EXCHANGE AND INTERACTION IN WESTERN ALEUTIAN PREHISTORY: THE EFFICACY OF GEOCHEMICAL ANALYSIS OF LITHIC RAW MATERIAL PROCUREMENT ON AMCHITKA ISLAND

By

Nicholas P. Jew

RECOMMENDED:

Kenneth Severin, Committee Member

Patty Gray, Committee Member

Daniel Odess, Committee Chair

Chair, Department of Anthropology

APPROVED:

Dean, College of Liberal Arts

Dean of the Graduate School

April 9, 2007

Date

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A

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Nicholas P. Jew, B.A.

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Abstract

There are two main objectives of this thesis; the first is to evaluate the efficacy of geochemical techniques for the identification of lithic raw materials used to make stone tools in the Aleutian Islands. The second objective is to use the data set acquired from the analytical methods to generate hypotheses pertaining to exchange and interaction on Amchitka Island. Looking at Amchitka's geology using x-ray fluorescence will provide the basis for examining the elemental characterization for identification of basalt materials. From this analysis, I compared the elemental concentration of basalt artifacts between six archaeological sites found on Amchitka. Through the use of principal components analysis, the basalt artifacts were chemically matched with those specimens containing similar elemental properties to determine if they derived from the same geologic sources on Amchitka. The generation of hypotheses was directed towards identifying potential basalt sources locations on Amchitka Island and archaeological sites which may be appropriate candidates for further investigations of exchange and interaction.

Table of Contents

Page

Page

List of Figures

List of Tables

Page

List of Appendices

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Chapter 1 Introduction

Recent advancements of technological research tools have enabled archaeologists to characterize commonly utilized lithic materials that a few decades earlier were thought untraceable. The integration of geochemical analysis and its ability to acquire accurate elemental concentrations in ceramic and lithic artifacts has allowed exploration of exchange of non-rare materials and study of interaction on a more localized geographic scale. This has led archaeologists to a renewed interest in prehistoric exchange and interaction.

This research is an exploratory study testing the efficacy of x-ray fluorescence (XRF) as a research tool for characterization of basalt materials commonly found in the Aleutian Islands. There are two questions addressed throughout this thesis. The first question is directed towards the evaluation of the efficacy of geochemical analysis. With the use of principal components analysis, a descriptive statistic commonly utilized in characterization studies, I will evaluate: 1) how efficient is x-ray fluorescence for determining the elemental composition of basalt artifacts found in the Aleutian Islands? After evaluating the geochemical technique, I will use the data comparison acquired from the descriptive statistics to answer: 2) how are basalt artifacts chemically similar and how do they relate to their archaeological sites of origin? Analysis of the descriptive statistical comparison provided the basis to formulate a set of hypotheses directed towards understanding the relationships between the chemical variation of basalt artifacts and their archaeological site origins. The hypotheses pertain to potential basalt source locations on Amchitka Island and archaeological sites which would make excellent candidates for future comparison of exchange and interaction on Amchitka Island. These analyses are all directed towards understanding the complexities of local exchange in circumscribed environments.

In addition to testing the efficacy of x-ray fluorescence and the formulation of hypotheses, this research provides the start of a geochemical database of basalt artifact composition in the Aleutian Islands. The goal is to provide supportive evidence for an efficient research tool, hypotheses to direct future investigation, and a database that will be available for replication or modification as needed in future comparisons.

This thesis is divided into eight main sections. The following section provides background on previous theoretical inquiry into prehistoric exchange and trade. This section also explains some key differences between previous studies and the study of Amchitka Island. The third section is devoted the Aleutian Islands, looking specifically at Amchitka's environment, geographic setting, archaeological history, and brief ethnographic history. The fourth section addresses the methods involved with the geochemical analysis of basalt artifacts taken from Amchitka Island. The fifth section provides archaeological site descriptions and site maps for geographic reference. The sixth section includes descriptive statistical analyses of the characterized basalt artifacts and evaluates the efficacy of XRF. The seventh section involves data analysis and the formulation of general hypotheses. The eighth section provides expanded discussion of exchange and interaction on Amchitka Island and addresses the complexities of local scale and some of the limitations to the data set. This section provides steps for future researchers and identifies some of the limitations in exchange studies on Amchitka Island. The final section summarizes the findings on Amchitka Island.

Chapter 2 Theoretical Background

In the last thirty years, archaeological examination of prehistoric exchange has primarily focused on development of theory, models, and techniques to better understand prehistoric economics, exchange, trade, and interaction. Ericson and Earles' volumes *Exchange Systems in Prehistory* (1977) and *Contexts for Prehistoric Exchange* (1982) were primarily focused on theoretical and model developments of exchange systems. The major areas of interest were spatial patterning, sourcing, productions of exchange, and consumption (Ericson and Earle 1982). In 1984, Renfrew compiled a number of his articles into a book entitled, *Approaches to Social Archaeology*. This book encompasses a detailed analysis specifically examining the models, modes, and theories archaeologists utilized in examining exchange and trade in prehistory.

A decade later, Baugh and Ericson produced a two volume series; the first entitled *The American Southwest and Mesoamerica: Systems of Prehistoric Change* (1993) and the second, *Prehistoric Exchange Systems in North America* (1994). These volumes were organized by geographic region and oriented towards the examination of lithic raw materials in relation to their geological provenance.

One of the most recent publications by Glascock, *Geochemical Evidence for Long-Distance Exchange* (2002) contains contributions from researchers who examine long-distance trade and exchange through the analysis of geochemical techniques. Each of these volumes contributes to the growing literature intended to understand trade and exchange in prehistoric societies but are all primarily interested in long-distance procurement.

2.1 Exchange and Interaction

Examining exchange and interaction in prehistory "is central to the study of society because of the association of goods and information in most exchanges, is an aspect of the embeddedness of the economy" (Renfrew 1984:89). In archaeology, exchange is defined as the "spatial distribution of materials from hand to hand and from social group to social group" (Earle 1982:3).The study of exchange is of particular interest to archaeologists because of the potential it holds for reconstruction of economic interaction, social organization, and political structures of prehistoric societies (Baugh and Ericson 1994;Glascock 2002). In most situations, archaeologists have only a fraction of the material record to draw inferences about exchange and interaction. Interaction, defined for this study "as the exchange of materials, ideas, beliefs, and information between members of different corporate groups" (Odess 1998:417), encompasses transactions of both material and non-material commodities and items. It is the archaeologists' task to examine the available material remains to draw inferences about the additional types of interaction as those defined. In particular, characterization studies seek to chemically identify materials, compared the data sets using statistics, and test models of exchange and interaction to the data to infer back to the prehistoric societies.

Characterization studies of lithic raw materials, ceramics, metals, and organic materials and implementation of statistical methods for comparison, have allowed archaeologists to identify the possible relationships among artifacts which may be traced onto an objective landscape. An objective landscape in prehistoric exchange studies is important because as Molyneaux suggests:

> geography and distance represent the real-time space within which people, goods, and materials moved, and the exploitation of this landscape of possibilities yields the patterns of sites and resources that exchange theorists use to sketch out their ideas of economic interaction (2002:134).

If a material can be traced and linked between two archaeological sites, it provides the basis for further inquiry.

2.2 Local versus Long-distance Procurement

The difference between previous studies of prehistoric exchange and the study of Amchitka Island is geographic distance. I am interested in identifying the spatial distribution of locally procured materials on a single island, where these earlier studies focus on long-distance prehistoric exchange over large geographic areas. For purposes of this study, the term local refers to any materials procured on-island and exotic refers to materials procured off-island. Previous studies trace regional procurement where distance between sites and source areas is hundreds of kilometers. One of the best examples of prehistoric exchange pertains to obsidian studies (Ammerman 1979; Ammerman and Andrefsky 1982; Ericson 1982; Findlow and Bolognese 1982) where isolating specific geologic sources for material procurement is important for tracing material movement from their origins. Obsidian sources are relatively few compared to the prospective sources for basalt. Isolating basalt sources is difficult because of its abundance in island environments. For purposes of this study, the general geologic data taken from the United States Geologic Survey (USGS) provides a general context for basalt provenance on Amchitka Island. Although the long-distance exchange models cannot be directly applied on a local scale, the characteristics of prehistoric exchange studies provide a template to the study of local material procurement on Amchitka Island.

2.3 Characteristics of Prehistoric Exchange Studies

Three types of data should be present in examining exchange in prehistory: types of commodities, the amounts or quantities and the sources that they are derived from, if possible (Baugh and Ericson 1994). Earle suggests three interrelated jobs for the researcher who undertakes exchange studies: to source commodities, describe spatial patterning, and reconstruct organization of the prehistoric exchange (1982). Regardless of the material type or applied models / modes, there are a number of steps followed by most studies of prehistoric exchange.

The first is to identify which materials will be selected for analysis. This is ultimately determined by the research question and materials available. The second is the selection of an analytical technique or techniques that can be used to characterize material present in the data set and the natural environments. The third is the use a statistical method to compare the characterized materials. The fourth is to identify which archaeological samples are derived from sources sharing similar characterization properties. The fifth is to use the data set in relation to the geologic sources to test the hypothesis derived from models of exchange. Because the geologic sources for Amchitka Island are unknown and the sample size is relatively small, this step will be replaced with the generation of hypotheses from the data set of basalt characterization, to infer possible locations of basalt sources, which may be used in future studies to test the models of exchange and the sixth step, to make inferences about the prehistoric inhabitants of the past. The inferences drawn from characterization studies can range from general interpretations to very specific inferences to exchange, trade, and interaction. The conclusions drawn from the data analyzed in this thesis only permit general inferences and hypotheses generation regarding interaction on Amchitka Island.

2.4 Lithic Raw Materials

The most common lithic material examined in exchange and sourcing studies is obsidian. Less prevalent are studies addressing chert, steatite, and basalt (Glascock 2002). Obsidian is the most commonly sourced material because the rarity of the sources decreases the prospective quarries and its geochemical signature permits a more precise sourcing (Harbottle 1982). Chert, steatite, and basalt sources are more abundant than obsidian, increasing the difficulty in identifying specific provenance over hundreds of kilometers. Obsidian is a glassy black volcanic rock that produces a highly prevalent conchoidal fracture. There are only a few recorded artifacts derived from this material on Amchitka Island. McCartney notes "one obsidian source located in the northern part of Amchitka Island" (1977:87). It is unclear whether the artifacts derived from obsidian were of local or exotic sources and because there are only a few cases of obsidian artifacts on Amchitka Island and its origin is unknown it was not selected for this research.

In sourcing studies, the most important component is the nature of the material. The material should possess a unique chemical signature with the potential to be sourced or compared to other artifact specimens. Once the specimens have been matched, interpretation and theoretical models may be applied to reconstruct exchange and interaction. The degree of reconstruction varies with the nature and quality of the data. While some of these previous studies have established chronological models for exchange of materials, there is little data available for chronological controls on Amchitka Island. As a result, the study of Amchitka is one focused on the spatial distribution of material between source areas and archaeological sites.

2.5 Characterization Methods

The progression in archaeometric sourcing studies over the last couple of decades has been primarily aimed at linking geological sources and archaeological sites through distance and time (Weisler 2002). Specifically, the development of geochemical techniques and petrographic analysis of geologic materials in archaeology since the 1950s, has led to more accurate methods for sourcing archaeological materials (Glascock 2002; Webb 1974; Wright 1993). For example, Glascock states:

> Over the past half century, and especially during the past 25 years, studies of prehistoric exchange and trade have become one of the most rapidly growing areas of archaeology. With the aid of geochemical methods (i.e. those based on the principles of physics, chemistry and the earth sciences), characterizations of artifacts and source materials on the basis of their mineralogical, chemical and/ or isotopic properties have greatly enhanced exchange studies and, hence are leading archaeologists toward the development of better models for long-distance exchange and the understanding of the social relations of production and group interaction (2002:1).

With more accurate approaches for sourcing lithic raw materials, past archaeologists' speculative claims of long-distance trade can now be tested using more accurate types of analysis. This has led to a renewed interest in examining prehistoric exchange and interaction.

An analytical method or technique is required to attribute materials from archaeological sites to geologic sources. What method is used in a study depends on time, efficiency, availability, cost, restrictions on destructive analysis, and material type. Two commonly used methods of geologic sample identification include petrographic and geochemical analysis. Petrographic analysis describes a rock type based, in part, on the kinds of minerals present in the rocks and their relationships, while geochemical analysis measures the elemental weight abundances.

2.5.1 Petrographic Analysis

Optical petrographic analysis involves the examination of a thin section with an optical microscope. The textural and mineral composition of the sample is quantified and compared by the observer under a mineralogical or petrographic microscope equipped with a polarizer. The polarizer enables the petrographer to, "determine the index of isometric crystals and with appropriately oriented sections, the refractive indices of diametric crystals and of trimetric crystals" (Mottana et al. 1978:47). This means comparison of artifact samples are conducted based on similarities and differences between the crystalline compositions of minerals presence in a sample. One of the benefits of petrographic analysis is cost efficiency enabling characterizing a large number of samples.

As Earle suggests, petrographic analysis is the most appropriate choice if "the appearance of a material is sufficiently distinctive to permit source identification mega-scopically; however, such qualitative identification should be cautiously evaluated for accuracy by chemical analysis" (1982:4). Fine grained microbasalts are difficult to distinguish visually and as suggested by Earle, would need to be supported with chemical analysis. In contrast there has been an attempt to discriminate petrographically basalt materials in the Aleutian Islands. Mason and Aigners' (1987) petrographic analysis of three Aleutian sites compared basalt artifacts to a potential geologic source. From their analysis, they suggest, based on the exploratory analysis, that the basalt samples are petrographically similar and there is evidence supporting common procurement from a single basalt source. Although petrographic comparison has been used in the Aleutians, I am interested in exploring the efficacy of geochemical techniques as a characterization method of basalt materials in the Aleutian Islands.

2.5.2 Chemical Analysis

Chemical characterization methods include: scanning electron microscopy (SEM), proton-induced x-ray emission (PIXIE) x-ray diffraction (XRD), atomic absorption spectroscopy (AAS), thermal ionization mass spectrometry (TIMS), and x-ray fluorescence (XRF) (Glascock 2002; Harbottle 1982). The purpose of these techniques is to characterize the chemical composition of an artifact. Once each sample has been characterized by one of these techniques, then descriptive statistics are implemented to compare the chemical composition of the samples to seek a relationship. In more advanced characterization studies in which geological samples have also been characterized, then geological sources of an artifact can be matched to the elemental abundances of a specific geological provenance (Descantes et al. 2002).

X-ray fluorescence, in particular, can determine the elements present in a sample by analyzing the secondary fluorescent spectrum produced after the sample has been irradiated. In briefly describing the XRF procedure, Andrefsky states:

> The sample is irradiated with a beam of x-rays that excite electrons into higher energy levels. The electrons then settle back and emit secondary or fluorescent x-rays. The fluorescent x-rays have wavelengths characteristic of the element from which they were emitted. By measuring the intensity of the x-rays at different wavelengths it is possible to determine the concentrations of different elements in the sample (1998:42).

XRF characterizes the weight fractions of elements present in a sample. From this analysis, XRF identifies which elements and how much is present in each sample. Unlike petrographic analysis which identifies mineralogical compositions, XRF and similar geochemical techniques identify the elemental composition of a sample offering a quantitative bulk measurement, rather than a microscopic evaluation of physical of microscopic properties.

2.6 Weisler's Polynesia Characterization Study

Weisler's studies (1997, 1998, 2002; Weisler and Kirch 1996) of basalt adzes using characterization methods of XRF and XRD demonstrate the potential for similar studies in the Aleutian Islands. Both geographic locations contain islands of geologic compositions dominated by igneous rock formations. Over the last 10 years, a series of geochemical analyses have been conducted to compare basalt adzes of Tuamotus, Marquesas, Pitcairn, and Mangareva archipelagos. A large chemical database of basalt adzes and geologic sources has allowed Weisler to conduct an inter-island comparison and test exchange models. The research presented in this thesis is the first step to the accumulation of a chemical database of characterized materials. After a number of artifacts are characterized and geologic sources are identified, similar exchange studies may be possible in the Aleutian Islands

2.7 Theoretical Exchange Models and Modes

There is a distinction between *models* and *modes* of exchange. Models of exchange are testable equations where certain types of data conform to predictable mathematical patterns (Renfrew 1984) and modes of exchange, are commonly occurring types of exchange, trade, and procurement in prehistoric societies. While there are numerous predictive models available (Baugh and Ericson 1994; Ericson 1982; Renfrew 1984; Tankersley 1990) for distinguishing between methods of material procurement, the difference in geographic distance and limited sample size for this research does not permit testing between the different methods. Review of some of the modes and models of exchange tested in prehistoric exchanges studies are important in understanding the process that occurs after the data set is characterized and statistically compared.

Three common types of exchange models discussed in prehistoric exchange studies are direct access, directional, and down-the-line trade. **Direct Access** is defined where "*B* has direct access to the resource at *a* without reference to *A*. If a territorial boundary exists, he can cross it with impunity. There is no exchange transaction"

(Renfrew 1984:119). In the available Aleutian literature, there are references to on-island territorial conflicts and warfare (Bank 1951; Black 1981; McCartney and Veltre 1999) suggesting that, at least during some periods, direct access would only have been granted with a social mechanism permitting access to resources. Despite the lack of exchange as the form of interaction, interaction between peoples would have been necessary to permit access to resources.

Down-the-line trade and exchange is apparent, "where commodities travel across successive territories, through successive exchanges" (Renfrew 1984:119). As distance between sites and sources increase, the quantities of materials should decrease. This mode of exchange is possible based on the law of monotonic decrement. This law states:

> When a commodity is available only at a highly localized source or sources for the material, its distribution in space frequently conforms to a very general pattern. Finds are abundant near the sources, and there is a fall-off in frequency or abundance with distance from the source (Renfrew 1984:136).

This law is the basic principle that allows for application of distance-regression models such as *Pareto*, *Exponential Distance-Decay*, and *Gaussian Fall-Off*. These are three commonly utilized models to examine down-the-line trade when there is extensive distance between sites. Sites farther from the lithic source contain a decrease in waste material. In contrast, scarce materials are commonly recycled and retouched for conservation of material.

One violation of the law of monotonic decrement pertains to **directional trade**.

If trade is being conducted between peoples based on preference, materials present at these sites may have higher percentages than those closer to the source. Directional trade is represented by exchange and trade of two or more goods between groups or individuals. This mode can manifest as either home-base reciprocity or boundary reciprocity.

These trade and exchange modes are designed to offer possible scenarios, or economic systems, to account for the spatial distribution of goods, items, or materials. These modes do not represent all exchange systems in a particular society. In actuality, multiple modes of exchange, trade, and interaction are co-occurring in complex webs or as simple as random chance meetings of exchange. There are also both formal, functional, and ceremonial exchanges and trade to consider within any given society. These exchange models should be used with caution but are non-the-less important in providing a frame of reference into possible types of interactions that may have occurred within a given prehistoric society.

Chapter 3 Aleutian Islands

The Aleutian Islands are located between Alaska and Kamchatka, running 1,700 km east to west separating the north Pacific Ocean and the Bering Sea. There are approximately 120 islands and islets that make up the Aleutian chain. From east to west, the chain is divided into five groups; Fox, Four Mountain, Andreanof, Rat, and the Near Islands (figure 3.1). Between each island and archipelago are treacherous oceanic passages usually at least 20 km wide, or between Baldir and Amchitka, for example, exceed 100 km. With the exception of the Near Islands, the Rat Islands are the westward most group on the Aleutian chain. The chain is differentiated among researchers by western and eastern orientation. The western Aleutians refers to the Near and Rat Islands and the eastern Aleutians; Fox, Andreanof, and Four Mountains island groups.

