TOOLSTONE PROCUREMENT IN MIDDLE-LATE HOLOCENE IN THE KODIAK ARCHIPELAGO AND THE ALASKA PENINSULA

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A

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Abstract

The Norton tradition (2300-950 BP) in the Alaska Peninsula and the Late Kachemak phase (2700-900 BP) in Kodiak are distinct cultural traditions yet contain some similarities in lithic assemblages and house form, suggesting some contact or influence occurred. The subsequent Koniag tradition (900-200 BP) is present in both the Alaska Peninsula and Kodiak, indicating direct influence or migration. While the Koniag tradition is found in sites located throughout the North Pacific region, the Koniag tradition in Kodiak is characterized by changes in social climate and subsistence strategies including greater warfare/raiding and resource consolidation. In order to obtain these resources, Koniag populations living in Kodiak may have traveled farther distances than previous populations. In contrast, Alaska Peninsula populations did not experience significantly different subsistence strategies over time and therefore would not need to travel as far as Kodiak populations or significantly alter subsistence patterns. Determining the probable origins of toolstone materials in late prehistoric sites can reveal changes in the ways people in this region obtained their resources and give a more comprehensive understanding of the degree to which the Koniag lifestyle differed from the preceding cultural traditions in the region.

Due to the eruptive history in the Alaska Peninsula, the presence of volcanic toolstone in Kodiak sites, and the close proximity between the two locations, central Alaska Peninsula and Kodiak sites are optimally located in order to determine possible changes in the direction where volcanic toolstone originated. This thesis explored differences between volcanic toolstone procurement locations in late prehistoric sites on the Kodiak Archipelago and the central Alaska Peninsula by comparing samples according to size and abundance of tool types, site location, cultural affiliation, and time periods using element values obtained from x-ray fluorescence (XRF) technology. Results show possible geographic boundaries of toolstone containing similar element values using Alaska Peninsula samples, which were subsequently compared with Kodiak samples. Data presented in this thesis shows the geographic range of likely toolstone procurement locations increased over time in Kodiak sites, while Alaska Peninsula sites contain evidence that toolstone remained locally procured over time.

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All errors in this work are my own and should not reflect upon others with whom I have worked.

1.0 Introduction

Since archaeological work began in the Kodiak Archipelago by Ales Hrdlicka, extensive research has been performed in order to understand the changes that occurred in the North Pacific region which allowed the Koniag tradition (900-200 BP) to expand over a large geographic area (Clark 1974; Fitzhugh 1996; Hrdlicka 1944; Jordan and Knecht 1988). The Koniag tradition is preceded by relatively geographically isolated and distinct cultural traditions, with the Norton tradition (2300-950 BP) in the central Alaska Peninsula and the Late Kachemak tradition (2700-900 BP) in the Kodiak Archipelago. While these traditions contain evidence for increasing interaction due to an increase in trade/exchange items, Koniag populations experienced different circumstances that necessitated more frequent off-archipelago travel. Larger populations, bigger villages, consolidating resources, and kinship markers show Koniag populations increased populations and developed increasingly hierarchical societies as discussed in Section 1.2.4. In contrast, the Koniag tradition in the central Alaska Peninsula showed a lower population density, smaller site sizes, and less evidence for trade/exchange with fewer non-local materials (Dumond 1991, 1998a, 1998b, 2003:105-106). Changes in tool procurement patterns that Kodiak and central Alaska Peninsula populations used over time can support evidence for late prehistoric subsistence patterns.

Examining changes in toolstone procurement can reveal changes in the ways people in this region obtained their resources and would allow for a more comprehensive understanding of the degree to which the Koniag lifestyle differed from the preceding cultural traditions in the region. Therefore the purpose of this thesis is to explore possible changes in volcanic toolstone procurement during the late prehistoric period in Kodiak and the central Alaska Peninsula by establishing and comparing possible toolstone locations where artifacts were likely to have originated. While many lines of evidence point to new populations or influences emerging on the Alaska Peninsula and Kodiak that brought the Koniag tradition to the region, the purpose of this study is not to test ideas of population movements but rather to obtain and compare elemental data among volcanic toolstone used in Alaska Peninsula and Kodiak late prehistoric sites.

