkSt-1	-2.9515	-5.13239	-4.85484	-4.96605	-5.98626	-3.92114	-7.60951
3-5	EkSt-1	-3.51738	-3.82401	-6.14143	-4.8404	-5.8404	-4.5564	-4.29158
3-6	EkSt-1	-4.27245	-3.67586	-5.79533	-4.78815	-5.84921	-4.84921	-4.92027
3-7	EkSt-1	-7.67829	-4.19542	-7.67829	-7.67829	-6.27175	-6.67829	-7.67829
3-8	EkSt-1	-3.58696	-4.87398	-5.35232	-4.98313	-5.7439	-4.25442	-5.67332
4-1	ElSx-1	-3.94659	-4.89926	-5.41955	-5.80113	-6.81213	-5.63919	-6.7715
4-10	ElSx-3	-3.47034	-6.57263	-6.90498	-4.48528	-6.04252	-4.78964	-5.86092
4-2	EjSv-5	-4.1138	-7.25794	-6.14937	-5.89622	-5.60041	-5.15262	-5.56555
4-3	ElSx-1	-3.56776	-5.0718	-5.46346	-5.89626	-4.51399	-4.26812	-5.51437
4-4	ElSx-10	-3.72287	-4.74299	-5.23156	-5.32258	-6.53931	-3.9925	-4.56339
4-5	ElSx-1	-3.28926	-4.08008	-5.42225	-4.95869	-5.57963	-4.15485	-6.7503
4-6	ElSx-1	-3.38918	-4.04527	-4.79718	-4.25797	-5.77495	-4.18371	-4.35255
4-7	ElSx-1	-2.61956	-4.33523	-4.55648	-4.16303	-5.47521	-3.85227	-4.96285
4-8	ElSx-1	-3.10932	-5.20554	-4.74375	-3.93677	-5.05489	-4.18503	-5.1928
4-9	EjSv-5	-3.4488	-3.9316	-5.47423	-6.71408	-4.65705	-4.45643	-6.71408
5-1	ElSx-1	-3.49599	-5.23763	-5.02142	-5.09552	-6.25332	-3.97025	-4.9808
5-10	EjSv-3	-3.37633	-4.29495	-5.18705	-5.22731	-5.97572	-3.86033	-5.15082
5-2	ElSx-1	-2.81881	-4.85807	-4.99196	-4.24348	-5.67673	-3.57964	-4.75106
5-3	ElSx-1	-2.84392	-4.73044	-5.47935	-6.29323	-5.26103	-4.1357	-4.94815
5-4	ElSx-1	-3.21782	-4.36488	-5.345	-4.67223	-5.35496	-4.19592	-5.1753
5-5	ElSx-1	-3.11513	-5.06005	-5.09481	-5.81866	-4.10927	-4.04652	-4.54982
5-6	EjSw-1	-3.41179	-4.78008	-6.79759	-5.0494	-5.37598	-4.49647	-5.00453
5-7	EjSw-1	-2.91408	-4.63071	-5.69981	-6.22456	-3.80802	-3.74527	-5.32147
5-8	EjSw-1	-2.833	-4.60007	-6.1858	-4.99389	-3.52297	-3.46022	-4.27217
5-9	EkSt-1	-7.69219	-5.40802	-6.21793	-6.2016	-6.46175	-6.06934	-5.80017