The Rat Islands, shown in figure 3.2, consist of 11 islands. Amchitka is the largest southernmost and lies 51.5°N and 179°E. It is 65 km long oriented north-west to south east, and averages between 2 and 7 km wide. Amchitka's topography and environment is representative; an archetype of the rest of the western Aleutians (McCartney 1977; Merritt 1977). The coastline is composed of steep sea cliffs and grassy slopes with relatively few sandy beaches appropriate for launching watercraft and has a number of different bays and inlets. The northern part of the island contains semi-mountainous areas of hills and steep bluffs and the southern portion of Amchitka Island is composed of low-lying flat areas (Desautels et al. 1970). Within the interior region of Amchitka, lie numerous scattered shallow / ephemeral ponds, drainage streams, and small lakes each containing a variety of freshwater fish (Merritt 1977).

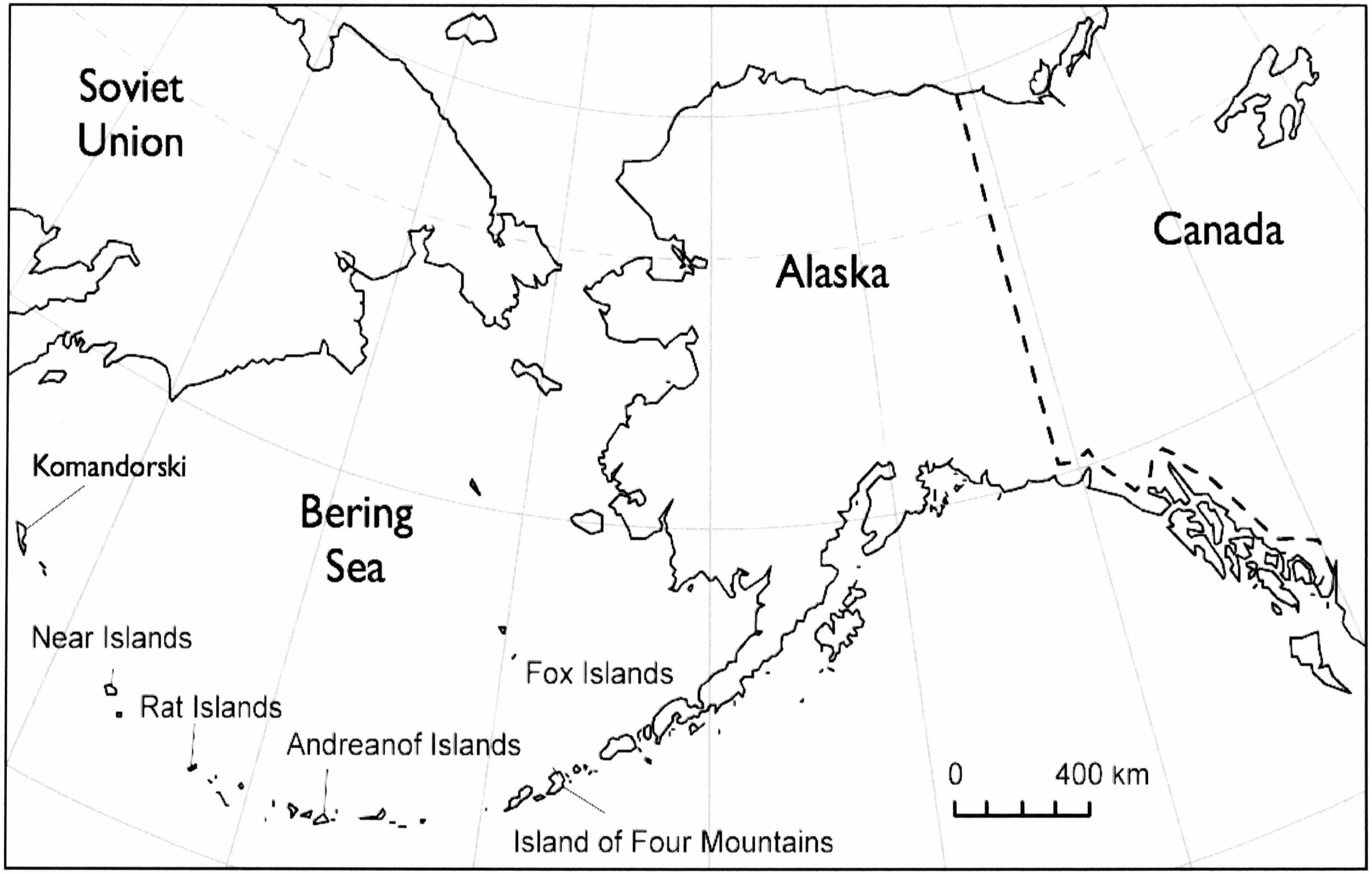

Figure 3.1: Map of Aleutian Islands

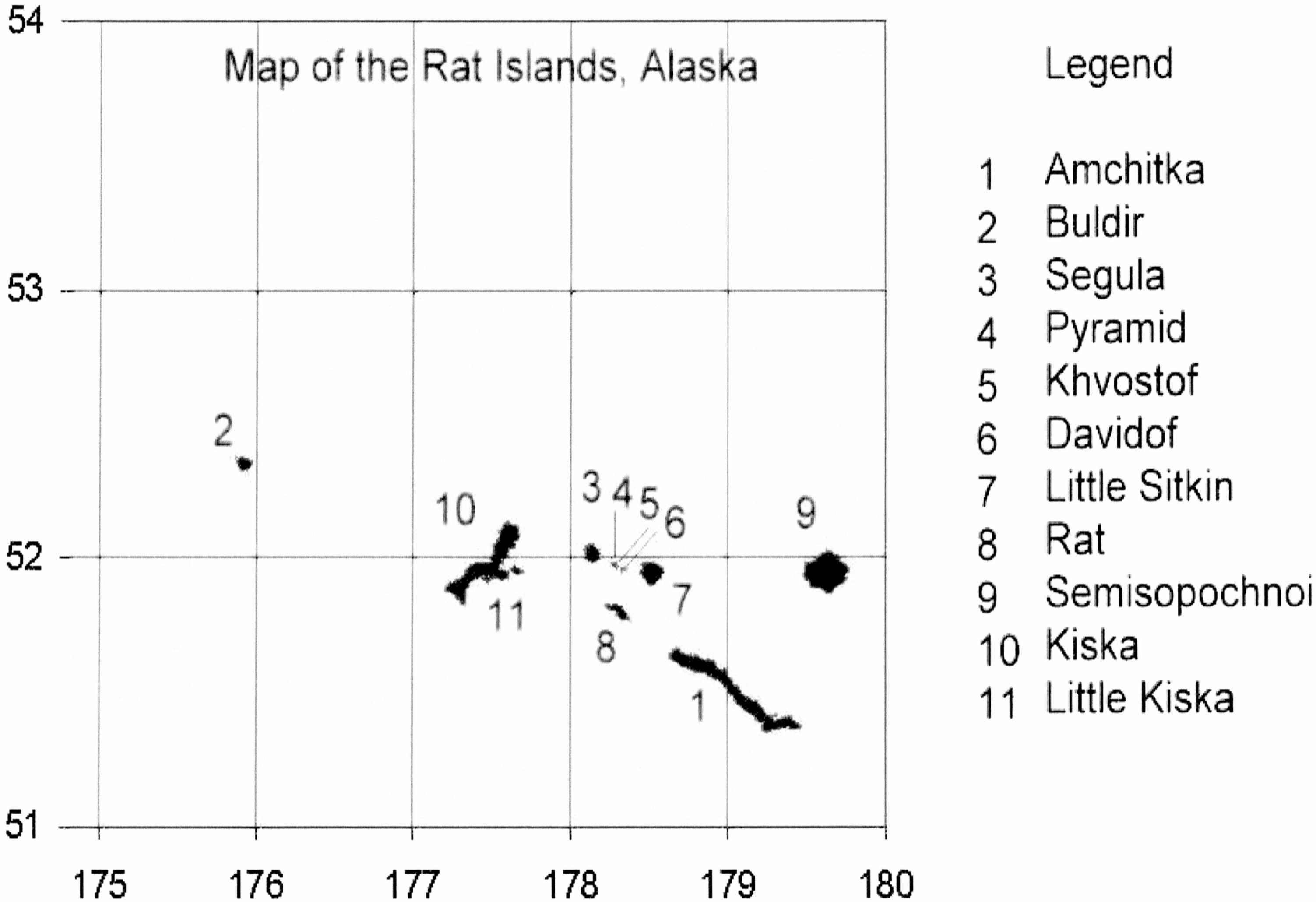

Figure 3.2: Map of the Rat Islands

3.1 Climate

The Aleutian Islands have a maritime climate. The islands are located along the North Pacific (or Aleutian) storm track with annual temperatures[1] fluctuating between 10 °C and 0 °C. The mixing of warm moist air and the surrounding cold ocean surface shrouds the Aleutians in low lying clouds and dense fog. The daily averages of precipitation during the summer, spring, and fall seasons on Amchitka usually lie between 0.25 mm -12.70 mm. During the winter season, snowfall ranges between 2.54 cm and 30.48 cm. There is no prevailing wind direction on Amchitka. The incoming migratory pressure systems create a constant presence of extreme variable high surface winds that average 25 - 35 kph, and sometimes in excess of 160 kph. All of these factors make the Aleutian environment unstable and unpredictable (Armstrong 1977).

3.2 Geology

The Aleutian chain lies in the Aleutian arc, a submarine trench stretching 3,200 km from the Gulf of Alaska to Kamchatka and in some areas exceed a depth of 7,600 meters (Gard 1977). Formed during the Tertiary Period, the Aleutians' geological composition primarily consists of volcanic tuffs, lavas, basalts, porphyries, andesites, granites, and diorites (Desautels et al. 1970). There is also an assortment of sedimentary and metamorphic rocks. The emergent chain is the result of volcanic lava flows produced from tectonic activities that make the islands susceptible to frequent seismic and volcanic activities as well as tsunamis (Bank 1951; Black 1981; Frohlich 2002; McCartney and

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[1] Averages and percentages for climate data taken from Armstrong (1977)

Veltre 1999). The tectonic factors are attributed to the converging North American and Pacific Plates located just south of the Aleutian arc. Amchitka has not been subject to major volcanic episodes and has been tectonically stable between the last 2,000 - 4,000 years (Gard 1977).

In 1966 - 1967, the USGS published a detailed report describing Amchitka's geological composition. Defined in this report are seven major geological regions, represented in figure 3.3. The northern and central geological regions of Amchitka include andesite lava flows and breccias. The lower-central and southern regions contain pillow and glassy lavas, older breccias, basalt, hornsfels, and a small concentration of diorite. For the archaeological site report of Amchitka (1970), Desautels et al. submitted eleven artifact samples for petrographic analysis to the Geological Museum at the University of California at Los Angeles. The materials reported from this analysis all shared the characteristic of small grain size (Desautels et al. 1970). Local basalt, common to the Aleutians, was used as a substitute for unavailable higher quality materials such as obsidian and chert. The microcrystalline - basalt selected for tool making possess extremely small grain size making them more durable than other local materials such as andesite and porous stones.

3.3 Vegetation

The Western Aleutians have a sub arctic maritime tundra regime. With some exception of the sparse occurrence of spruce, willow, and alder, trees in the Aleutians are mostly absent (Walker 1945). Vegetation in the western Aleutians is dominated by families of low lying shrubs such as crowberry (*Empetrum nigrum*), grasses, sedges,

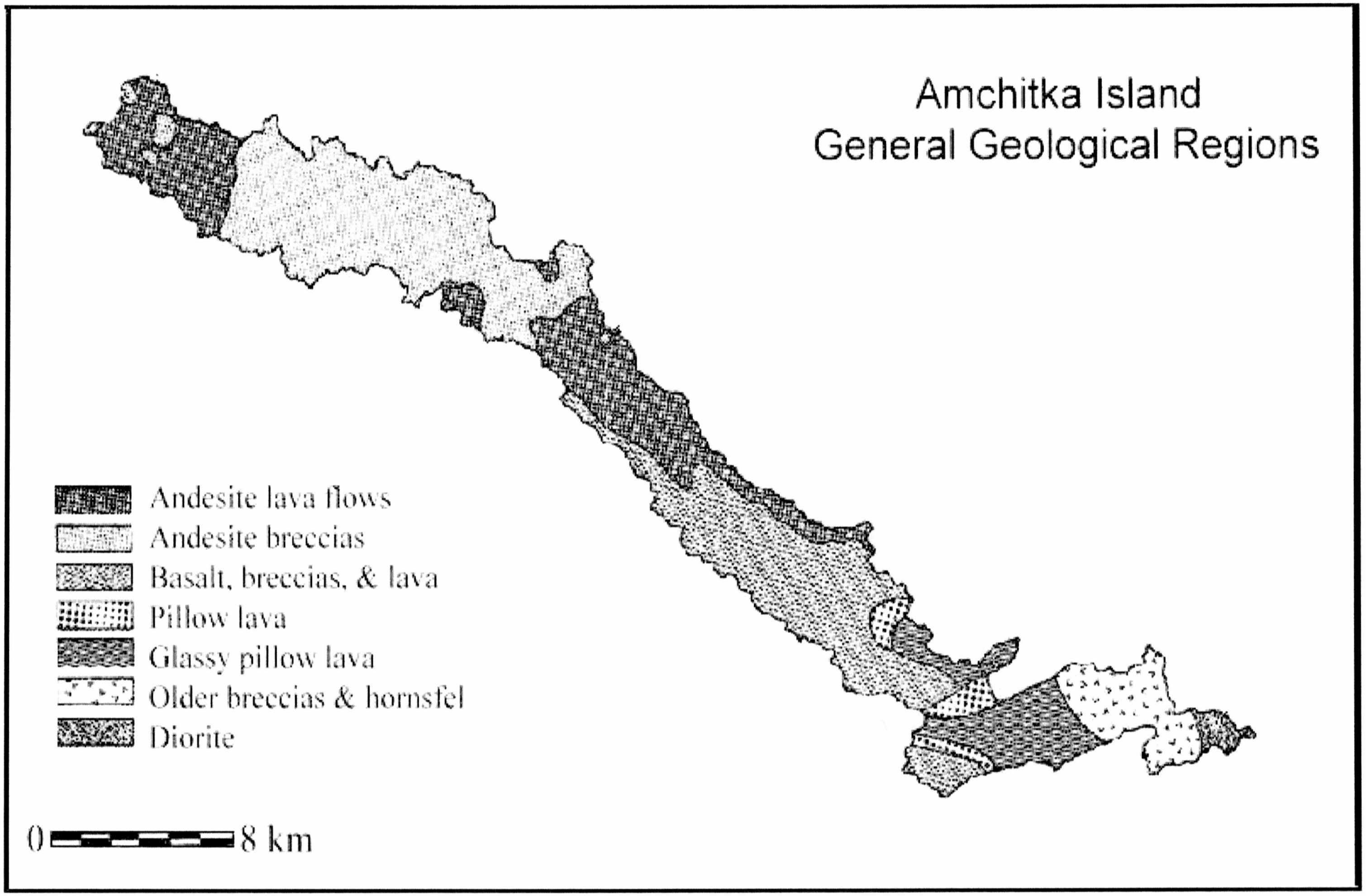

Figure 3.3: Geologic Map of Amchitka Island, (after Desautels et al. 1970:9)

lichens (e.g., *Cladonia, Mycoblastus,* and *Thamnolia Vermicularus*), and mosses (e.g., *Bryum, Mnium, Polytrichum*) (Amundsen 1977).

There are also a number of different species of vascular plants. On Amchitka, 300 samples were collected and from those; 47 different families were identified (Amundsen 1977). The limited growth and productivity of vegetation in the Aleutians are attributed to six key factors: 1) narrow temperature ranges 2) constant winds of high velocity, 3) evenly distributed precipitation 4) heavy fog and cloudiness, 5) low solar-energy input, and 6) igneous bedrock that hinder nutrient release (Amundsen 1977). Vegetation growth and mortality rates are also attributed to sea water salinity and the oceans overproduction of plankton (Black 1981). Despite the environmental factors restricting vegetation growth, the islands maintain thriving microenvironments for plant life. Amchitka Islands' vegetation can be divided into three types of topoenvironmental units:
1) beach, 2) lowland, and 3) upland tundra (Amundsen 1977). These microenvironments are influenced by elevation, surface exposure to wind, and drainage systems.

The beach environment is located along the shorelines near bluffs, ridges, and cliffs. Vegetation in this area is dominated by species of grasses, lichens, and mosses located between cobble beaches and sand dunes (Amundsen 1977). The lowland tundra is located in the insular regions between the drainages, freshwater lakes, and ponds. This area is subdivided into wet and dry lowlands. The vegetation present in the wet lowlands is the result the slow drainage patterns obstructed and trapped by peat substrates and is predominately covered by crowberry, followed in decreasing appearance by sedges, and lichens meadows (Amundsen 1977). The dry lowlands are located higher in elevation and have crowberry, grasses, and a subtle presence of sedge meadows. The upland tundra contains a well defined drainage system located on elevated areas most commonly found on top of bluffs and ridges. Vegetation in this area, consists primarily of grasses (e.g., *Calamagrosti* and *Nutkaensis*), sedges (e.g., *Carex Circinnata, C. Lyngbyaei,* and *C. Macrochaeta*), and crowberry (Amundsen 1977).

3.4 Aleutian Prehistory

Environmental stressors, climate, geology, and isolated geographic location have influenced human occupation and adaptation in the Aleutian Islands (Black 1981). Migration across oceanic passages could only have been accomplished by peoples possessing a well developed maritime adaptive technology. Poor solar radiation input, absence of nutrients in the soils, and inclement weather, led to a sea resource based, instead of agricultural, subsistence. Despite the inhospitable environment and weather, the Aleutian Islands were occupied throughout most of the Holocene, starting around 9,000 B.P. with the Anangula Tradition.

The Anangula Blade Site is the earliest evidence of human occupation in the Aleutian chain. The site is located in the eastern Fox Islands, on the islet of Anangula, near Umnak Island. The site dates between ca. 8,750 – 8,250 B.P. (Mason and Aigner 1987; McCartney and Veltre 1999; Laughlin 1980) and is comprised of primarily large blades and cores. The assemblage for Anangula is described as "A unifacial toolkit based on Upper Paleolithic-derived core and blade production: large to small cores and blades, platform rejuvenation flakes, transverse burins, burin spalls, end and side scrapers made on blades and other related tools" (McCartney and Veltre 1999:504). Unfortunately, interpretations are limited because there is no faunal preservation at the Anangula site (McCartney and Veltre 1999). Anangula is followed by a period of absence for approximately 3,000 years until the appearance of midden sites on the Eastern Aleutians (Aigner et al. 1976).

Around ca. 5,500 BP, sites from the Proto or Early Aleut Tradition appear throughout most of the Aleutian chain. Midden sites are one of the prevalent archaeological features found along coastal areas of the islands. Unlike Anangulas' unifacial blade technology, the Proto-Aleut assemblage is comprised of a more complex bifacial flaked tools directed towards a maritime subsistence (McCartney and Veltre 1999). Some of the tools include harpoon points, fishhooks, wedges, and an assortment of bone and ivory tools. The archaeological sites on Amchitka start appearing during the Proto Aleut Tradition and continue throughout the next period termed the Aleut Tradition.