The central Alaska Peninsula and the Kodiak Archipelago provide an ideal area to examine differences in volcanic materials. The predominant stone tools found in sites throughout southwest Alaska are slate and basalt. Mafic and intermediate (basaltic/andesitic volcanics) rocks are found throughout the Alaska Peninsula due to its active volcanic history (Kienle and Nye 1990:10). Mafic and intermediate raw material produced from frequent volcanic activity on the Alaska Peninsula has provided ample toolstone for prehistoric populations, whereas basalt does not naturally occur in Kodiak Island in quantities sufficient for tool making; leaving researchers to infer that basalt artifacts found on Kodiak sites derived from the peninsula (Fitzhugh 2003:348, Fitzhugh 2004; Knecht 1995:72-73; Tennessen 2009:54-55, 95; Steffian et al. 2006:118-119).

Were the people in Kodiak obtaining toolstone from farther distances as the Koniag tradition spread across the central Alaska Peninsula? If they were, it is possible Koniag populations were driven by socioeconomic factors to search for resources. Information in Sections 1.2.4 and 2.3 contains evidence for food shortages/unequal access to resources on Kodiak during the Koniag tradition. Were central Alaska Peninsula residents using locally available volcanic toolstone throughout the late prehistory or does a difference in toolstone procurement locations occur over time? If central Alaska Peninsula populations experienced no change in toolstone procurement locations over time, local toolstone was produced in sufficient quantities and access to stable food resources was available (Coltrain 2010; Dumond 1998b:189). As described in Section 2.2, there is a history of population movement to the Alaska Peninsula particularly to the Pacific coast due to the ecological "pull" of abundant food resources (Dumond 1998a:71). This thesis attempts to answer these questions by comparing the abundance of tool types, relative sizes of artifacts, and elemental signatures of artifacts from late prehistoric sites in the study area and tool-quality volcanic rocks. The following section provides an overview of the environmental and archaeological background to this study.

1.1 Geology and Volcanic Activity in the Alaska Peninsula and Kodiak

The Alaska Peninsula and Kodiak Archipelago are located in the 'Ring of Fire', a chain of volcanoes located at the northern border in the North American plate near a convergent boundary with Pacific plate, forming the Aleutian Trench. The study area is illustrated in Figure 1.2. The subduction of the Pacific plate has produced the 2500 km long Aleutian Volcanic Arc that begins in the Kamchatka Peninsula, extends through the Pacific coast side of the Alaska Peninsula, and ends in the Cook Inlet (Detterman et al. 1996:60; Nokleberg et al. 2005). While the two plates meet at about a 90 degree angle near the Pacific coast of the Alaska Peninsula which created a rugged coastline, the Bering Sea coast of the peninsula gradually slopes down to the Bering Sea continental shelf (Burk 1965, Vallier et al. 1994:384).