Appendix E: Eigenvector Values for the First Three Principal Components

Eigenvector values including outliers

EL	PC 1	PC 2	PC 3
Ti/Fe log10	0.24263196	-0.14004	0.10284459
V/Fe log10	0.23655656	-0.0725307	0.09739073
Al/Fe log10	0.25711251	-0.0907381	0.04477407
Cl/Fe log10	0.07135134	-0.0218837	0.41033503
Ca/Fe log10	0.24565289	-0.038298	0.08210146
Mn/Fe log10	0.23226044	0.00975506	0.15305772
Th/Fe log10	0.19844243	-0.0445584	-0.0780639
Cr/Fe log10	0.05907446	0.50005296	0.05770097
Sc/Fe log10	0.2491799	-0.09436	-0.0017291
Co/Fe log10	0.18443868	0.07984196	0.12006138
Eu/Fe log10	0.2157765	0.02352352	-0.0344534
Nd/Fe log10	0.23900917	-0.0359639	-0.0296522
Sm/Fe log10	0.24862489	-0.0844647	0.00005316
As/Fe log10	-0.017125	0.13101882	0.41390442
Sb/Fe log10	0.107962	0.26858001	0.43733401
Rb/Fe log10	0.10464225	0.30643653	-0.1160374
Na/Fe log10	0.23348296	-0.1464306	-0.0146875
La/Fe log10	0.25649333	-0.12463	0.05408804
Ba/Fe log10	0.09460623	0.10445819	-0.396825
Au/Fe log 10	0.10947121	0.44065433	-0.0514258
Ce/Fe log10	0.23970798	-0.0723347	-0.1007727
Cs/Fe log10	0.09526427	0.45026278	-0.0029062
Tb/Fe log10	0.1744404	0.13366627	-0.153915
Yb/Fe log10	0.17188414	0.07342981	-0.3366695
Lu/Fe log10	0.14348641	-0.0985932	0.14431394
Hf/Fe log10	0.24684246	-0.0850956	-0.0615382
Ta/Fe log10	0.15179307	0.12288086	-0.2058447

Eigenvector values excluding outliers

EL	PC 1	PC 2	PC 3
Ti/Fe log10	0.24062327	-0.1503072	0.1396526
V/Fe log10	0.24215493	-0.0635741	0.1319071
Al/Fe log10	0.26492737	-0.0935689	0.077461
Cl/Fe log10	0.04918224	-0.0354356	0.3339135
Ca/Fe log10	0.24556734	-0.0257216	0.1345198
Mn/Fe log10	0.24471556	0.01599285	0.2065913
Th/Fe log10	0.16699472	-0.0400458	-0.1332049
Cr/Fe log10	0.02509942	0.4950214	0.0239551
Sc/Fe log10	0.25660201	-0.04228	-0.0334204
Co/Fe log10	0.16362029	0.03899124	0.1529483
Eu/Fe log10	0.21766508	0.10610387	-0.0073022
Nd/Fe log10	0.2297184	0.02923139	-0.0684119
Sm/Fe log10	0.26491792	-0.0297237	-0.068593
As/Fe log10	-0.0680015	0.07285864	0.2238581
Sb/Fe log10	0.07556803	0.2896197	0.4177243
Rb/Fe log10	0.10949828	0.2795844	0.012308
Na/Fe log10	0.22677237	-0.1633137	-0.0607082
La/Fe log10	0.26654746	-0.1157467	0.0553363
Ba/Fe log10	0.05173255	0.12093969	-0.4565785
Au/Fe log 10	0.05718769	0.47266205	0.0114851
Ce/Fe log10	0.25685339	-0.0637232	-0.069336
Cs/Fe log10	0.05098306	0.45758162	-0.0045369
Tb/Fe log10	0.20112388	0.11478341	-0.1502815
Yb/Fe log10	0.18060691	0.06944187	-0.3855699
Lu/Fe log10	0.12073636	-0.0324747	0.2666897
Hf/Fe log10	0.25377577	-0.0643251	-0.092388
Ta/Fe log10	0.16684392	0.13188224	-0.1916275

Appendix F: Means and Standard Deviations of Elemental Concentrations for Geochemical Groups