The Aleut Tradition began 4,500 BP and lasted until Russian contact in the 18th century (Dumond 1987). One of the characteristics of the Aleut Tradition was the presence of long-term occupation sites. Settlements consisted of numerous semi-subterranean houses (*barabara*) which were usually constructed of whale bone, driftwood, and peat or grass mat for roofs. McCartney argues village placement was determined by three factors: 1) defensibility from inclement weather or invading enemies, 2) close proximity to fresh water, and 3) within launching distance for their watercraft or kayaks (*baidarkas*) (McCartney 1977; McCartney and Veltre 1999).

The peoples of the Aleut Tradition adopted an exclusive maritime strategy. Subsistence included sea mammals, shellfish, salt / freshwater fish, and marine invertebrates (Desautels et al. 1970; Dumond 1987). Among the archaeological remains on Amchitka, Desautels et al. collected 11,000 faunal specimens from 49Rat 31 identifying over 100 different species of marine wildlife. The variety of bird, mammal, and fish remains demonstrate diversification among maritime subsistence at a single site. McCartney's examination of prehistoric Rat Islanders categorizes eight types of procurement systems in which these species can be organized: 1) sea mammal hunting (offshore), 2) sea mammal hunting (onshore), 3) bird hunting on water, 4) bird hunting on nesting sites, 5) fishing offshore 6) fishing onshore 7) intertidal and beach collecting, and 8) onshore collecting (McCartney 1977). The species procured in these different locations also provided a wide range of resources for clothing, tools, watercraft, weapons, and shelters. The archaeological assemblages of the Aleut Tradition contain a variety of stone, bone, and ivory artifacts. Common stone artifacts were net sinkers, adzes, scrapers, unifacial / bifacial points, drills, projectile points, and hammerstones; bone and ivory artifacts consisted of awls, fishhooks, eyed needles, wedges, harpoon points, shafts, *ulu* handles, and darts. Material procurement of wide variety of resources allowed prehistoric peoples of the Aleutian Island to survive in an environment that was both unstable and often times unpredictable (Black 1981).

3.5 Previous Archaeological Investigations on Amchitka Island

The Aleutian Islands were first documented by Russian explorer Vitus Bering in 1741. Bering's discovery prompted Russian expeditions to the Aleutians that persisted for the next one hundred years. These early expeditions to the Aleutians were not for scientific exploration, but rather, for exploitation of sea otter, and seal fur and pelts (Collins 1945). General scientific investigations in the Aleutians did not take place until after the United States purchased Alaska in 1867 (Fuller 1977). Since then, the Aleutians have intrigued American scientific investigators and explorers. Of all the western islands, Amchitka has been the constant focus of both scientific and governmental interest. As a result, Amchitka Island is perhaps the most well studied island in the western Aleutians.

The first known archaeological investigation on Amchitka Island was conducted during a three year expedition in 1871 - 1873 by naturalist Dall. During his expeditions in the Aleutian Islands, Dall observed enormous shell-heaps (Dall 1874). The need to further understand these large middens prompted Dall to test the imposing sites on the Aleutian landscape. While at anchorage on Amchitka, Dall partially excavated 49 RAT[2] 2, located in Constantine Harbor. Included in his reports, were the general physical descriptions of some artifacts and archaeological remains.

In 1938, archaeologist Hrdlička, of the Smithsonian Institution, took a group of students with him to explore the Aleutian and Commander Islands. During this expedition, Hrdlička stopped at a number of the Aleutian Islands, including Amchitka. Hrdlička's time on Amchitka was spent excavating portions of 49 RAT 2 and 49 RAT 3 (1941a, 1941b, 1945). His 2,059 artifacts recovered from Amchitka were deposited at the National Museum of Natural History, Smithsonian Institution.

[2] 49 RAT refers to the Alaska Heritage Resource Survey (AHRS) assigned numbers

In World War II, Amchitka was occupied by a large population of U.S. soldiers. During this period, one of Hrdlička's former students, Guggenheim, was stationed on Amchitka. Many of the sites located on Amchitka today were first identified by Guggenheim while stationed on Amchitka. Throughout his stay, Guggenheim witnessed the destruction of numerous archaeological sites due to the digging of foxholes, pot hunting, and construction of military installations (Guggenheim 1945). In spite of the damage to the archaeological sites on Amchitka, he encouraged soldiers to systematically identify and record the locations of archaeological sites. In his final report of his time spent on Amchitka, Guggenheim discusses some the difficulties of preserving the archaeological resources. For example, he discussed how the U.S. soldiers held contests for whoever found the best artifacts (Guggenheim 1945). In lieu of pot hunting by soldiers, Guggenheim managed to create an archaeological map of Amchitka where 40 prehistoric sites were identified. In addition, Guggenheim also managed to obtain general descriptions of many artifacts now in possession of private collectors.

In October 1965, the first of three nuclear tests was conducted on Amchitka. *Long Shot* was a nuclear detection research experiment detonated at a depth of 700 meters (2,300 feet) with a yield of about 80 kilotons (Engdahl 1971). In 1966, The Atomic Energy Commission (AEC) initiated a study of Amchitka to monitor the effects of these nuclear experiments. Mitigation to archaeological resources was not assessed until 1967. It was during this period, from 1968-1970 that the majority of archaeological investigations took place. Some of the archaeological investigators of this time were Sense and Turner (1970) and Desautels et al. (1970). Two additional nuclear tests occurred in October 1969, and November 1971. The second nuclear test, *Milrow*, was a high-yield seismic calibration test detonated at a depth of 1,220 meters (4,000 feet) yielding one megaton (Engdahl 1971). The last test, *Cannikin*, was detonated at a depth of about 1,790 meters (5,875 feet), with a yield less than five megatons (Engdahl 1971).

In 1968, Holmes and Narver Inc. hired Sense and Turner to evaluate archaeological resources on Amchitka Island. The purpose of these investigations was to "prevent loss of archaeological materials through unauthorized excavation and inadvertent destruction of sites by construction activities" (Sense and Turner 1970:1). Sense and Turner identified the 40 original sites reported by Guggenheim, and discovered 36 additional sites. Of these 76 reported sites, fourteen sites were tested and approximately 1,400 artifacts were recovered. After the second nuclear test in 1969, the AEC contracted Desautels et al. and Archaeological Research, Inc. (ARI) to salvage and excavate threatened archaeological resources. ARI excavated six archaeological sites on Amchitka including: 49 RAT 31, 35, 36, 10, 14, and 60. These excavations were conducted through 1969-1970 and produced 6,800 artifacts (Desautels et al. 1970). The primary interests of AEC was to establish an inventory for surface sites, test those sites in immediate danger, and assess the effects nuclear testing would have on archaeological resources on Amchitka Island (McCartney 1977). After the third nuclear test in 1971, Cook excavated 49 RAT 32, recovering approximately 3,000 artifacts. The site reports, surveys, and excavations conducted during these years of nuclear testing make up the bulk of archaeological information recovered on Amchitka Island. For the next decade following 1971, Amchitka Island received little interest in terms of archaeological research. Archaeological investigation would not continue to be conducted on Amchitka Island until the mid 1980s. However, during this brief interim period of fieldwork on Amchitka Island, one of the most important publications pertaining to Amchitka Island was released.

In 1977, the Energy Research and Development Administration (ERDA), formerly known as the AEC, published *The Environment of Amchitka Island, Alaska.* Contained in this publication are numerous contributions to studies on Amchitka's climate, prehistory, geology, soils, hydrology, limnology, and aquatic ecology. Most of the scientific research conducted on Amchitka was initiated by AEC for their responsibilities in conducting nuclear experiments on U.S. soil. The environmental report, produced by ERDA "… compiles and condenses the information developed in these studies and to make this information broadly available" (Merritt and Fuller 1977: iv). ERDA's evaluation of archaeological resources by McCartney is one of only a few theoretical inquiries through examination of recovered archaeological resources on Amchitka Island. Initial synthesis of the prehistory on Amchitka Island began with McCartney's contribution in the ERDA report.

The initial and follow up environmental studies on Amchitka Island were to evaluate the pre / post effects nuclear tests that would incur to the immediate and surrounding environment. Selecting Amchitka Island to conduct these nuclear experiments prompted archaeological resource mitigation by Sense and Turner, Desautels et al. and others involved in AEC research. The archaeologists' primary interests were directed at the prevention of archaeological resource losses due to construction, preparation, and execution of the three nuclear experiments.

In the summer of 1984, Kent in association with the Bureau of Indian Affairs (BIA) and cooperation with the Native Aleut Corporation through the Alaska Native Claim Settlement Act (ANCSA) revisited the 76 prehistoric archaeological sites on Amchitka Island. The objectives of this survey were to identify the physical locations of the previously reported archaeological sites and determine which sites contained criteria eligible for protection under ANCSA 43 CFR § 2653.5. BIA's investigation included detailed surface and subsurface evaluations for each archaeological site. The report contains descriptions of previous investigations, disturbances, actual location, adjacent environmental settings, prevalent features and correlation to other sites. The BIA investigation was the first to thoroughly test all of the prehistoric sites on Amchitka Island. Previous investigations acknowledged all of the sites, but usually only selected sites were tested and partially excavated. In contrast, the BIA investigations tested, surveyed, and evaluated all of the sites, providing detailed information that can be used to further compare archaeological sites.

Another section in the BIA report interprets the cultural remains for each site and discusses future mitigation. Included in this section are reiterated site applications followed by a statement of significance. One example, taken from 49 RAT 12 or BIA's assigned BLM AA-11972:

> In its application the Aleut corporation noted that the complete site survey conducted by Sense (1970) in 1969-1970 indicates that the island was once extensively utilized by the Aleut population, the survey provides only a first step and that further research must be conducted utilizing data gathered from many sites on the island before a complete picture of Aleut settlement patterns, subsistence activities, and cultural adaptation can be delineated. Specifically, the application goes on to note, this site has the potential of yielding significant archaeological data concerning the history and prehistory of the Aleuts in this portion of the Aleutian Chain (Kent 1984).

Most of the sites recorded by BIA investigators were recommended eligible for protection because of their potential to yield significant data about the prehistoric inhabitants on Amchitka Island. The archaeological resources recovered from Amchitka Island are a rarity for the western Aleutians because it is the only island in the western region to have undergone extensive archaeological evaluations. Prior to McCartney's assessment of the Rat Islands and BIA's complete archaeological survey, only a partial synthesis based on selectively tested archaeological sites directly threatened by nuclear testing could be addressed. With the incorporation of the recent archaeological investigation and publication concerning Amchitka Island, future research has the potential to yield specific insight into the on-island interactions between the prehistoric inhabitants on Amchitka Island.

Chapter 4 Methods

4.1 Data Collection

The collections utilized for this research were produced by previous archaeological investigations on Amchitka Island and are currently located at the University of Alaska Museum. Data sets for this research include all available documentation and catalogue information pertaining to Amchitka Island especially that directed towards the six archaeological sites under investigation. The basalt artifacts chosen for geochemical analysis were selected from these collections and information regarding artifact types, distributions, and identifications were recorded by previous archaeological investigators.

To evaluate the efficacy of XRF for the characterization of basalt artifacts, my samples were analyzed by a *PANalytical* Axios Wavelength Dispersive Spectrometer controlled by *Super Q+*. In addition, a protocol was created to ensure the selected analytical techniques consistently characterized each sample. Protocol involves the evaluation of 1) sampling preparation methods 2) scanning surface sizes, and 3) operating conditions which include scanning length times from the analytical software applications. Compositional data were normalized to 100 % to help minimize variability caused by surface irregularities. For this study, each method was compared and evaluated based on their time efficiency, capacity for contamination, and potential errors. Before evaluating the efficacy of XRF as a research tool for the characterization of basalt, I needed to ensure the results from the analytical techniques were comparable and not misrepresented or distorted by an error in the process.

4.2 X-Ray Fluorescence

Basalt artifact UA72[3]-57-301 was used to evaluate the different methods available for XRF analysis. The samples were prepared per each sample preparation method and then analyzed and compared under the different scanning length times. The purpose of this procedure was to see if there were any significant differences between the characterizations of basalt using the various methods.

4.2.1 Sample Preparation

The first decision made in the sample preparation process is to choose destructive or non-destructive analysis. In archaeology, destroying artifacts for any type of analysis is done so with great trepidation. Each artifact is unique and if destroyed for any analysis cannot be reexamined in its entirety. However, using non-destructive analysis for this research would not allow for an accurate evaluation of the efficacy of XRF. There are a number of problems inherent in non-destructive analysis of archaeological artifacts. Artifacts used in non-destructive analysis have certain requirements for an accurate characterization. The artifact sample must not exceed that maximum requirement to fit in an XRF machine. Second, only the surface characteristics of an artifact are penetrated for measurement. The surface of an artifact is exposed to weathering and environmental elements, in some instances, these effects can alter the surface chemical composition of an artifact which will skew characterization and therefore misrepresent the chemical composition. Another problem with non-destructive analysis is the possibility of biasing the characterization by measuring an area of the artifact that does not represent all

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[3] This number refers to the University of Alaska Museum catalogue number.

elements present in the entire sample. Creating a homogenous representation of the sample is of great importance in characterization studies to ensure correct characterization. Destructive analysis was selected for this research to increase the efficiency in obtaining an accurate classification of the basalt samples.

There are three possible destructive sample preparation methods that can be used in examining the specimens through XRF analysis. These methods are the cross-section, lithium borate fusion discs, and powder pellets. Each of these preparation methods requires the removal of a section of the specimen. The preparation process varies between methods but each is designed to accurately represent the elemental composition of the sample.

The powder pellet, also referred to as the pressed powder, sample preparation method involves the removal of a segment of the sample using a rock saw, followed by pulverization using a rock tumbler creating a powdered sample. Despite how thoroughly the tumbler is cleaned, microscopic remnants of elemental particles possessing the potential to contaminate the next processed sample remain. The powder is removed from the tumbler and approximately 10 grams of powdered specimen is placed in a mortar and combined with a binder to stop the sample from crumbling. Approximately 10 tons of pressure is applied using a hydraulic pump for 10 - 15 minutes. If inadequate pressure is applied to the sample there is a risk of discrepancies due to differences in packing densities (Williams 1987).

Similar to the pressed powder, the lithium borate fusion discs, also referred to as the fused disc or glass bead, requires initial removal with a rock saw and pulverization with the rock tumbler. Approximately 0.5 grams of the powdered specimen is combined with 10 grams of flux (typically $LiBO_2$). The sample is then placed in a platinum crucible and heated for approximately fifteen minutes after which it is poured into a platinum mold for cooling. In this process, the "samples are fused, either in a muffle furnace or gas burners at between 950° -1200° C for 10 to 20 minutes. Sulphide sulphur is normally lost during fusion (sulphur sulfite is retained)" (Williams 1987:271).

Of the three preparation methods, the cross-section is the simplest process only requiring the removal of a section with a rock saw. The benefit of this preparation method is that it does not need additional pulverization using the rock tumbler. The greater the number of preparation steps involved, the greater the risk of contaminating samples. Although the cross-section preparation method requires fewer preparation steps, there are still potential problems utilizing this method. As with non-destructive analysis, the problem with cross-section preparation method is a chance that the sample section may not represent the entire specimen. To test the homogeneity of the specimen, the different sample methods were prepared from different sections of the specimen and compared.

After preparing three samples from basalt artifact UA72-57-301, they were each analyzed for fifteen minutes under the same operating conditions. The XRF test results of the three different sample preparation methods in table 4.1 show elemental concentrations of a single sample prepared as a fused disc, cross-section, and pressed powder. Descriptive analysis of the results from all three measurements suggests that the differences occur in relative low frequencies (less than one-tenth of a percent). The elements identified in all three scans fall within a range of ± 2% variation. Some minor

Table 4.1: Elemental Comparisons of Sample Preparation Methods			
	Fused disc	Cross-section	Pressed powder
Name	(%)	(%)	(%)
Na_2O	3.186	2.904	2.958
MgO	5.412	7.01	6.088
Al_2O_3	15.626	15.307	15.429
SiO_2	49.6	50.059	51.147
P_2O_5	0.256	0.441	0.438
S	0.552	0.012	0.012
Cl	0.367	0.032	0.032
K_2O	0.128	0.127	.115
CaO	10.237	10.709	9.626
TiO_2	3.194	3.006	2.65
Cr	0.262	0.021	0.02
MnO	0.894	0.116	0.114
Fe_2O_3	9.931	10.064	10.909
Ni	0.003	-	-
Cu	0.018	0.007	0.006
Zn	-	0.012	0.012
Sr	-	0.049	0.048
Y	-	-	0.003
Zr	-	-	0.007
Ba	-	-	0.034
Nb	0.004	-	-
Mo	0.001	-	-
Co	0.025	-	-
Rb	-	0.012	0.002

variation is expected due to the differences in the sample preparation methods and is assumed to be random and statistically insignificant.

While there are some minor differences between the sampling methods, selection of a single method used consistently in this preliminary study ensures precision for data comparison. From the three possible sample preparation methods, the cross-section was selected for this study because of its time efficiency involving the least steps of preparation, thus decreasing the capacity for contamination.

4.2.2 Scanning Surface Area

Three common sample sizes for specimens are 6 mm, 27 mm, and 37 mm. The size of the specimen refers to diameter of the surface scanned during XRF analysis. The smallest scanning surface area, 6 mm, may not always represent an entire sample. Selecting the 37 mm or greater specimen size would preclude analyzing artifacts that do not contain a wide enough cross-section. The 27 mm sample size was selected for this research because is has over sixteen times the scanning surface compared to the 6 mm and is small enough to include samples that did not meet the threshold size requirement of 37 mm.

4.2.3 Operation Conditions

Operating conditions refer to the analytical program utilized for XRF analysis to determine the major, minor, and / or trace elemental composition of a sample (Williams 1987). The scanning conditions (see appendix 1 for specifics) for each specimen are part of the *PANalytical* software application programs analyzed in an Axios Wavelength

Dispersive XRF Spectrometer. The IQ+[4] program analyzes each specimen and collects 10 high resolution scans (spectra) which include elements between Oxygen – Uranium. Each scan is quantified using the *PANalytical* full fundamental parameter (FP) inter-element correction model to produce elemental frequencies for each sample. The software has built in algorithms to perform corrections for x-ray line overlap that may occur due to spectral interferences. The FP model also corrects for inter-element matrix effects.

There are two applications that are relevant to this study 1) *IQ+27mm regular vacuum*, and 2) *IQ+27mm slow vacuum*. Except for the duration of scanning times, all other conditions specified in appendix 1 are the same. The slow vacuum tests take approximately 60 minutes per sample and the regular vacuum test runs for approximately 15 minutes per sample. The analysis of the two running times determined how scanning time affect the accuracy of the characterization of basalt samples. The elemental concentrations from applications *IQ+27mm regular vacuum* and *IQ+27mm slow vacuum* are shown in table 4.2 One of the differences between the results was the four additional elements that were identified in the slow vacuum test.

In this comparison, the additional elements identified in the slow vacuum scan were less than one-tenth of percent in concentration. As will be explained in the next section, principal components analysis will not include the minor and trace elements of one-tenth percentages of concentrations. This will alleviate random errors that can create false comparisons based on the presence or absence of elements of low concentrations that are below testing tolerances.

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[4] Specifics for the FP model were obtained through written communication with *PANalytical* Personnel.