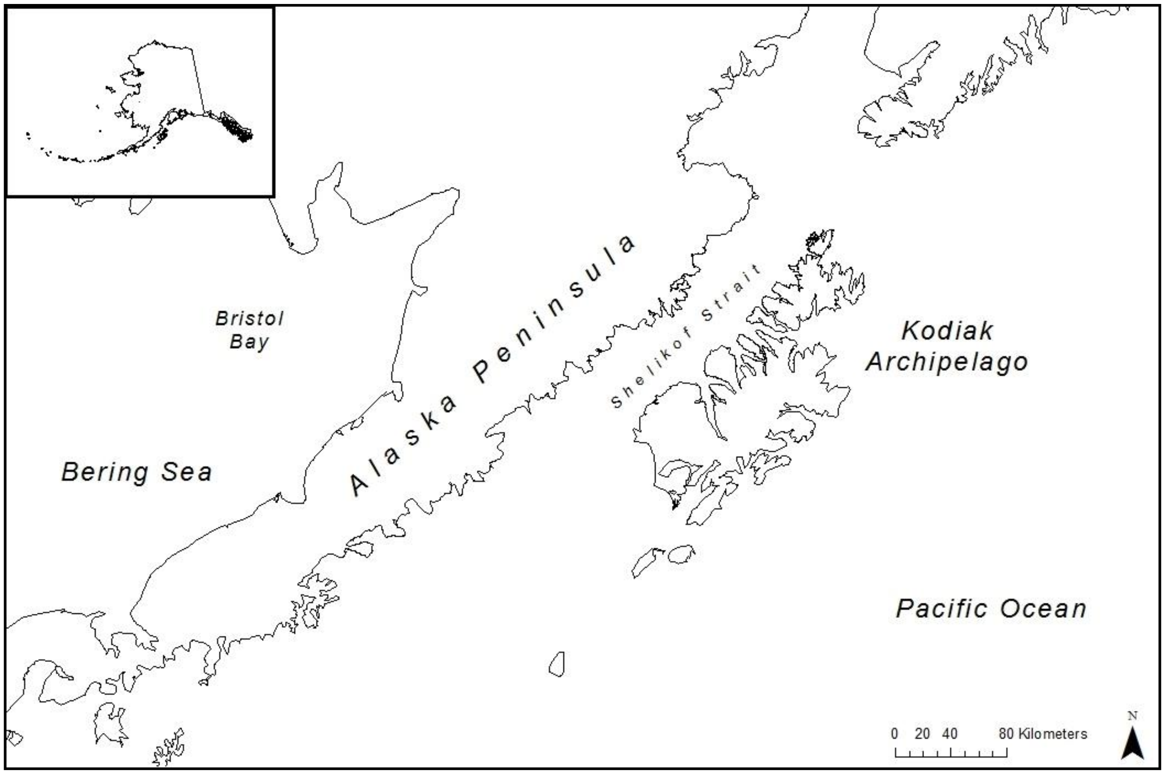

Figure 1.1. Map of study area.

The geologic framework in this region is comprised of several terranes and faults. The Alaska Peninsula is comprised of the Alaska Peninsula terrane. The 530 km-long Bruin Bay fault is located from the Cook Inlet and runs halfway across the north-central peninsula, to the southern shore of Becharof Lake, roughly paralleling the Aleutian Range on the peninsula (Detterman et al. 1996:4-6; Miller and Richter 1994:761). This fault separates the peninsula into geologically distinct areas. The area from the Bering Sea coast to the Ugashik Lakes and Kulik Lake contains Quaternary unconsolidated deposits from past glacial, flooding, and eolian processes (Detterman et al. 1996; Riehle and Detterman 1993). The area east of the Bruin Bay fault to the Pacific coast contains a variety of rock types produced by several formations; Mesozoic intrusive igneous rock, Tertiary sedimentary rock, and Tertiary and Mesozoic granitic rocks comprise most of this area (Figure 1.2). The Aleutian Arc on the Alaska Peninsula has been active since the Quaternary; therefore more recent volcanic rocks (Quaternary and Tertiary) are located near volcanoes and between Iliamna Lake and Naknek Lake (Detterman et al. 1996; Vallier et al. 1994:377).