	Raw data (EL in ppm)						
		Group 1 (n=8)		Group 2 (n=13)		Group 3 (n=12)	
		Avg.	St.Dev	Avg.	St.Dev	AVG.	St.Dev
Al	**%**	5.2	3.1	6.8	2.0	8.1	1.5
Ca	**%**	3.2	2.0	5.2	2.4	5.3	4.1
Fe	**%**	19	18	3.6	1.5	3.8	2.4
Na	**%**	1.7	1.6	1.9	1.5	3.3	1.7
Br	**ppm**	16	20	5.0	3.7	1.8	1.3
Cs	**ppm**	18	28	4	2	1	2
Ta	**ppm**	3.0	3.9	1.4	1.2	0.7	0.8
Co	**ppm**	9.4	6.1	6.2	3.6	5.5	5
Au	**ppm**	1.8	2.3	1.0	1.2	0.06	0.04
Ti	**ppm**	318	181	342	177	520	269
As	**ppm**	7.2	8.0	6.1	8.0	1.8	1.6
Cr	**ppm**	32	25	37	28	3.2	2.1
Eu	**ppm**	2.9	2.7	1.9	1.2	1.3	0.7
Zn	**ppm**	218	163	1033	1302	204	202
Sc	**ppm**	10	5	20	12	12	6
Mn	**ppm**	883	388	897	345	835	505
Ba	**ppm**	798	753	849	1073	1662	2735
Cl	**ppm**	321	320	229	151	301	217
Hf	**ppm**	2.6	2.2	2.4	1.3	3.7	2.2
Rb	**ppm**	30	44	30	39	0	0
Sb	**ppm**	1.0	1.1	0.5	0.5	0.4	0.9
Th	**ppm**	2.9	3.5	3.1	2.1	3.3	2.5
V	**ppm**	88	39	182	95	120	41
Ce	**ppm**	24	20	25	15	29	17
La	**ppm**	19.3	25.4	15.2	6.9	21.3	11.1
Lu	**ppm**	0.3	0.3	0.6	1.2	1.2	2.1
Nd	**ppm**	22	21	22	37	17	15
Yb	**ppm**	1.7	2.3	0.8	0.4	1.2	1.8
Tb	**ppm**	0.2	0.2	0.5	0.3	0.4	0.3
Sm	**ppm**	3.5	2.8	4.1	2.0	4.5	2.6

Appendix F: Means and Standard Deviations of Elemental Concentrations for Geochemical Groups

Fe normalized data (EL/Fe)						
	Group 1 (n=8)		Group 2 (n=13)		Group 3 (n=12)	
	Avg.	St.dev	Avg.	St.dev	Avg.	St.dev
Al	0.9	0.9	2.1	0.8	3.3	2.2
Ca	0.55	0.54	1.71	0.99	1.79	1.19
Fe	1.00	0.00	1.00	0.00	1.00	0.00
Na	0.37	0.41	0.56	0.44	1.5	1.4
	med		high		low	
Br	0.99	0.60	1.39	0.97	0.79	0.74
Cs	0.77	0.76	1.52	1.40	0.31	0.29
Ta	0.19	0.19	0.46	0.38	0.18	0.17
Co	1.3	1.2	1.6	0.7	1.4	0.7
Cr	3.9	3.0	11.2	6.9	0.73	0.24
	low		high		med	
As	0.38	0.23	1.61	1.44	0.50	0.43
Au	0.09	0.09	0.29	0.28	0.02	0.02
Eu	0.27	0.21	0.61	0.48	0.43	0.22
Sc	1.5	1.4	5.9	3.8	3.8	1.9
V	11	9	61	48	47	37
Zn	51	58	343	527	73	91
Mn	117	109	286	166	241	106
	low		med		high	
Ba	85	78	337	633	795	1671
Cl	29	29	71	51	130	143
Hf	0.4	0.4	0.8	0.4	1.3	0.9
Rb	6.1	8.7	10.7	16.7	0.02	0.02
Sb	0.08	0.07	0.16	0.12	0.22	0.58
Th	0.57	0.89	0.95	0.64	1.09	0.84
Ti	49	50	108	68	177	111
Ce	3.6	3.7	7.8	5.4	9.8	6.4
La	3.9	6.6	4.5	2.1	7.6	4.9
Lu	0.02	0.01	0.16	0.27	0.49	0.91
Nd	3.0	3.7	5.4	6.5	5.9	8.3
Yb	0.10	0.06	0.26	0.16	0.32	0.37
Tb	0.04	0.05	0.16	0.12	0.09	0.08
Sm	0.62	0.74	1.3	0.7	1.5	1.3