Table 4.2: Elemental Comparison of Software Applications

	Cross-section IQ+27mm slow vacuum	Cross-section IQ+27mm regular vacuum
Name	(%)	(%)
Na_2O	2.684	2.904
MgO	6.8	7.01
Al_2O_3	15.2	15.307
SiO_2	49.56	50.059
P_2O_5	.2503	0.441
S	..23	0.012
Cl	.02	0.032
K_2O	.106	0.127
CaO	9.68	10.709
TiO_2	3.37	3.016
Cr	.002	0.021
MnO	.0002	0.116
Fe_2O_3	11.96.	10.064
Ni	.00028	-
Cu	.0523	0.007
Zn	.0038	0.012
Sr	.015	0.049
Y	.0028	-
Zr	.0008	-
Ba	.0015	-
Rb	-	0.002

4.2.4 Precision and Accuracy of Instrumentation

The Axios Wavelength Dispersive Spectrometer XRF instrumentation was tested for both precision and accuracy. Precision refers to the repeatability of the instrumentation to consistently measure the elemental weight abundances of a specimen. Accuracy or instrumentation bias (Gill and Ramsey 1997), refers to how close the measured values are to the true reported values of the standard. The reported value or "true value" is an average of a number of independent runs on various machines (Gill and Ramsey 1997). USGS basalt standard BHVO-1 was measured 3 times under the same operating conditions to test instrumentation precision. The results of these analytical run (see appendix 2) demonstrate that the instrumentation used for sample analysis in this thesis is relatively precise, consistently measuring the elemental weight abundances for a specimen.

To test the accuracy of the instrumentation, known standard BHVO-1 was measured and compared to the reported standards values (Abbey 1977) (table 4.3).Those elements that show significant differences between reported and measured values can be corrected for by future researchers by adding or subtracting the necessary values to remove instrumentation bias. While there may be slight differences between the reported and measured values, these differences will not affect comparison of the data set for Amchitka Island.

Table 4.3: Accuracy of Instrumentation

	Reported Standard (Abbey 1977)	**BHVO-1 Average (3analytical runs)**	**Std. deviation (3 analytical runs)**
Name	(%)	(%)	(%)
SiO_2	49.5	48.78553	0.250643
Al_2O_3	13.699	16.22067	0.270678
FeO	12.14	11.65137	0.403899
CaO	11.13	11.3567	0.015591
MgO	7.17	4.908633	0.062302
Na_2O	2.24	3.006867	0.072849
TiO_2	2.69	2.8697	0.038157
K_2O	0.5162	0.5212	0.016195
P_2O_5	0.271	0.269233	0.003855
MnO	0.166	0.1734	0.024987
Sr	.04	0.044067	0.002818
Cl	.091	0.035133	0.005969
BaO	.0137	0.0308	0.003158
S	.0101	0.022533	0.000737
Cu	.0135	0.021267	0.003029
Zr	.0177	0.017067	0.001721
Zn	.0104	0.010133	0.002593
Ni	.012	0.01383	0.005079
Cr	.02868	0.02163	0.003158
Y	.00268	0.002797	0.000355

4.2.5 X-Ray Fluorescence Protocol

While XRF is accurate at acquiring the elemental frequencies of a sample, there are a number of factors inherent in the process that can cause slight variation in results. There are two major types of operational errors in XRF analysis: *random* and *systematic*. Random errors occur due to fluctuation in experimental conditions and errors in the methods of measurement. Systematic errors or measurement errors occur while any given specimen is run under XRF analysis. The protocol created for this study was designed to decrease the probability error occurrences.

Protocol consisted of preparing each specimen as a 27 mm cross-section sample, running software *IQ+ 27mm regular vacuum scan* (15 minutes) per sample. These conditions proved to be the most appropriate selection for this study because 1) the selected sample preparation method has the least potential for contamination 2) the scanning size selected is large enough to provide a representative surface area for analysis but small enough not to preclude any potential basalt samples and 3) The running time selected was the most time efficient while not affecting the quality of the analysis.

If I had prospective basalt sources and wanted to lower the detection limit by one or two factors, the samples could have been run under *IQ+ slow scan* requiring 60 minutes of scanning time per sample. However, because the basalt source provenance is unknown and is being directly inferred through comparison of the artifact samples, the *IQ+ regular scan* is adequate for determining the relative elemental abundances for comparison between artifact samples. The precision for the preliminary evaluation of testing the efficacy of XRF as a research tool for discrimination between basalt samples selected from archaeological sites only needs to be precise enough to identify if basalt artifacts 1) possess enough heterogeneity for characterization, and if so 2) are any of the basalt samples chemically similar on Amchitka Island.

Chapter 5 Archaeological Site Descriptions

Six types of coastal environments are present on Amchitka Island. The environments are: 1) low depositional 2) spit shores 3) wave-cut escarpment shores 4) constructional shores undergoing mass wasting and wave wind erosion 5) cliff shores with higher constructional slope and talus beach and 6) steep cliff shores with no beach (McCartney 1977). Archaeological sites have been identified on types one, two, three, and five. Types four and six profiles are steep sloping terrains that are inhospitable for human occupation. Sense and Turner (1970) define archaeological sites based on their location relative to elevation as hillside settlements, seaside camps, or blowout quarries. The distinguishing characteristic between hillside settlements and seaside camps is geographic location. Hillside settlements are located on cliff or bluff edges that overlook the coasts, similar to types three and five. In contrast, seaside camps are located on low elevations with a gradual slope; such as types one and two.

Seventy-six prehistoric archaeological sites have been identified on Amchitka Island. The six sites from which basalt samples were tested and their respective geologic regions are depicted in figure 5.1. All of the sites contain evidence of semi-subterranean houses. Parameters of sample selection for this research were based upon accessibility of previously collected materials and collections containing an adequate lithic population for sampling. Basalt samples from the archaeological site collection were selected from specimens that met the necessary size prerequisite of being greater than 27 mm in diameter.

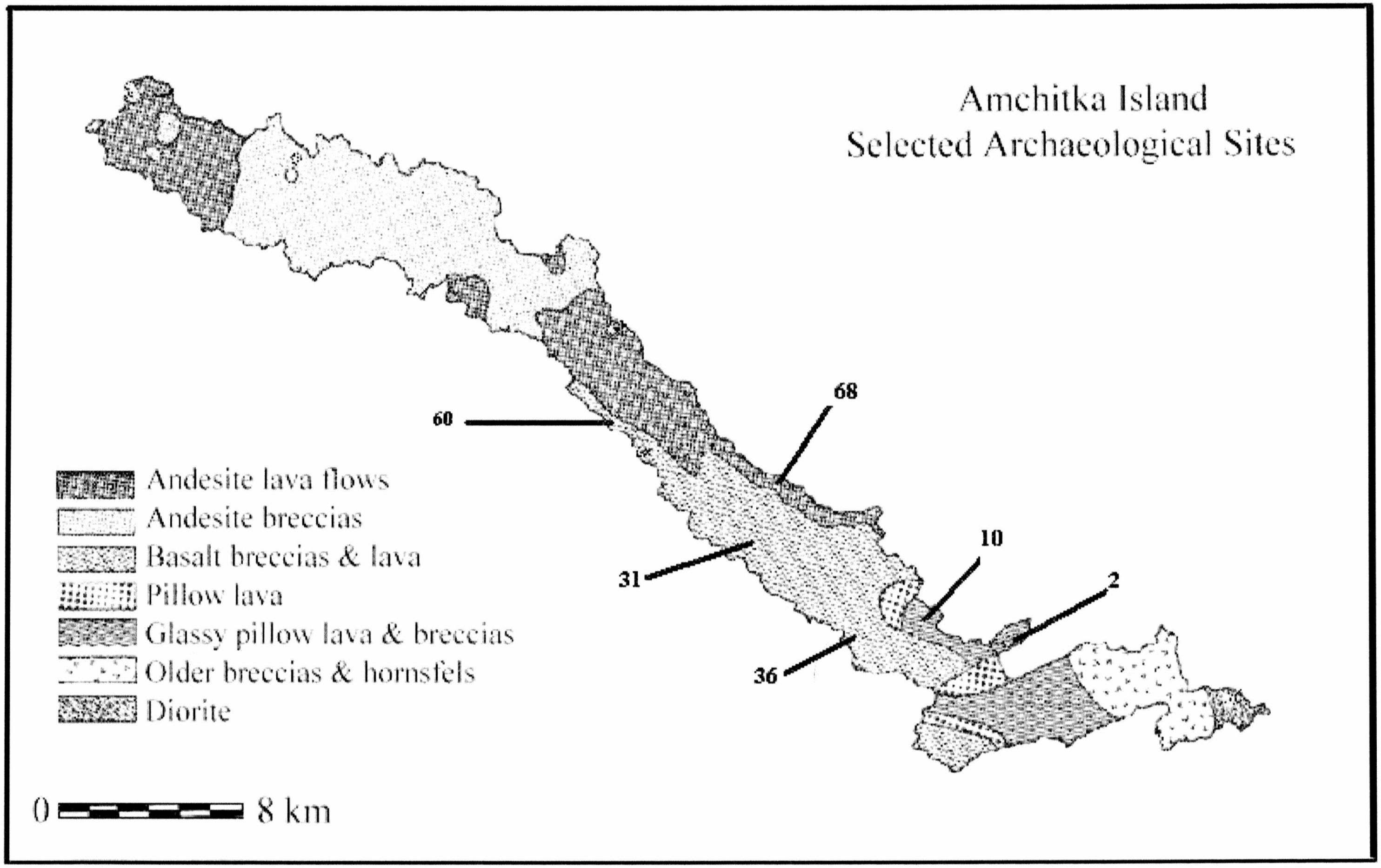

Figure 5.1: Map of Sampled Archaeological Sites (modified after Desautels et al. 1970:9)

The archaeological sites selected for this study, 49 RAT 2, 31, 36, and 60; are identified as hillside settlements by Sense and Turner (1970). Sites 49 RAT 10 and 68 are seaside camps (Sense and Turner 1970). The site maps presented in the subsequent sections are from Sense and Turner's 1970 report. Although the maps are not to scale they still depict the site location and profile elevations. Their site descriptions include: 1) type of site (hillside or seaside) 2) food resource areas 3) driftwood source 4) boat launching / landings 5) security and 6) relation to other sites.

World War II construction, vandalism, nuclear testing, and continuous archaeological excavations have made obtaining accurate radiocarbon dates of archaeological sites on Amchitka Island extremely difficult. Evidence for contemporaneous occupation of 49 RAT 10, 31, 36, and 60 are presented in the AEC 1970 archaeological report. All four sites have recorded cultural materials in similar strata depths and layers extending to at least 150 cm in depth. The archaeological site depths are: 49 RAT 31: 200 centimeters below datum (cmbd), 49 RAT 36: 310 cmbd, 49 RAT 10: 160 cmbd, and 49 RAT 60: 174 cmbd (Desautels et al. 1970). BIA reports recorded stratigraphic depths for 49 RAT 2 and 68 at approximately 2 meters deep (Kent 1984). The quality of data from previous research investigations is not sufficient to permit demonstration of contemporaneous occupations. However, the recorded depths by these investigations provide data that is consistent with site occupation over a long period of time.

The following site descriptions are a synthesis of previous archaeological investigations on Amchitka Island. All of the following sites were originally reported by

Guggenheim (1945), resurveyed by Sense and Turner (1970) and AEC investigator Desautels et al. (1970). The most recent survey was conducted by the Bureau of Indian Affairs investigator Ron Kent (1984).

5.1 Site 49 RAT 2

Site 49 RAT 2 is a prehistoric midden site approximately 20 x 40 m located NW of Constantine Harbor (figure 5.2). This site was investigated by Dall in 1873 and Hrdlička in 1938. The site is located on a high bluff 15 m in height. There is evidence of numerous semi-subterranean house depressions, some of which extend to a depth of 2 m (Kent 1984). Site 49 RAT 2 contains wide variability in faunal remains and lithic materials commonly found in the archaeological sites on Amchitka Island. The following is a description provided by Sense and Turner.

> Food Resource Areas: Narrow (50 ft wide) reef exposed at low tide. Freshwater Jones Lake (waterfowl) ½ mile to the west; a trout stream drains the lake. Shallow harbor is ideal for halibut. Driftwood: Sparse. Boat Landing: No obstacles. Security: The site commands an excellent view of the harbor and coast and could be easily defended. The terrain behind the site is obstructed by low hills (1970: 10).

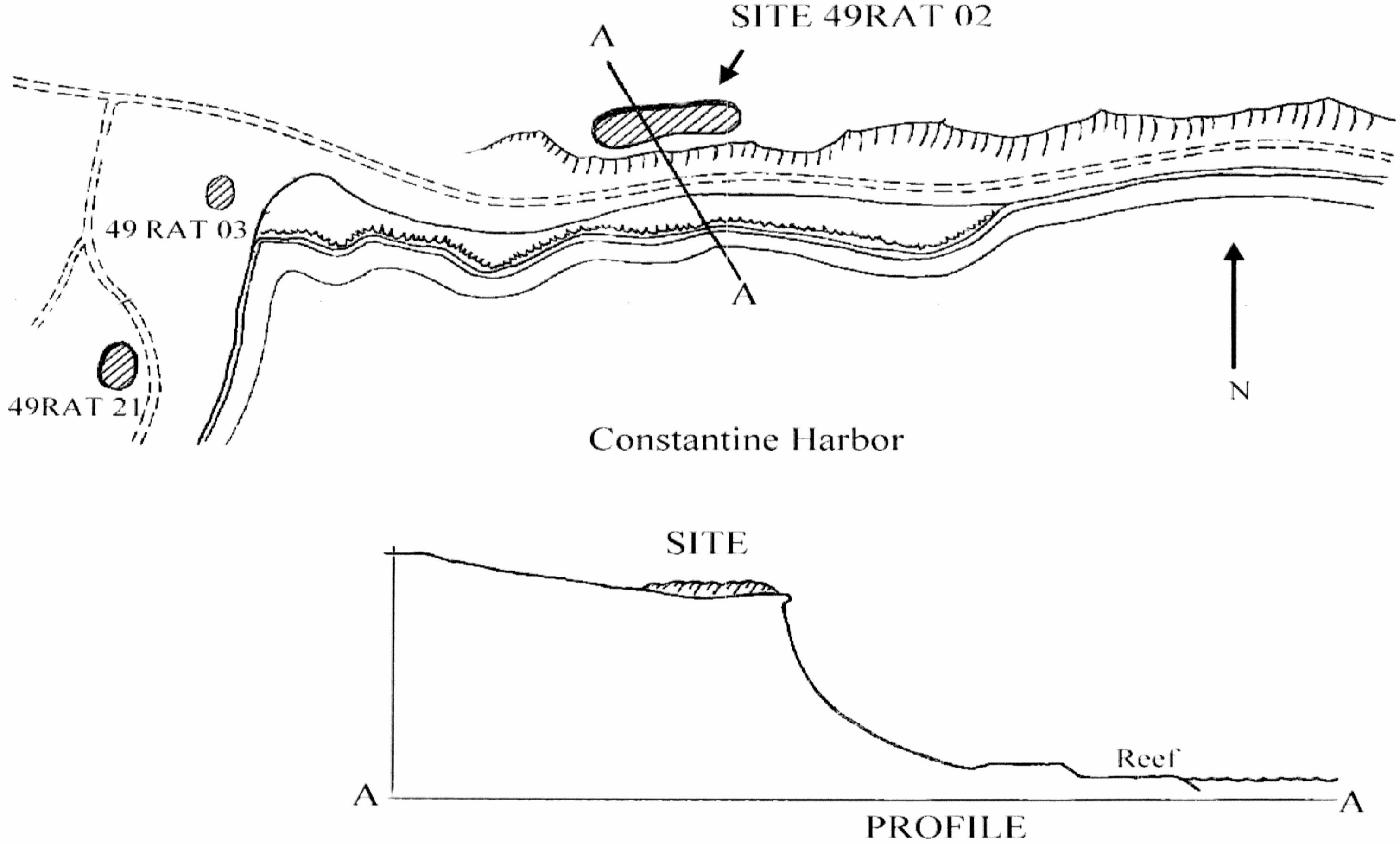

Figure 5.2: Site Map 49 RAT 02 (after Sense and Turner 1970:7)

5.2 Site 49 RAT 10

Site 49 RAT 10 is located on the Bering Sea side of Amchitka Island near Kirilof Bay (figure 5.3). The site is roughly 15 x 30 m, and is located on a low lying beach terrace approximately 10 m in elevation. It contains over twenty features, one of which is identified as a house pit (Desautels et al. 1970; Kent 1984; Sense and Turner 1970). Sixty percent of the original site was reported destroyed during WW II (Guggenheim 1945) and other disturbances appear to be the result of previous archaeological investigations by Guggenheim, Sense and Turner, and Desautels et al. (Kent 1984).

> Food Resource Areas: Reef exposed at low tide is about 100 feet wide. A wider reef is 0.3 miles to the east. Salmon stream 1.0 mile to the west. Broad open valley behind the site Driftwood: Moderate quantity. Boat Landing: Wide channel through reef leads to cobble. Security: No defense. Restricted view of coastline. Relation to Other Sites: 0.9 miles from sites 9 and 63 (Sense and Turner 1970: 47).

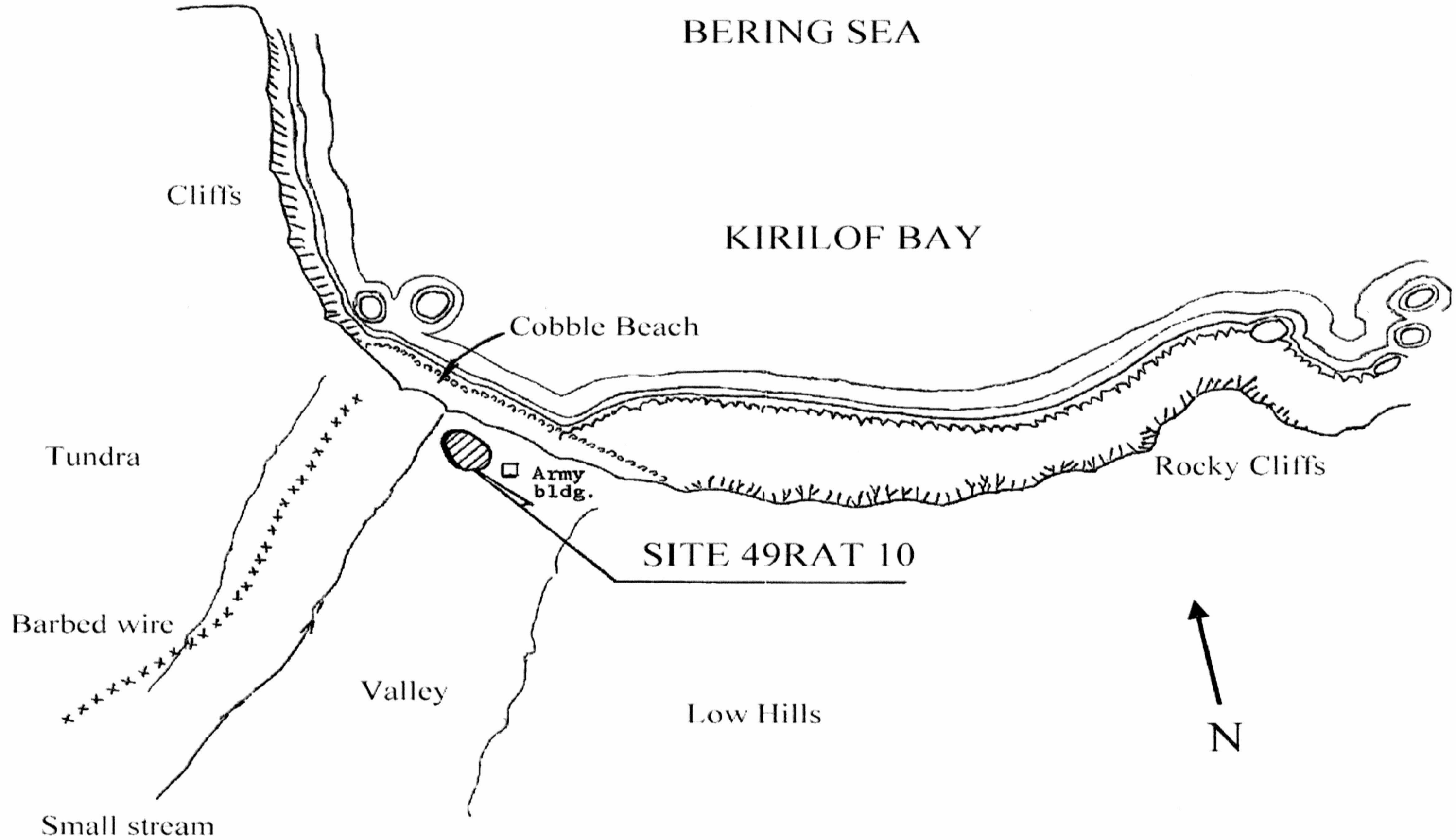

Figure 5.3: Site Map 49 RAT 10 (after Sense and Turner 1970:45)

5.3 Site 49 RAT 31

Site 49 RAT 31 is located on a Pacific Ocean side bluff 25 m above sea level and is approximately 20 x 40 m (figure 5.4). It is a midden site with at least two house depressions, each approximately 5 x 10 m and exceeding a depth from 2 - 3 m (Desautels et al. 1970; Sense and Turner 1970). Desautels et al. (1970) report gives an in depth description of the faunal and lithic assemblages recovered from this site. The faunal data was later assimilated into McCartney's (1977) examination of prehistoric inhabitants of the Rat Islands. It is perhaps the best studied archaeological site to date on Amchitka Island.

> Food Resource Areas: About 200 feet of reef exposed at low tide. Salmon stream below site. Terrain behind site is a broad valley flanked by low hills. Deep stream at base of hill has abundant waterfowl. Driftwood: Abundant. Boat Landing: Broad channel through reef leads to gravel and sand beach. Security: Easily defendable. Restricted view of coast from site, but higher point with a better view is 450 feet to the SE. Relation to Other Sites: Sites 57, 76, and 32 about 1.5 miles to the NW and SE. Site 56 is in the same cove (Sense and Turner 1970: 137).

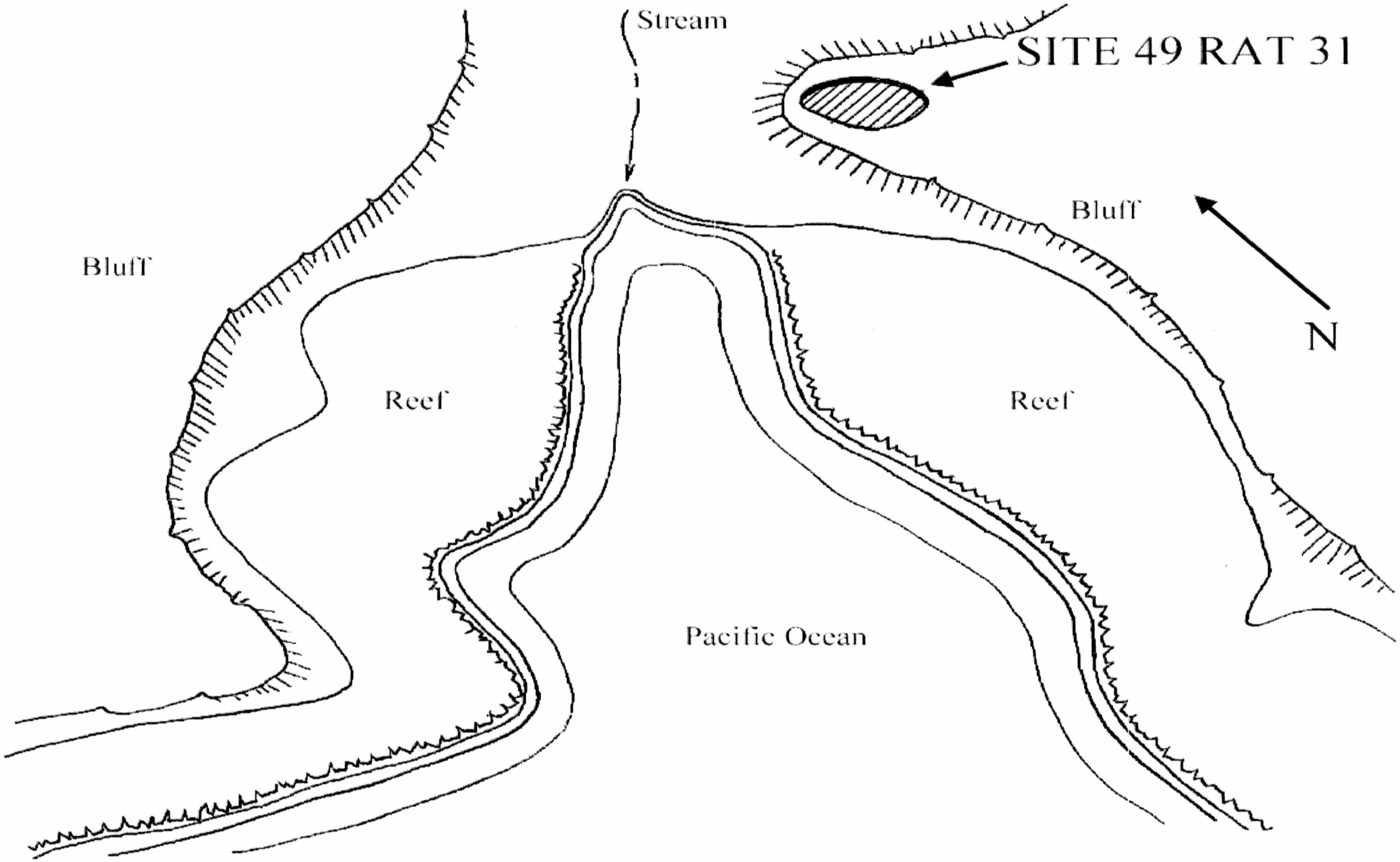

Figure 5.4: Site Map 49 RAT 31 (after Sense and Turner 1970: 135)

5.4 Site 49 RAT 36

Site 49 RAT 36, shown in figure 5.5, is a high elevation site 17 x 20 m located 15 m above sea level atop a bluff's edge (Kent 1984). RAT 35 is located just below the bluff and on a beach terrace and is considered an extension of the site. 49 RAT 36 contained the deepest midden of all of the recorded sites. Desautels et al. suggests the higher elevation sites endured seasonal storms and could be occupied year round: "the absence of driftwood or intermittent sterile sand layers indicated that the site was high enough above sea level so that even large storm tides did not reach the site" (1970:47). Additional description by Sense and Turner states:

> Food Resource Areas: A reef about 200 feet wide is exposed at low tide. A trout stream passes north of the site. The terrain behind the site is open, rising to the north. Driftwood: Abundant. Boat Landing: Open water leads to a cobble beach. Security: The site could easily be defended. The view is restricted to the cove. Relation to Other Sites: Site 35 is 450 feet to the west; site 14 is 0.8 miles to the SE (1970:165).

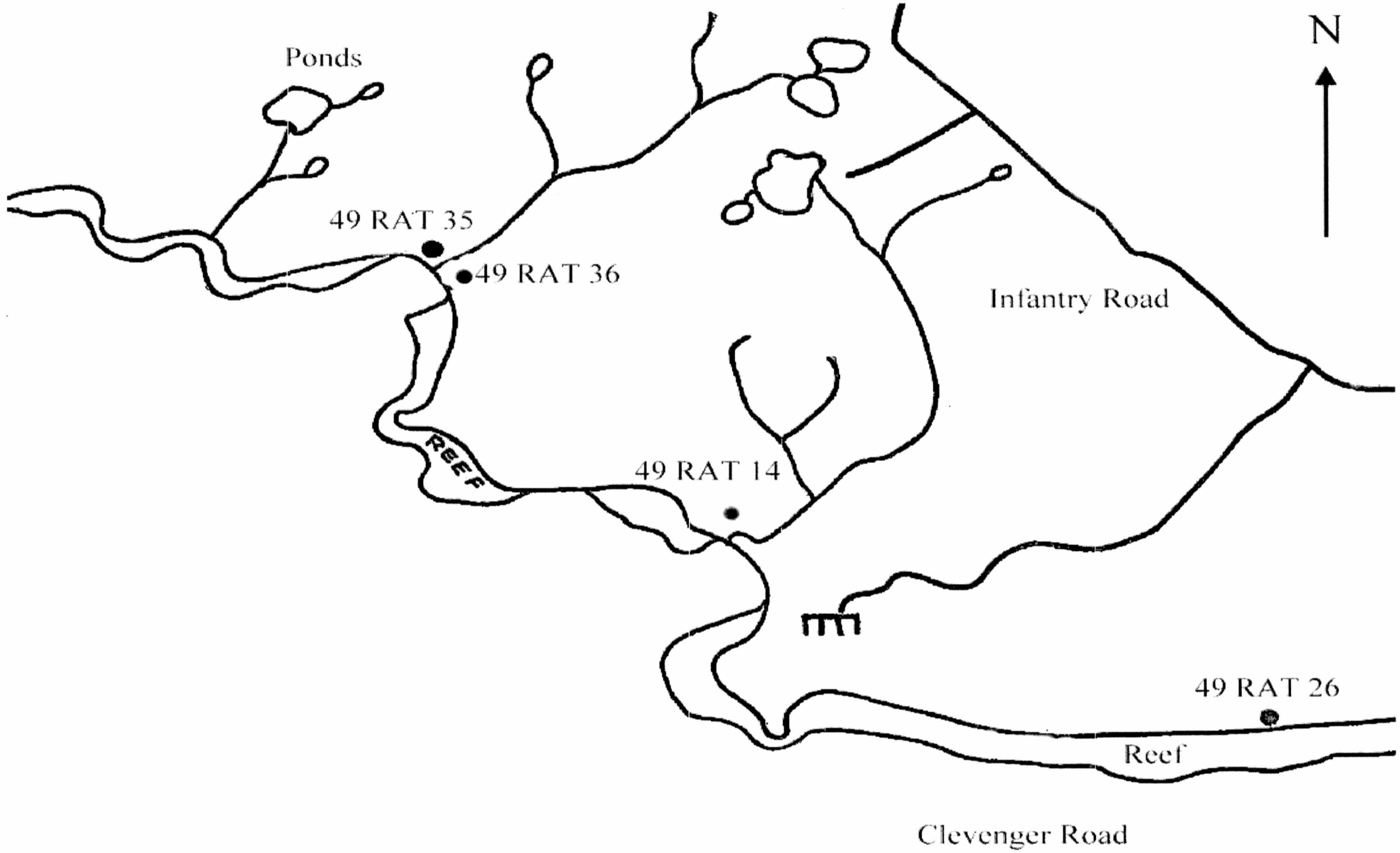

Figure 5.5: Site Map 49 RAT 36 (after Sense and Turner 1970:163)

5.5 Site 49 RAT 60

Site 49 RAT 60 is 25 x 40 m, located on the south shore of Amchitka Island. 49 RAT 60 shown in figure 5.6 is a prehistoric midden site with six semi-subterranean house features (Kent 1984). The site is located atop a high cliff approximately 24 m above sea level. The frequency of faunal and lithic materials suggests the settlement was occupied for extended periods. 49 RAT 60 is also one of the few sites showing little disturbance (Kent 1984).

> Food Resource Areas: A reef about 150 feet wide is exposed at low tide. The terrain behind the site is open with low hills. The ground rises to the east. Three large lakes are situated a short distance behind the site. Driftwood: Abundant. Boat Landing: Unknown. Security: The site could be defended. View restricted to the cove. Relation to Other Sites: Site 53 is 1.2 miles to the NW; site 59 is 1.8 miles to the SE (Sense and Turner 1970:261).

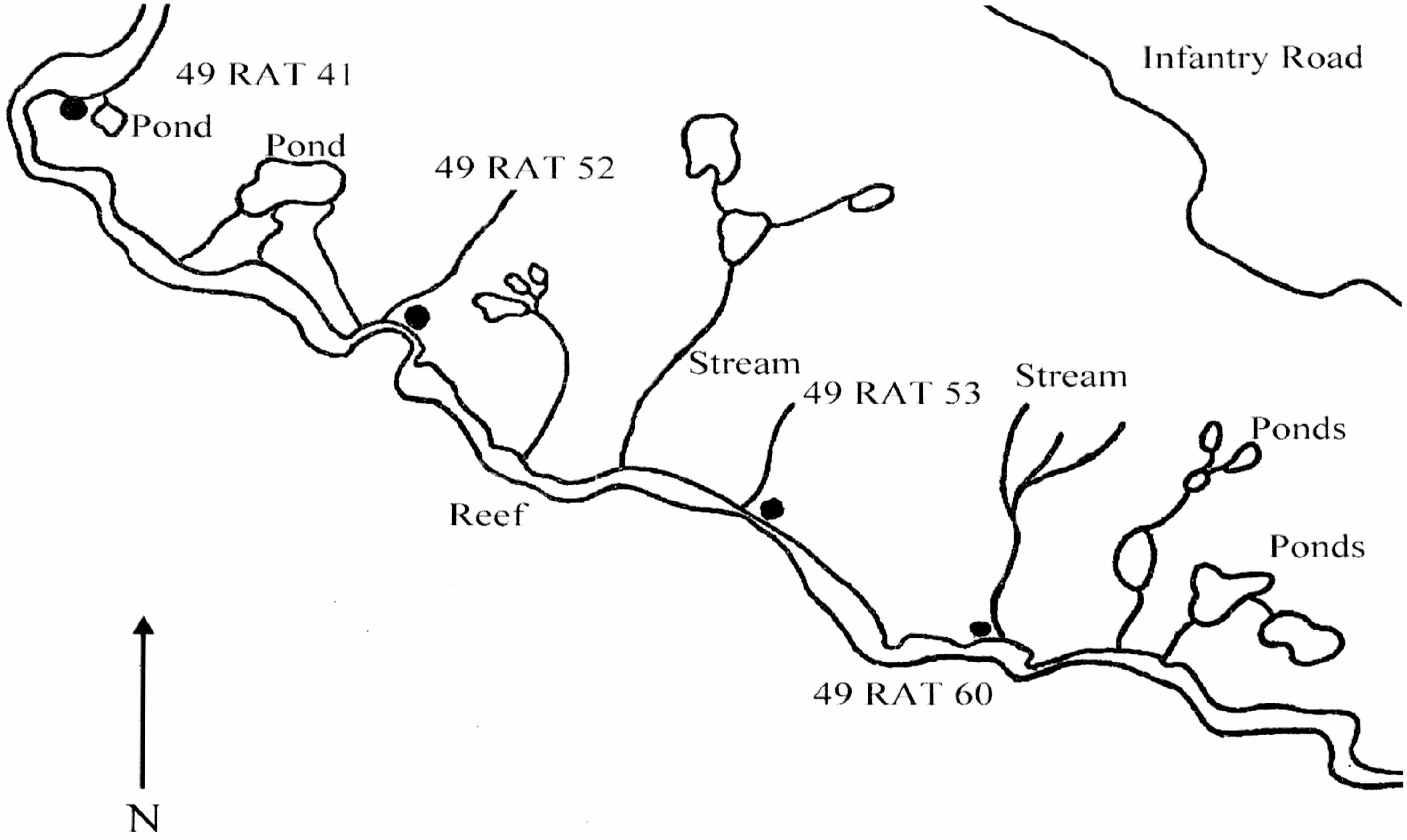

Figure 5.6: Site Map 49 RAT 60 (after Sense and Turner 1970:259)

5.6 Site 49 RAT 68

Site 49 RAT 68, represented in figure 5.7, is a midden site approximately 15 m in diameter. The site is located at the base of a storm terrace and contains a number of indiscernible features and a single house depression (Kent 1984). Previous investigation by Sense and Turner identified three more depressions possibly representing house pits (1970). The depth of the faunal remains indicates the long term occupation of this site (Kent 1984). However, the relative low elevation brings into the question of a seasonal occupation of this site.

> Food Resource Areas: A reef about 350 feet wide is exposed at low tide. The terrain behind the site is hilly. Relatively flat area on the elevated coastal plain is about 600 feet wide. Driftwood: Sparse. Boat Landing: A channel through the reef to the east leads to a cobble beach. Security: Easily defendable. A good vantage point is on a low hill about 250 feet to the east. Relation to Other Sites: Site 17 is 5.8 miles to the NW; site 67 is 5.4 miles to the SE (Sense and Turner 1970:293).

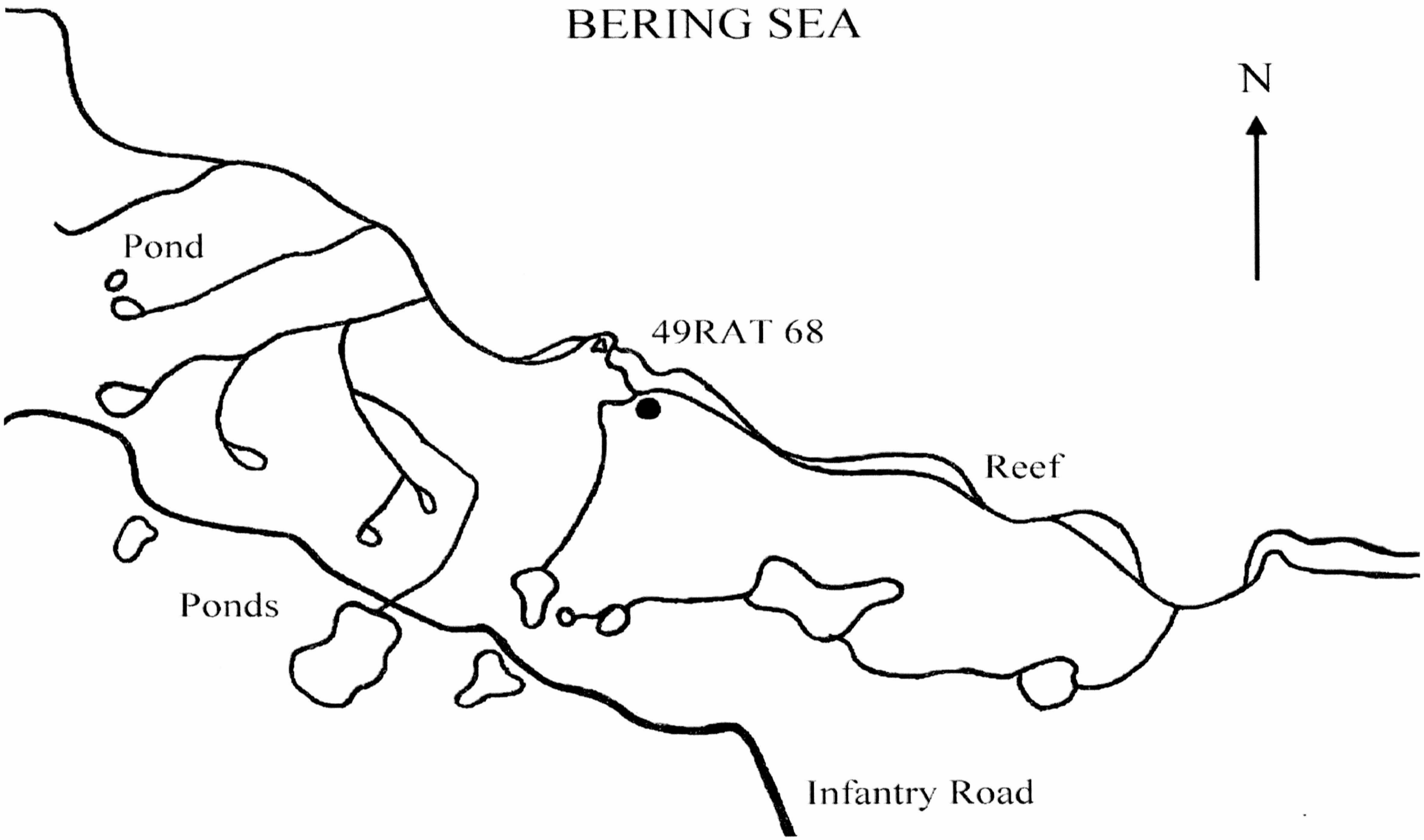

Figure 5.7: Site Map 49 RAT 68 (Sense and Turner 1970:259)

Chapter 6 Statistical Analysis

Statistical analysis for this study included the comparison of forty-nine characterized basalt artifacts selected from six previously excavated archaeological sites on Amchitka Island. The artifact distributions, shown in table 6.1, were selected from the collections located at the University of Alaska Museum. The elemental characterization acquired through XRF for each sample can be found in appendix 3.

Table 6.1: Artifact Sample Distribution

Archaeological site on Amchitka Island	Number of basalt artifacts (n)
49 RAT 60	10
49 RAT 02	10
49 RAT 36	7
49 RAT 31	7
49 RAT 10	7
49 RAT 68	8

There is a number of different multivariate descriptive statistics that can provide a low-dimensional representation of artifact compositional data (Baxter 2003). These include cluster, multidimensional scaling, principal components, discriminant, and correspondence analyses. From the statistical methods available, recent characterization studies (Cobry and Roper 2002; Creel et al. 2002; Descantes et al. 2002; Molyneaux 2002; Perttula 2002; Parks and Neff 2002; Rodrigues - Alegria 2002) have recognized the potential and utilized principal components analysis (PCA) to provide an accurate visual representation of the chemical variation between archaeological samples. Principal components analysis is an appropriate method for characterization studies because, it "can be a useful means of determining trends and / or relationships in a dataset, because it classifies multiple variables according to the principal components relative to the particular dataset" (Cobry and Roper 2002:159). One advantage in utilizing PCA, as opposed to discriminant analysis in characterization studies, is that PCA compares the elemental concentrations of uncorrelated variables, without requiring *a priori* group membership (Dunteman 1989). This means that the samples are initially plotted without regard to their geographic origins and are evaluated only on their chemical properties independent of any archaeological variables. This statistical approach is also applicable when provenance of material sources is unknown and may aid in determining if compositional groups can be found in the data. After plotting the data, each sample is assigned its archaeological origin and patterns / trends are sought within the data to see if groupings are also associated with archaeological variables of interest (Baxter 2003).

The data set was first analyzed using descriptive statistics to determine which elements contained the most variation between samples. Nine of the 23 elements contained relative standard deviations greater than 0.1 and the remaining 14 elements possessed standard deviations less than 0.1. The standards deviations of the elemental oxides Na_2O, MgO, AL_2O_3, SiO_2, P_2O_5, TiO_2, FeO, K_2O, and CaO represented the highest variation. To maximize the differences between samples, those elements possessing the least variation were removed. Elements excluded in the PCA were only present in a few of the samples of extremely low concentrations (i.e. .001 %). When compared to samples containing 0 % (or absence) of a particular element, the variation between samples would be insignificant. This does not suggest that the presences or absence of specific elements are insignificant. However, as previously discussed, the variation of elements containing .001 %, could be present or absent in a single sample analyzed under the selected detection limits. The removal of certain elements is typical if the operating conditions do not permit lower detection of certain elements (Baxter 2003). If the operating conditions for the samples were run under longer scanning times, detection of lower level elements would have allowed for their inclusion in the PCA analysis. Unfortunately, cost and time factors did not permit the longer scanning conditions. Working with the parameters of the XRF protocol, the ten elements showing the greatest variation between samples ($x > .01$) are the most appropriate for discrimination between samples using PCA.

6.1 Principal Components Analysis

Two figures are used from PCA to illustrate the relationships between the basalt samples. Figure 6.1 illustrates the forty-nine basalt samples plotted on the first two principal components. The first two components represent 76 % of the total variation between samples. The biplots illustrated in figure 6.2, depicts the elemental distribution within the proximity matrices of components 1 and 2. Several important things can be inferred based on the distribution of elements on the biplot matrix (Baxter 2003). If the analysis was conducted correctly, all of the elements distributed in the matrix should approximate a circle. The biplots also determine which elements are more apparent in the

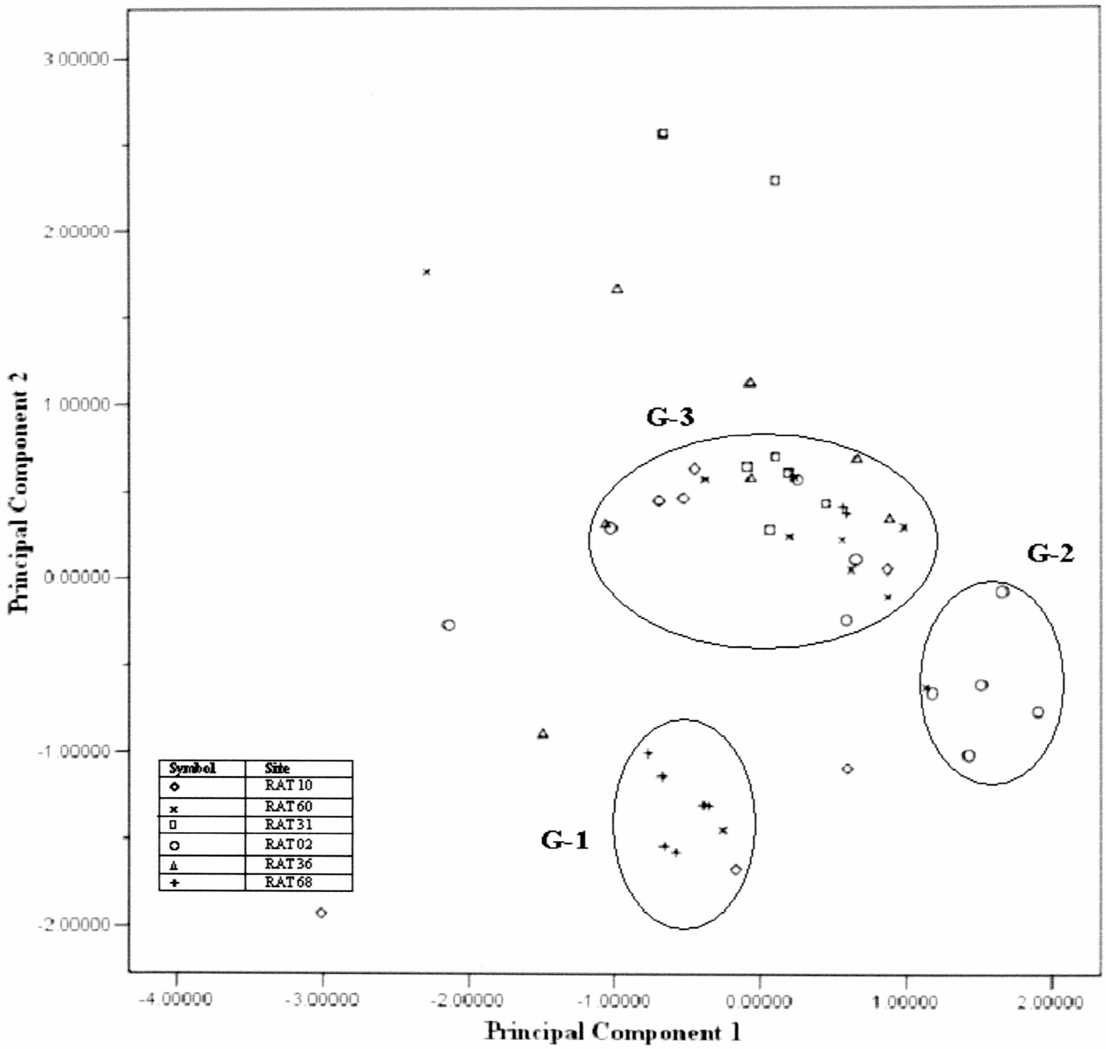

Figure 6.1: Principal Components Analysis

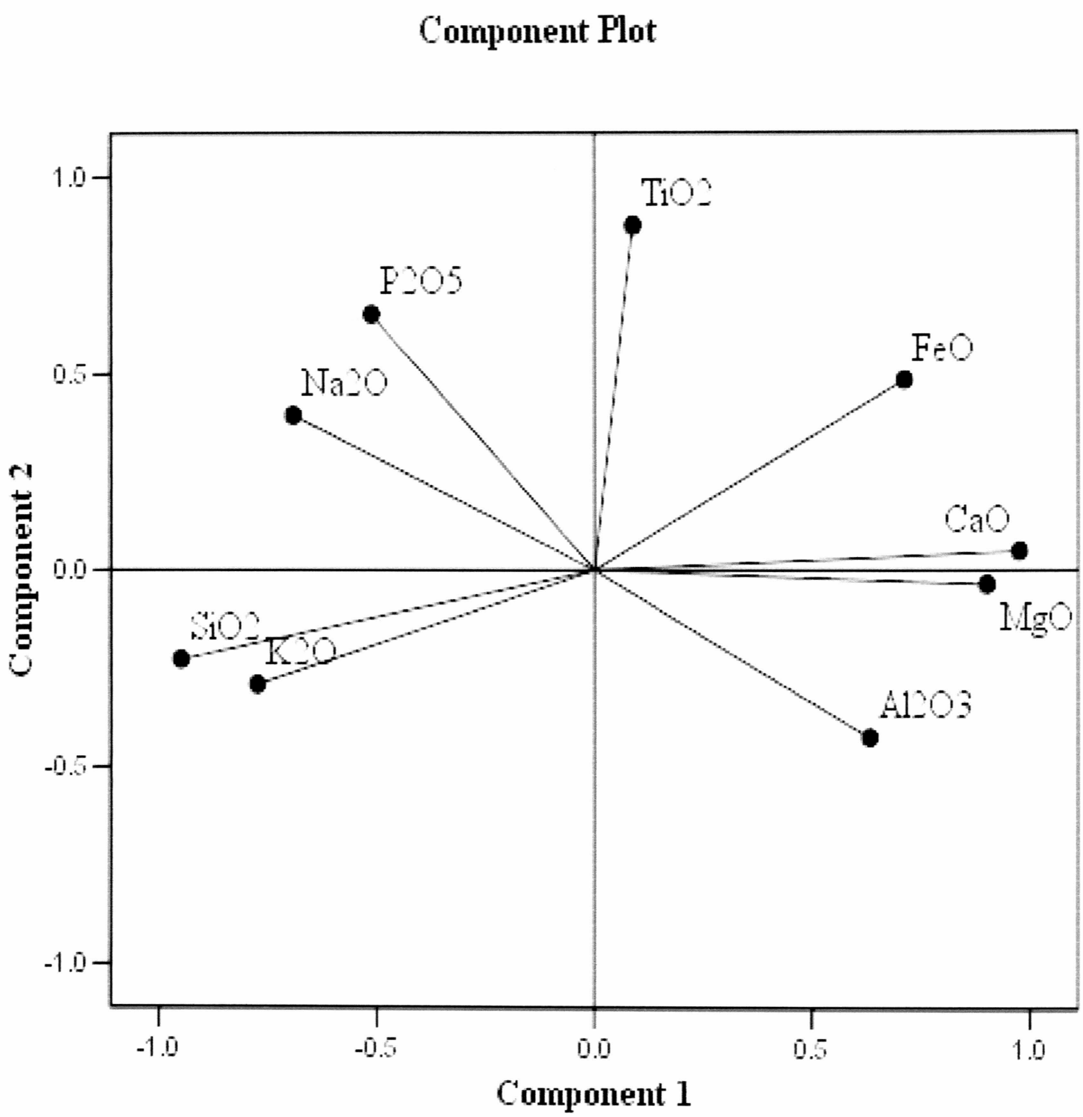

Figure 6.2: Loading Plots

samples. Comparing the samples to the loading plots provides a visual representation of which elements are driving the variation discriminating between samples.

The defined groups for this study are treated as tentative basalt sources. Group boundaries based on a diminutive sample size are subject to change with the incorporation of additional samples. There are nine outliers and at least three distinct groups. Grouping parameters are defined by interval levels for each component. Group 1 (G-1) and group 2 (G-2) approximate a 1.00 interval for each components 1 and 2. Group 3 (G-3) was defined using a 2.00 interval for components 1 and 2. The interval scale for G-3 was selected because the samples included in this area are too closely dispersed to create a more precise boundary. I could have separated G-3 into two separate groups drawing a distinction between the 0.00 X axis of component 1. However, there are insufficient data pertaining to the chemical variation of basalt sources on Amchitka Island to allow additional distinctions. Although I am treating this area as a single group, I will discuss possible sub-grouping and their implications when comparing the samples to the biplots.

6.2 Synopsis

After plotting and grouping the samples, I reassigned their archaeological site values to identify any possible patterns within the groups. The sample distribution is summarized in table 6.2. G-1 contains a total of eight artifacts, six of which originate from 49 RAT 68, one originating from 49 RAT 10, and another from 49 RAT 60. Characterization of this group includes samples possessing lower compositions of silicon and potassium dioxide. G-2 contains six samples, five of which originate from 49 RAT

02 and one from 49 RAT 60. This group can be characterized containing higher levels of calcium, aluminum, and magnesium oxides. There are a total of nine outliers. Although they are termed outliers in this study, they are from sources that are not significantly represented by the samples. When compared to the biplot data, these samples possess extremely higher or lower percentages of various elements making them altogether chemically different when compared to the other samples.

Table 6.2: Groupings Based on Components 1 and 2

49 RAT	Grouping # (G-1)	Grouping # 2 (G-2)	Grouping # 3 (G-3)
10 n =	1	0	4
02 n =	0	5	4
31 n =	0	0	5
36 n =	0	0	4
60 n =	1	1	7
68 n =	6	0	2

G-3 contained 26 samples, including at least one sample from each archaeological site. Characterization for this group includes two distinct subgroups. The artifacts falling into the negative side of component 1 (left of the 0.00 on the X axis) contain less variability in phosphorus pentoxide and sodium dioxide. Those samples to the right of the 0.00 axis of component 1 contain higher variation in calcium and iron oxides, and titanium dioxide. Although there are chemical differences within G-3, they are subtle and cannot be accurately subdivided without additional samples or sourcing information. If I had decided to divide G-3 using a 1.00 interval to create two separate groups, those samples falling within ± .02 of 0.00 on component one would have been considered different sources. However, there is no evidence in the data to validate or refute such a division. Wide variation within a single basalt source is one possible explanation for the variation in samples within G-3. An alternative explanation is there are multiple basalt sources containing slightly similar chemical variations. For these reasons and because there is no way to test either hypothesis with the current data, G-3 was grouped as a single cluster rather than attempting to create further distinction within this cluster. One way to increase the resolution within G-3 and allow for further division is by increasing the number of samples characterized from the sites. If additional samples from RAT 10, for example, are collected, processed, and plotted, they may fall close but outside the boundary of G-3, which would increase the boundary or may be distinct enough to create two groups.

One interesting pattern observed within G-3, is the relative grouping of samples from the same archaeological sites. While it is more evident in G-1 and G-2, closer examination of G-3 revealed similar clustering. For example, RAT 31 (represented by a square) has five samples within close proximity of one another all near the 0.00 axis of component 1. Another example can be seen with RAT 10 (represented by a diamond) where three of the samples all have higher concentrations of phosphorus pentoxide and sodium dioxide. The correlation of chemically similar samples deriving from the same archaeological sites observed in G-1, G-2, and to a lesser extent, G-3, supports procurement from a homogeneous basalt source(s).

Comparing the samples to the biplot matrix identifies where the chemical variation occurs and which artifact samples contain more or less of the different element oxides. The application of PCA also provides the necessary information to evaluate the efficacy of XRF as a characterization tool for basalt materials commonly found on Amchitka Island.

6.3 Efficacy of XRF

I argue that the statistical examination of the characterized basalt samples presented in this thesis supports the efficacy of XRF as both an efficient and appropriate research tool for the characterization of basalt artifacts on Amchitka Island. Using PCA as a method to discriminate between artifact samples, it is clear, based on the plotting of components 1 and 2 that chemical differences exist between basalt samples found in archaeological sites on Amchitka. The additional characterization through the comparison of the biplots of components 1 and 2 describe which elements represent the variation between samples. The emergent patterns of the grouping in the component matrix in relationship to archaeological sites, suggest that basalt procurement sources utilized by the prehistoric occupants of the settlements may in fact possess a unique chemical signature for potential source isolation. The graphical plotting through PCA also reveals that there is a relationship between the chemical characterization of samples and archaeological sites. This relationship can be seen in G-1, G-2, and to a lesser extent G-3.

Characterization studies of basalt materials have flourished in a number of geographic areas including adze studies in Polynesia (Weisler 1997, 1998, 2002) basalt quarry analysis in the Hawaiian Islands (Bayman and Nakamura 2001; Weisler 1990a, 1990b), and procurement, function, and quarry sourcing in Egypt (Greenough and Mallory - Greenough 2001; Mallory - Greenough and Greenough 2004; Mallory - Greenough et al. 1999, 2000). Although it has taken a number of years to accumulate enough compositional data to draw inferences pertaining to prehistoric exchange and interaction in these areas, the data presented in this thesis has demonstrated the first successful application of characterizing basalt materials in the Aleutian Islands. With each successful application of XRF in the Aleutian Islands, a continuous chemical database of artifact materials will grow and eventually, may allow for an inter-island or pan-Aleutian comparison of lithic raw material procurement. Only after archaeologists have a relative idea of the spatial distribution of lithic materials and sources on the landscape will we be able to test the models of exchange and draw inferences about the prehistoric inhabitants of the Aleutian Islands. While small sample size and absence of basalt sourcing samples prohibit testing of exchange models in the study of Amchitka Island, there are some general hypotheses that may be inferred from this study for further inquiry.

Chapter 7 Archaeological Significance of the Data

This characterization study was a necessary first step to exploring and understanding lithic material procurement of basalt artifacts in the Aleutian Islands. There are approximately 3,700 basalt artifacts identified[5] in the six archaeological sites examined in this thesis. Characterization of forty-nine artifacts makes up less than one percent of the basalt materials available for analysis. This sample size, while appropriate for the evaluation of the efficacy of XRF, is not adequate enough to test exchange models used to draw specific inferences into the nature of material transactions between prehistoric peoples on Amchitka Island. Although there is not enough data characterized to draw specific inferences into procurement methods, there are general conclusions that may be inferred from the emergent trends in the similarities of basalt samples identified in the principal components analysis. These conclusions are presented as sets of hypotheses with the hope they will provide direction for future characterization studies of basalt materials in the Aleutian Islands.

7.1 Hypotheses Summary

The first set of hypotheses addresses the potential location of basalt sources on Amchitka Island. If characterization of basalt quarries / sources can be achieved on Amchitka Island, then archaeologists will gain a better understanding of the chemical variation that exists within these sources. This will aid in determining more precise groupings of archaeological samples that have been characterized and perhaps lead to

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[5] Total number of calculated basalt artifacts from the six archaeological sites derived from the catalogues located at the University of Alaska Museum.

linking specific artifacts to geologic sources. The second set of hypotheses pertains to exploring general interaction between the selected prehistoric sites on Amchitka Island, inferred through the descriptive statistics examined in this thesis.

The hypotheses presented in this chapter are summarized as follows:

(1) Basalt source G-1 lies within proximity to 49 RAT 68.

(2) Basalt source G-2 lies within proximity to 49 RAT 02.

(3) G-3 is a single source possessing wide chemical variation or

(4) G-3 contains multiple sources chemically similar.

The hypotheses pertaining to exchange and interaction are summarized as:

(1) Prehistoric people of Amchitka Island were exploiting and procuring lithic raw materials from multiple sources.

(2) Prehistoric occupants of 49 RAT 10, 60, and 68 participated in exchange or interacted, based on the chemical similarities of basalt artifacts and distance between archaeological sites and potential geologic sources.

(3) 49 RAT 02 and 60 participated in exchange or interacted based on the distance between sites and potential sources and chemically similar artifacts.

7.2 Basalt Sourcing Hypotheses

The hypothesis for the prospective locations of basalt sources on Amchitka Island are based part of the principles governing the law of monotonic decrement which states:

> Finds are abundant near the source, and there is a fall-off frequency or abundance with distance from the sources.... Frequencies of occurrence declines with distances. That this should be so is not unduly surprising,

> since, in general, the transport of goods from a sources requires input of energy and, other things being equal, the greater the distance the greater the energy input (Renfrew 1984:136).

This rationale, when applied to the observed patterns in the PCA, suggests that the abundance of samples from particular archaeological sites may have the potential to lead archaeologists to the sources from which the material derived. 1) Prehistoric peoples at 49 RAT 68 were exploiting G-1 more often than any other group under study, suggesting that access and procurement of this source may be the result of a close proximity to the archaeological site. To further validate this hypothesis, basalt source sampling within proximity to 49 RAT 68 would need to be conducted and tested against the data from this study. 49 RAT 68 is located in a geologic region dominated by andesite providing a low frequency of potential basalt sources in the area. 2) 49 RAT 02 represents the majority of samples from G-2, suggesting potential location of this source may be located around the vicinity. Similar to 49 RAT 68, 49 RAT 02 is also located outside the USGS defined basalt region; instead lying in glassy pillow lava & breccias regions. This in turn, should lower the number of prospective basalt sources in this area.

The chemical diversity in the samples within G-3 presents two alternating hypotheses. G-3 may be explained 3) as a single material source containing wide chemical variation or 4) multiple sources containing similar chemical variation. To evaluate the hypothesis and its alternative, an increase in sample size of characterized artifacts would likely produce a better resolution of scale for components 1 and 2. As previously mentioned, one of the current limitations in this study is the uncertainty of variation within a given basalt source on the island. If multiple sources are characterized and the sources are all relatively chemically similar then it refutes a hypothesis of a single source containing wide variation. In contrast, if sources are chemically different, then it would be more likely that G-3 is a single source containing wider variation. The identification of potential sources is necessary to trace the artifacts derived from the archaeological sites to a stationary geologic source. If this can be accomplished, then the additional hypotheses pertaining to exchange and interaction can be further evaluated.

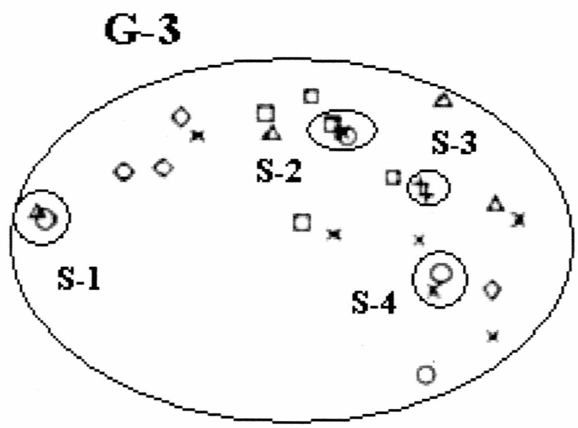
7.3 Exchange and Interaction Hypotheses

The presence of chemically similar basalt artifacts found in archaeological sites located in different geographic locations on the island suggest that peoples in these settlements were somehow circulating basalt material. Circulation of materials can include direct procurement, exchange, trade, or any other method of sharing of basalt materials originating from the same geologic sources. Although it is out of the scope of this study to identify which method of procurement accounts for the spatial distribution of artifacts observed through PCA, the chemical matching of basalt artifacts does reveal something into the nature of the inhabitants of the selected archaeological sites in regard to interaction on Amchitka Island. This may seem to belabor an already obvious human behavior given the relatively small size of the island and human nature to interact. However, there are 78 archaeological sites on Amchitka Island. Without any data analysis, how does one argue between which prehistoric settlements on the island interacted? These hypotheses have been formulated to identify specific sites which through this study, presented artifacts possessing chemically similar basalt samples and may be appropriate candidates for future archaeological comparison and exchange model testing. Discussion into some of the implications of these hypotheses is reserved for the discussion section.

1) Prehistoric peopling occupying different geographic parts of Amchitka Island were procuring basalt from multiple sources. This hypothesis is supported by the wide chemical variation between the different groups and the intermixing of artifact samples from the archaeological sites. 49 RAT 02 containing artifacts derived from G-1 and G-3 suggests, that although there may have been sources exploited more frequently than others, material from more than one basalt source were being procured by prehistoric peoples occupying 49 RAT 02.

There are beginning trends observed within G-1 and G-2 indicative of interaction between prehistoric peoples on Amchitka Island. Each group is dominated by artifacts from a single archaeological site with the exception of one or two artifacts from another site. 49 RAT 10, 60, and 68 all contain artifacts characterized within basalt source G-1. While the presence of a single artifact from 49 RAT 10 or 60 is not adequate for formulating a strong argument of interaction; it does allow for some discussion about the prospect of interaction taking place between the inhabitants that occupied these three sites. These sites are geographically dispersed, where 49 RAT 10 is located in glassy pillow lava & breccias region and 49 RAT 68 is located in a region dominated by andesite. The only site within a basalt geologic region is 49 RAT 60. This suggests these chemically similar samples were circulated between these groups over distances measuring approximately half the island. 2) The prehistoric inhabitants of these three archaeological sites were interacting via participation in procurement of basalt materials from the same source. Further characterization of basalt samples and comparison of other lithic materials from these sights may lead to a stronger linkage between the sites.

Similarly, G-2 is comprised of mostly 49 RAT 02 artifacts and a single artifact from 49 RAT 60. Unlike the one or two sample similarity between those archaeological sites in G-1, there are a number of cases strengthening the likelihood of interaction between 49 RAT 02 and 49 RAT 60. I wish to draw attention to four specific overlap of samples occurring in G-3. Although the parameters for defining the boundaries of G-3 may change with the addition of more samples, the chemical overlap in signatures of these specific samples should maintain relatively similar. Illustrated in figure 7.1, a number of basalt samples overlap one another from different archaeological sites.



Symbol	Site
◇	RAT 10
×	RAT 60
□	RAT 31
○	RAT 02
△	RAT 36
+	RAT 68

Figure 7.1: Group 3 Sample Overlap

An overlap indicates their chemical signatures are almost identical. One of the overlapping samples is comprised of two artifacts from 49 RAT 68 (S-3). It is not unusual for a site to procure multiple lithic raw materials from a single source. However, the three of particular interest are the overlaps from different archaeological sites. 49 RAT 60, 31, and 02 (S-2) has one sample each which are closely chemically similar. 49 RAT 36 and 02 (S-1), and 49 RAT 02 and 49 RAT 60 (S-4) also have another sample of similar composition. These specific instances are evidence directly linking two, or in some cases, three archaeological sites based on basalt artifacts sharing similar chemical properties. This provides a better idea of which settlements were interacting, whether through trade, exchange, or direct access to the resources. All of the overlap contains samples from 49 RAT 02. G-2, composed of mostly 49 RAT 02 samples, has a single sample from 49 RAT 60. This represents three cases from which 49 RAT 60 and 49 RAT 02 has samples which are chemically similar. Taking all of the artifacts similarities between these two sites into account, I propose a hypothesis that 3) 49 RAT 02 and 49 RAT 60 interacted most likely through exchange or sharing of basalt materials. The geographic distance between sites seems too distant for direct procurement. It would appear more plausible that procurement of basalt materials from these sources manifested as exchange or trade. To further support or refute this hypothesis, additional lithic materials originating from the two archaeological sites could be compared to identify prospective patterns indicative of exchange and trade.

Chapter 8 Discussion and Conclusion

The data presented in this thesis does not permit testing of prehistoric exchange models. However, discussion of the implications of those hypotheses directed towards exchange and interaction on Amchitka Island will permit examination of some of the possible explanations that could account for how basalt materials may have been circulated between the settlements on Amchitka Island. Three factors of the data analysis presented in this thesis greatly constrain the degree of speculation. I use the term speculation over interpretation for this discussion because the explanations are based on logical deductions of human behavior rather than over interpretation of a relatively small data set, the first constraint. In most cases only a few artifacts from each archaeological site contained chemical similarities at any given prospective geologic source.

Secondly, the geologic sources have not been identified on the landscape. Many interpretations in prehistoric exchange studies utilize distance between archaeological sites and geologic sources to identify control over resources and trace origins (Renfrew 1984). Lack of geologic source information prohibits inferences between prehistoric settlement controls over basalt resources on Amchitka Island. The basalt source locations proposed in the hypotheses are integrated into the discussion to exemplify the importance of identifying procurement sources for future studies of exchange and interaction on Amchitka Island.

The third factor is how the lack of temporal controls obfuscates prospective patterns in the archaeological record on Amchitka Island. The patterns observed in the archaeological record are the result of numerous transactions over a period of thousands of years. Although the similarities between relative depths of archaeological remains and the presence of semi-subterranean house pits provide evidence of contemporaneous long-term occupation settlements; additional research and radiocarbon dating is required to further substantiate this claim.

Despite these limitations, it is important to recognize the spatial distribution of basalt artifacts on Amchitka's landscape as the result of human activities, such as exchange and direct procurement. While these procurement strategies can be separated for analytical reasons, in reality, all of them likely occurred on Amchitka Island. These scenarios demonstrate how multiple methods of procurement can manifest similar spatial patterns on a landscape. Given a small data set from a confined geographic setting and large temporal range, it is not possible to identify specific types of exchange and interaction on Amchitka Island with the current data set. The spatial distribution of lithic materials present in the archaeological sites on Amchitka Island are the result of countless transactions, procurements, and events between different peoples accumulating over thousands of years.

For purposes of discussion, the settlements are treated as independent groups governed by chiefs who maintained territorial boundaries, access, and procurement of resources. It has been suggested (Black 1981; McCartney and Veltre 1999) that social complexity in the Aleutians was comparable to village settlements, each having an elite, or chief of noble rank. This degree of complexity implies leadership presiding over the individual settlements who maintained access and control over particular resources. It is within this social context that examination of two general forms of exchange and interaction may have occurred on Amchitka Island.

The two explanatory forms of material procurement addressed are exchange and direct access. Speculation into these procurement strategies provide insight into interactions that could result in the observed spatial distribution of the basalt data from Amchitka Island. Second, this discussion demonstrates some of the complexities of addressing exchange and interaction on a local scale. Transactions occurring through long-distance exchange are lower in frequency compared to local exchange because of the difference in distance between settlements and the sources. The differences in frequency are reflected in the appearance of the materials in the archaeological record and therefore, make identifying specific types of exchange more difficult. Often times in prehistoric exchange studies, "different exchange mechanisms produce similar patterns of artifacts in the archaeological record" (Renfrew 1984). As with the case of Amchitka Island, it is important to recognize co-occurring interactions can equally explain the observed patterns from which the hypotheses are derived.

The two hypotheses relating to exchange and interaction between settlements on Amchitka Island are: (2) Prehistoric occupants of 49 RAT 10, 60, and 68 participated in exchange or interacted, based on the chemical similarities of basalt artifacts and distance between archaeological sites and potential geologic sources and (3) 49 RAT 02 and 60 participated in exchange or interacted based on the distance between sites and potential sources and chemically similar artifacts. These hypotheses are used to exemplify how the current data set can be explained in multiple ways and how future studies may progress to test and potentially refute some these explanations. The steps provided are one possible strategy for further research of the hypotheses presented in this thesis.

The first explanation is **exchange** between the inhabitants of the settlements where the transfer of actual commodities (basalt materials) occurred. The prehistoric inhabitants of Amchitka could have exchanged basalt materials at a number of locations including the quarry / source, settlements, or anywhere in between. The exchange could have been prearranged or a chance meeting. The settlement closest to the geologic source may have had control over the source and distributed materials between the two settlements in exchange for other commodities. This method is also referred to as directional exchange (Renfrew 1984). Another possibility is that the settlement closest to the source may have only exchanged with one of the groups, who in turn, exchanged with the third group, referred to as down-the-line exchange (Renfrew 1984). In long-distance exchange studies, each of these different transactions can be quantified based on material presence and distance (Renfrew 1984). One factor that makes quantification of the spatial patterns possible is distance between archaeological sites and geologic sources. The probability of the group farthest away directly procuring materials from a source hundreds of kilometers away is possible, but not as likely when compared to a small circumscribed location involving procurement of local materials.

Amchitka is a small island, where sources and sites are only kilometers away, introducing the prospect of direct procurement or access to resources. Because Amchitka is an island and the inhabitants were adept in seafaring technology, the method of procurement may have been accomplished by traversing the island by foot or by watercraft. Each of these types of mobility must be considered when examining local exchange, particularly through direct access, because procurement via watercraft may have higher weight capacities than by foot, increasing the amount of material that may be procured. Sources located on terrain difficult to traverse by foot may have been less strenuously accessed with the aid of watercraft. These possibilities may skew any type of regression analysis used in long-distance exchange. Aside from the different types of mobility there are also a number of interactions that may have occurred in the process of direct material procurement.

The second explanation is procurement through **direct access** to basalt sources. In this scenario, the prehistoric inhabitants of Amchitka Island were directly procuring materials from basalt sources. This scenario is not necessarily indicative of exchange of a material commodity; however, I argue interaction, defined in this study to encompass nonmaterial exchanges of "ideas, beliefs, and information between members of different corporate groups" (Odess 1998:417), was occurring through direct procurement. Direct access to materials without permission, within the previously stated social context, would not have been likely. Direct procurement either with or without permission, may still lend itself to interaction. Peaceful crossing of territorial boundaries involves interaction through communication with those in control and those who wish access of the resources. Direct procurement without permission may have led to territorial conflicts and acquisition of resources by force. The resulting warfare or disputes is another type of interaction. The importance of whether procurement occurred through material exchange or direct access is that both may result in interaction between inhabitants of the settlements on Amchitka Island.

8.1 Suggested Steps for Future Testing of Hypotheses

While it is difficult to identify methods of material procurement on a local scale, there are research steps that may provide a stronger argument of exchange between inhabitants of the settlements. These steps are designed to increase the connections between archaeological sites and geologic sources. By connection, I mean a reoccurring pattern in a data set linking either archaeological site with one another, or with a geologic source. If connections through material remains can be established between archaeological sites, then it will increase the likelihood that the prehistoric inhabitants at these sites interacted. The more materials are linked between archaeological sites, the stronger the association and likelihood of exchange and interaction between peoples of Amchitka Island.

To further examine hypothesis (2), the first step is to establish the location of basalt source G-1. If G-1 is located in relative proximity to RAT 68 then additional specimens from RAT 68 and G-1 can be chemically compared. If chemical similarities are found between samples then it will create a stronger link between source and settlement. The second step is to increase basalt sample sizes from all three archaeological sites and chemically compare the samples. This may reveal additional basalt sources and / or provide more samples connecting the sites and G-1. The third step is to incorporate additional lithic materials from the archaeological sites. Other prospectively exchanged lithic materials such as chert, steatite, opal, and perhaps pumice should be introduced into future research studies on Amchitka Island. Exchange and trade often times involve transactions of multiple commodities and materials.

To test hypothesis (3), the first step would be identify basalt sources G-2 and G-3. If the sources are within proximity to RAT 02 or RAT 60, further research of the material remains of the site closest to the source, part of step 2, may provide information into control over the basalt source. Once the sources can be connected to the sites closest in proximity, the additional steps suggested for hypothesis (2) can be explored.

If exchange were occurring at the basalt source then it is important to identify the location on the landscape along with its associated archaeological remains. When the location is identified, if large amounts of lithic material waste are abundant at the source, then it is possible this location was a workshop / quarry site. This would support an argument of exchange or direct procurement taking place at the geologic source.

In contrast, if the geologic sources are identified, sample size is increased, and the sites closest to the source contain the highest percentage of material then it may be argued that the material was procured by one group and distributed from a settlement to other groups. In all of these scenarios an increase in sample size and isolation of geologic sources are necessary to further identify which procurement strategies may have been more prevalent on Amchitka Island.

The preliminary evaluation of the research tool and data analysis presented in this thesis, combined with the available data on Amchitka Island, present future researchers with a foundation from which to further explore exchange and interaction in the Western Aleutians. The best approach for presenting an argument of exchange between prehistoric inhabitants on Amchitka Island is by identifying which exchange modes or models can explain the observed pattern form the data set. Once enough samples are compared and basalt quarries are identified then it may be possible to eliminate some of the modes until only a few possibilities remain. It is only at that time when the speculations presented in this thesis may become an interpretation of future studies to test.

8.2 Considerations for Future Research

Future researchers can support or refute material procurement through exchange and direct access by addressing the hypotheses, increasing the sample size, and identifying the geologic sources from which they are derived. If additional basalt samples are analyzed and chemical similarities are identified, it would strengthen association between archaeological sites and geologic sources. If geologic sources are collected and linked with archaeological sites closest to the source then it may be possible to examine different aspects of general interaction.

Although this study demonstrates a successful application of elementally comparing basalt samples with the aid of XRF as a characterization method, it also identifies some of the limitations and potential problems that must be weighted if future studies are to take place. These include 1) producing an adequate sample size through destructive analysis 2) temporal and spatial considerations for the data available on Amchitka Island, and 3) geographic scale: difficulty in applying long-distance exchange models to a local circumscribed area. These issues should be considered and addressed by future researchers interested in prehistoric exchange studies on a local scale utilizing similar methodologies used in this study.

For the preliminary evaluation of the efficacy of XRF as a research tool for the discrimination of basalt commonly found on Amchitka Island, 49 basalt samples were adequate. As stated earlier, this study utilized less than 1% of the available 3,700 basalt artifacts from the six selected archaeological sites. A representative sample size varies depending on the researcher's questions. For example, if geologic specimens are collected for XRF analysis, a larger sample size from each archaeological site would be needed for comparison to strengthen an argument linking archaeological sites to the geologic source. If an increase to 60 basalt artifacts per site was necessary for this analysis, I would need 360 basalt artifacts. This would increase the sample size from approximately 1% to 10% of the total available samples. Because of the destructive nature of the analysis, future researchers need to assess whether *the analysis is worth the destruction of large portions of archaeological resources*. This can be done by examining the potential of what information may be gained from the destructive analysis versus what the artifact can yield in its entirety. For this study the dimensions of each artifact was documented prior to destruction. However, changing technologies may require certain unforeseen variables that may be lost upon destruction.

Another problem involves the large temporal range within a relatively confined spatial location on Amchitka Island. Although the lithic landscape is well studied on Amchitka, Island, the lack of temporal controls limit isolating instance of specific types of exchange and interactions. As examined in this discussion section, there is also the question of what types of interaction in a local environment can be identified given the close proximities of archaeological sites and geologic sources. This is part of the third problem relating long-distance exchange models on a local scale.

There are different types of exchange and interaction that would be expected to occur in a local versus long-distance geographic setting. The nature of interaction between two peoples of great distance would be less frequent than two settlements only kilometers apart. While certain components or characteristics of long-distance exchange models may be extrapolated and applied on a local scale, it may be more appropriate to create new models specifically designed in inferring exchange and interaction from a local scale.

8.3 Conclusion

This thesis establishes the efficacy of X-Ray fluorescence as a research method for characterization of basalt artifacts commonly found in the Aleutian Islands. The plotting of the characterized data on the first two components using principal components analysis demonstrated the data set obtained through XRF can be discriminated. The discrimination allowed for the chemical comparison and matching of basalt specimens derived from six archaeological sites on Amchitka Island. The chemical similarities between archaeological specimens provided evidence which was used in the formulation of hypotheses. The hypotheses derived from this study were designed to encourage future research in the Aleutian Islands.

I argue that the statistical examination of the characterized basalt samples presented in this thesis supports the efficacy of XRF as both an efficient and appropriate research tool for the characterization of basalt artifacts on Amchitka Island. With each successful application of XRF in the Aleutian Islands, a continuous chemical database of artifact materials will grow and eventually, may allow for an inter-island or pan-Aleutian comparison of lithic raw material procurement.

While small sample size and absence of basalt sourcing samples prohibit testing of exchange models in the study of Amchitka Island, the general hypotheses inferred from this study provides specific sites and tentative geographic source locations for further inquiry. The presence of chemically similar basalt artifacts found in archaeological sites located in different geographic locations on the island suggest that peoples in these settlements were somehow circulating basalt material. The discussion of some of the possible explanations of how basalt materials were circulated exemplifies some of the complexities that arise in examination of local exchange and interaction and possible steps to further address types of exchange on Amchitka Island. The differences between prehistoric long-distance and local exchange requires further development into models considering the possibilities of direct access.

This thesis has provided the first steps in validating a research tool, providing hypotheses for future inquiry, and discussing some of the potential problems that may arise in futures studies of lithic raw material procurement on Amchitka Island. The next steps involve addressing the potential problems presented in this thesis and expanding the scope of research to incorporate more samples, identify geologic sources, and additional lithic materials. Only after more evidence is provided linking archaeological sites to one another and their respective geologic sources, will speculation have the potential to become inference addressing local exchange and interaction on Amchitka Island.

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Appendix 1: *PANalytical* Application Specifications

Application - IQ+ 27mm Vac							
Total Time	**909 (seconds)**						
No.	**Energy range**	**Crystal**	**Collimator**	**Detector**	**Tube filter**	**Start angle**	**End angle**
						(°2T)	(°2T)
1	Te-Ce	LiF 220	150 μm	Scint.	Brass (100 μm)	14	18.6
2	Mo-I	LiF 200	150 μm	Scint.	Brass (300 μm)	12	21
3	Kr-Tc	LiF 220	150 μm	Scint.	Al (750 μm)	26.6	42
4	Zn-Rb	LiF 220	150 μm	Scint.	Al (200 μm)	37	62
5	V-Cu	LiF 220	150 μm	Flow	None	61	126
6	K-V	LiF 200	150 μm	Flow	None	76	146
7	P-Cl	Ge 111	300 μm	Flow	None	91	146
8	Si-Si	PE 002	300 μm	Flow	None	100	115
9	Al-Al	PE 002	300 μm	Flow	None	130	147.04
10	O-Mg	PX1	300 μm	Flow	None	20	60.05
No.	**Step size**	**Time**	**Time/step**	**Speed**	**kV**	**mA**	
	(°2T)	(s)	(s)	(°2T/s)			
1	0.04	23	0.2	0.2	60	66	
2	0.03	75	0.25	0.12	60	66	
3	0.05	77	0.25	0.2	60	66	
4	0.05	100	0.2	0.25	60	66	
5	0.05	208	0.16	0.3125	50	80	
6	0.08	140	0.16	0.5	32	125	
7	0.1	110	0.2	0.5	32	125	
8	0.12	20	0.16	0.75	32	125	
9	0.12	22.72	0.16	0.75	32	125	
10	0.15	133.5	0.5	0.3	32	125	

Application - IQ+27mmVacSlow							
Total time	3636 (seconds)						
No.	KA range	X-tal	Collimator	Detector	Tube filter	Start angle	End angle
						(°2T)	(°2T)
1	Te-Ce	LiF 220	150 µm	Scint.	Brass (100 µm)	14	18.6
2	Mo-I	LiF 200	150 µm	Scint.	Brass (300 µm)	12	21
3	Kr-Tc	LiF 220	150 µm	Scint.	Al (750 µm)	26.6	42
4	Zn-Rb	LiF 220	150 µm	Scint.	Al (200 µm)	37	62
5	V-Cu	LiF 220	150 µm	Flow	None	61	126
6	K-V	LiF 200	150 µm	Flow	None	76	146
7	P-Cl	Ge 111	300 µm	Flow	None	91	146
8	Si-Si	PE 002	300 µm	Flow	None	100	115
9	Al-Al	PE 002	300 µm	Flow	None	130	147.04
10	O-Mg	PX1	300 µm	Flow	None	20	60.05
No.	**Step size**	**Time**	**Time/step**	**Speed**	**kV**	**mA**	
	(°2T)	(s)	(s)	(°2T/s)			
1	0.04	92	0.2	0.2	60	66	
2	0.03	300	0.25	0.12	60	66	
3	0.05	308	0.25	0.2	60	66	
4	0.05	400	0.2	0.25	60	66	
5	0.05	832	0.16	0.3125	50	80	
6	0.08	560	0.16	0.5	32	125	
7	0.1	440	0.2	0.5	32	125	
8	0.12	80	0.16	0.75	32	125	
9	0.12	90	0.16	0.75	32	125	
10	0.15	534	0.5	0.3	32	125	

Appendix 2 Instrumentation Precision

BHVO-1 Repeatability						
Element	**Run 1**	**Run 2**	**Run 3**	**Average**	±	**St. Dev**
SiO_2	48.9971	48.5312	48.8466	48.79163	±	0.237764
Al_2O_3	16.3153	15.9211	16.4300	16.22213	±	0.266936
FeO	11.4527	12.1201	11.3841	11.6523	±	0.406576
CaO	11.3440	11.3557	11.3741	11.35793	±	0.015174
MgO	4.8802	4.9989	4.8651	4.914733	±	0.07328
Na_2O	2.9397	3.0845	2.9961	3.006767	±	0.072987
TiO_2	2.8736	2.8490	2.9061	2.876233	±	0.028641
K_2O	0.5168	0.5401	0.5120	0.522967	±	0.015031
$P2O_5$	0.2735	0.2661	0.2682	0.269267	±	0.003814
MnO	0.1844	0.1449	0.1910	0.173433	±	0.02493
Sr	0.0450	0.0410	0.0463	0.0441	±	0.002762
Cl	0.0365	0.0287	0.0403	0.035167	±	0.005914
BaO	0.0285	0.0345	0.0295	0.030833	±	0.003215
S	0.0217	0.0229	0.0231	0.022567	±	0.000757
Cu	0.0234	0.0227	0.0178	0.0213	±	0.003051
Zr	0.0183	0.0179	0.0151	0.0171	±	0.001744
Zn	0.0131	0.0091	0.0083	0.010167	±	0.002572
Ni	0.0144	0.0085	0.0186	0.013833	±	0.005074
Cr	0.0192	.0205	0.0252	0.021633	±	0.003156
Y	0.0027	0.0032	0.0025	0.0028	±	0.000361

Appendix 3: Elemental Concentrations of Basalt Samples

Site / Sample	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	S	Cl	K_2O
R10 81	3.5240	3.7930	18.5840	51.4570	0.1740	0.0100	0.0280	0.4370
R68 269	4.0680	2.2180	17.6640	63.0620	0.1230	0.0060	0.0410	1.3600
R68 317	4.3640	2.0080	18.2210	61.6040	0.2350	0.0040	0.0240	1.6400
R68 268	3.6890	2.1410	18.4540	61.6940	0.1690	0.0020	0.0600	1.8150
R68 318	3.9000	3.1460	17.2330	61.2850	0.1370	0.0050	0.0280	1.3420
R68 348	3.5090	2.8500	18.6090	58.9490	0.1720	0.0070	0.0510	2.4270
R68 347	3.8310	3.4890	16.5220	54.0570	0.2350	0.0080	0.0710	1.0280
R68 270	3.6390	3.0440	18.0610	61.3020	0.2760	0.0050	0.0270	2.2410
R68 19	3.5170	3.9750	17.3260	53.2380	0.2250	0.0050	0.0400	0.5420
R68 334	3.6610	4.0000	16.8790	53.5420	0.2240	0.0080	0.0900	0.6100
R02 591	2.6700	3.5430	20.4760	49.7140	0.0151	0.0040	0.0370	0.3940
R02 270	4.1330	3.3870	16.5530	54.6710	0.2250	0.0080	0.0420	0.5800
R02 585	2.0260	6.0890	17.7370	47.7410	0.0232	0.0050	0.0150	0.3980

Site / Sample	TiO_2	MnO	FeO	Cu	Sr	Zr	BaO	CaO
R10 81	1.0050	0.2070	10.3380	0.0110	0.0510	0.0100	0.0310	10.3290
R68 269	0.5680	0.0090	4.3830	0.0060	0.0420	0.0010	0.0370	6.3110
R68 317	0.6740	0.0900	4.9300	0.0040	0.0600	0.0110	0.0500	6.0720
R68 268	0.5950	0.1100	4.6750	0.0060	0.0780	0.0090	0.0330	6.4950
R68 318	0.6130	0.0840	5.0890	0.0120	0.0380	0.0140	0.0590	7.0080
R68 348	0.7760	0.0900	5.4450	0.0090	0.0630	0.0170	0.0470	6.9720
R68 347	1.0570	0.1940	10.8780	0.0100	0.0540	0.0100	0.0440	8.4900
R68 270	0.7060	0.0650	4.4690	0.0070	0.0030	0.0210	0.0640	5.9480
R68 19	1.0320	0.2190	10.5830	0.0080	0.0520	0.0050	0.0430	9.1770
R68 334	1.0020	0.2170	10.5640	0.0120	0.0510	0.0060	0.0390	9.8400
R02 591	0.9160	0.1850	9.8790	0.0200	0.0680	0.0110	0.0390	11.7870
R02 270	1.0290	0.2330	10.4290	0.0270	0.0020	0.0030	0.0340	8.5750
R02 585	0.8200	0.1700	11.2970	0.0130	0.0670	0.0110	0.0270	13.2920

Site / Sample	Na_2O	MgO	Al_2O_3	SiO2	P_2O_5	S	Cl	K_2O
R60 303	3.6610	2.9360	17.5560	55.0530	0.2500	0.0130	0.0990	0.9640
R60 435	3.6530	5.2320	19.0290	51.4710	0.2430	0.0060	0.0150	0.5000
R60 439	3.5350	4.0020	16.6740	53.5360	0.1790	0.0080	0.0690	0.7040
R60 77	4.7060	2.3550	16.7070	57.7350	0.2570	0.0080	0.0690	0.8920
R60 83	2.8050	4.8970	19.0510	50.8860	0.2060	0.0060	0.0410	0.5320
R60 226	7.5350	1.4250	16.0700	62.6150	0.6430	0.1160	0.0520	2.2520
R60 0468	3.8080	3.0680	17.9270	60.8090	0.1240	0.0140	0.0640	1.1210
R60 73	3.4710	3.8690	17.5510	53.0080	0.2030	0.0090	0.0690	0.6800
R60 78	3.1440	4.5200	17.4940	51.1950	0.2010	0.0070	0.0340	0.4680
R02 1211	4.8280	1.5290	16.5310	61.5930	0.3710	0.0060	0.0240	1.4980
R02 726	2.7920	4.0780	21.1460	47.8150	0.2240	0.0090	0.0360	0.3010
R02 1349	4.9890	2.2950	15.1230	64.4390	0.4000	0.0060	0.0420	1.7060
R02 260	3.6700	3.9070	17.9980	52.7740	0.2090	0.0030	0.0590	0.5000
R02 384	2.7980	3.7850	20.2360	50.9860	0.1800	0.0150	0.0640	0.3850
R02 581	2.7940	6.0140	17.0300	48.7720	0.2590	0.0100	0.0230	0.2370
R02 88	3.5060	2.9780	18.7190	53.5200	0.1570	0.0080	0.0690	0.6050
R36 650	4.9630	0.3130	15.3300	68.9020	0.0000	0.0120	0.0340	1.2760
R36 858	4.3400	1.0470	16.2360	63.5680	0.3410	0.0070	0.0270	1.0130
R36 657	4.2450	1.2180	16.2200	60.5480	0.5540	0.0100	0.0360	1.2710
R36 0261	4.9510	3.1040	17.3840	54.2900	0.3680	0.0200	0.1920	0.6260
R36 1045	3.8500	3.9880	17.1230	51.8930	0.2120	0.0130	0.0860	0.4940
R36 300	3.5670	4.4640	17.3100	51.3150	0.1750	0.0080	0.0810	0.4360
R36 286	4.3670	3.3770	16.6800	56.4810	0.2900	0.0060	0.0420	0.6310
R31 2831	3.8900	1.3800	14.9020	58.6200	0.3750	0.0060	0.1720	1.6980
R31 3328	4.3050	2.8390	17.3140	55.7050	0.2100	0.0190	0.0570	0.6560
R31 2832	3.9790	3.2660	16.3860	55.2340	0.2560	0.0260	0.0260	0.8500
R31 1815	4.2500	1.9870	18.1750	55.1160	0.3290	0.0070	0.0360	1.0510
R31 1706	4.3240	3.3250	16.9260	54.7030	0.2430	0.0130	0.1160	0.5020
R31 3929	3.5800	3.5900	16.5800	54.8000	0.3140	0.0110	0.0440	0.6450
R31 1712	3.9320	3.5720	17.4800	53.5800	0.2220	0.0080	0.0540	0.5240
R10 85	4.7130	1.9430	17.2090	58.2870	0.2940	0.0050	0.0290	1.1600
R10 82	3.2040	0.4480	17.6650	52.8850	0.2850	0.0080	0.0390	0.7270
R10 321	3.8440	2.5950	19.6130	59.6300	0.1250	0.0060	0.0180	1.1900
R10 219	4.5990	2.4400	16.8480	58.1900	0.3230	0.0050	0.0180	0.9740
R10 88	3.5000	3.9510	18.3130	51.4540	0.1750	0.0090	0.0260	0.4250
R10 80	4.7100	1.7100	17.5610	58.9440	0.3460	0.0050	0.0400	1.3440

Site / Sample	TiO_2	MnO	FeO	Cu	Sr	Zr	BaO	CaO
R60 303	1.0480	0.2590	9.0960	0.0260	0.0590	0.0060	0.0390	8.9220
R60 435	0.9000	0.1670	9.1760	0.0310	0.0660	0.0050	0.0330	9.3890
R60 439	0.9840	0.2240	10.5080	0.0200	0.0520	0.0060	0.0360	9.4480
R60 77	1.0490	0.2500	9.0040	0.0210	0.0580	0.0060	0.0480	6.8200
R60 83	0.7840	0.1970	8.3280	0.0180	0.0650	0.0130	0.0340	12.1060
R60 226	1.0140	0.1080	5.8970	0.0050	0.0250	0.0140	0.0690	2.1520
R60 0468	0.5850	0.1190	5.2080	0.0000	0.0340	0.0100	0.0390	7.0580
R60 73	0.9310	0.2040	10.1320	0.0270	0.0600	0.0110	0.0400	9.7220
R60 78	1.0510	0.2120	10.6570	0.0250	0.0510	0.0100	0.0390	10.8350
R02 1211	0.9270	0.2400	6.1430	0.0140	0.0470	0.0090	0.0580	6.1700
R02 726	0.8440	0.1780	9.0220	0.0170	0.0690	0.0110	0.0220	13.4310
R02 1349	0.7430	0.1140	6.2770	0.0060	0.0020	0.0100	0.0630	3.7260
R02 260	0.9700	0.0220	9.7070	0.0240	0.0570	0.0450	0.0490	9.8300
R02 384	0.8640	0.1700	9.5690	0.0110	0.0610	0.0120	0.0420	10.7620
R02 581	0.8420	0.2810	11.2860	0.0100	0.0720	0.0080	0.0300	12.2480
R02 88	0.9620	0.2130	9.4910	0.0110	0.0630	0.0070	0.0440	9.6320
R36 650	0.9700	0.0730	3.1750	0.0000	0.0020	0.0060	0.0530	4.8160
R36 858	1.0220	0.1450	5.5330	0.0000	0.0510	0.0070	0.0450	6.6060
R36 657	1.3760	0.1320	7.2520	0.0080	0.0630	0.0120	0.0450	6.9810
R36 0261	1.1170	0.2420	9.3770	0.0220	0.0580	0.0100	0.0430	8.1750
R36 1045	1.1160	0.2530	11.1880	0.0100	0.0500	0.0070	0.0390	9.6680
R36 300	1.0330	0.1920	10.9200	0.0090	0.0550	0.0120	0.0380	10.3350
R36 286	0.9910	0.2040	9.2320	0.0070	0.0540	0.0120	0.0520	7.5470
R31 2831	2.1050	0.5310	8.7050	0.0230	0.1780	0.0140	0.1330	7.809
R31 3328	0.9800	0.2610	9.6000	0.0140	0.0540	0.0070	0.0470	7.9180
R31 2832	1.0940	0.2640	10.4070	0.0110	0.0500	0.0070	0.0570	8.0290
R31 1815	1.1260	0.2030	9.0530	0.0500	0.0600	0.0120	0.0530	8.5180
R31 1706	1.0380	0.2390	9.9710	0.0260	0.0610	0.0060	0.0440	8.4520
R31 3929	1.8330	0.2640	9.2340	0.0210	0.1870	0.0090	0.0950	8.4480
R31 1712	1.0540	0.2220	10.0300	0.0230	0.0540	0.0070	0.0380	9.1890
R10 85	1.0540	0.2030	7.8640	0.0000	0.0048	0.0060	0.0490	7.1200
R10 82	0.4890	0.1020	7.5880	0.0000	0.0030	0.0130	0.0580	6.4275
R10 321	0.5700	0.0900	5.2760	0.0060	0.0640	0.0110	0.0430	6.9080
R10 219	1.0610	0.2100	8.1550	0.0120	0.0470	0.0060	0.0420	7.0560
R10 88	1.0600	0.0340	0.1960	10.4010	0.0490	0.0100	0.0360	10.3270
R10 80	1.0460	0.1720	7.2670	0.0090	0.0500	0.0060	0.0550	6.6440