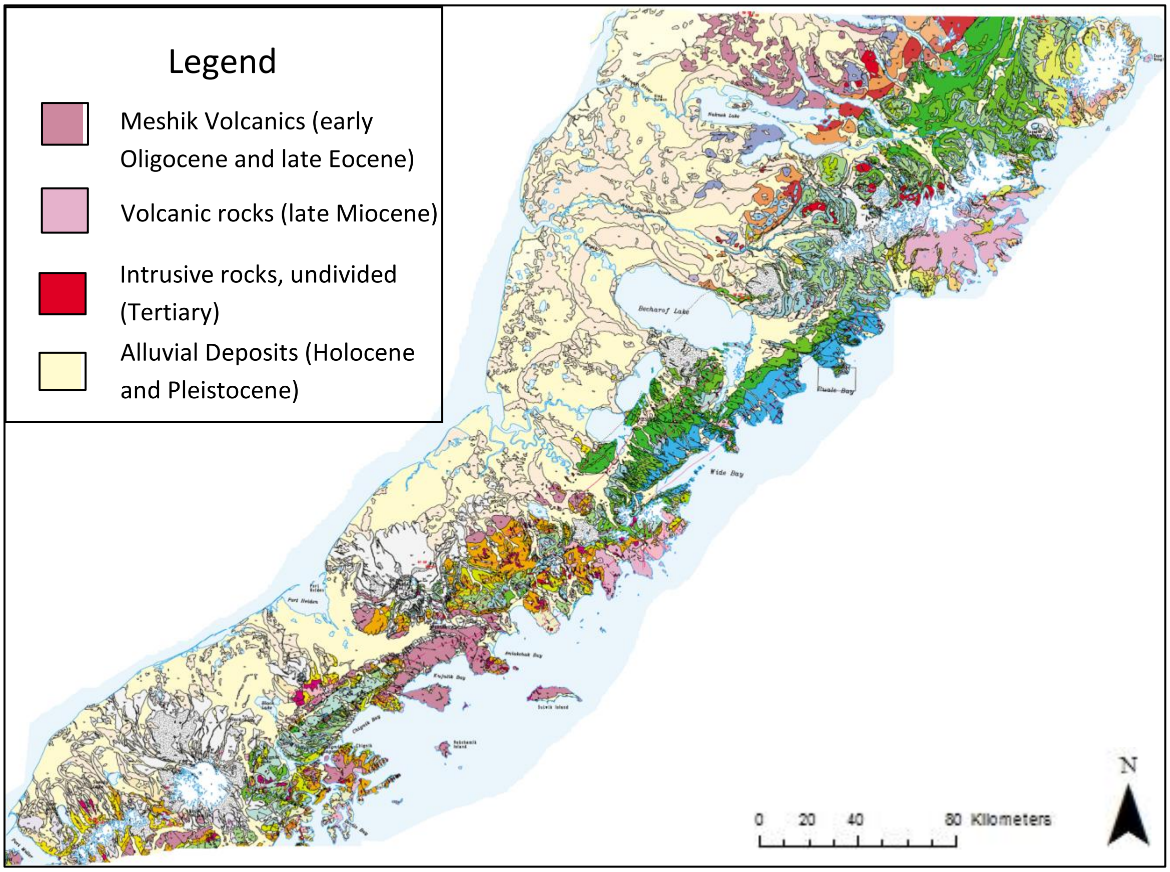

Figure 1.2. Geologic map of the Alaska Peninsula highlighting selected volcanic geologic rocks. Source: Detterman et al. 1996.

The Chugach Terrane comprises Kodiak except for the eastern coast where the Prince William terrane is located. The meeting of the Chugach and Alaska Peninsula terranes forms the Border Ranges fault, located in the Shelikof Strait and the western edge of Kodiak (Vallier et al. 1994:376). Another fault, the Uganik thrust, is located to the east of the Border Ranges fault and contains accretionary basalt and chert breccia as shown in Figure 1.3. The Chugach terrane on Kodiak Archipelago consists of the Kodiak Formation, primarily Mesozoic sedimentary rocks

(Vallier et al. 1994:379). The granitic Kodiak batholith is exposed in central Kodiak (Farris 2010:3). The Contact fault separates the Chugach terrane from the Prince William terrane on the eastern coast of Kodiak; the Ghost Rock formation of the Prince William terrane contains sedimentary rocks with a relatively higher percentage of greywacke than the Kodiak Formation (Farris 2010:2-3).

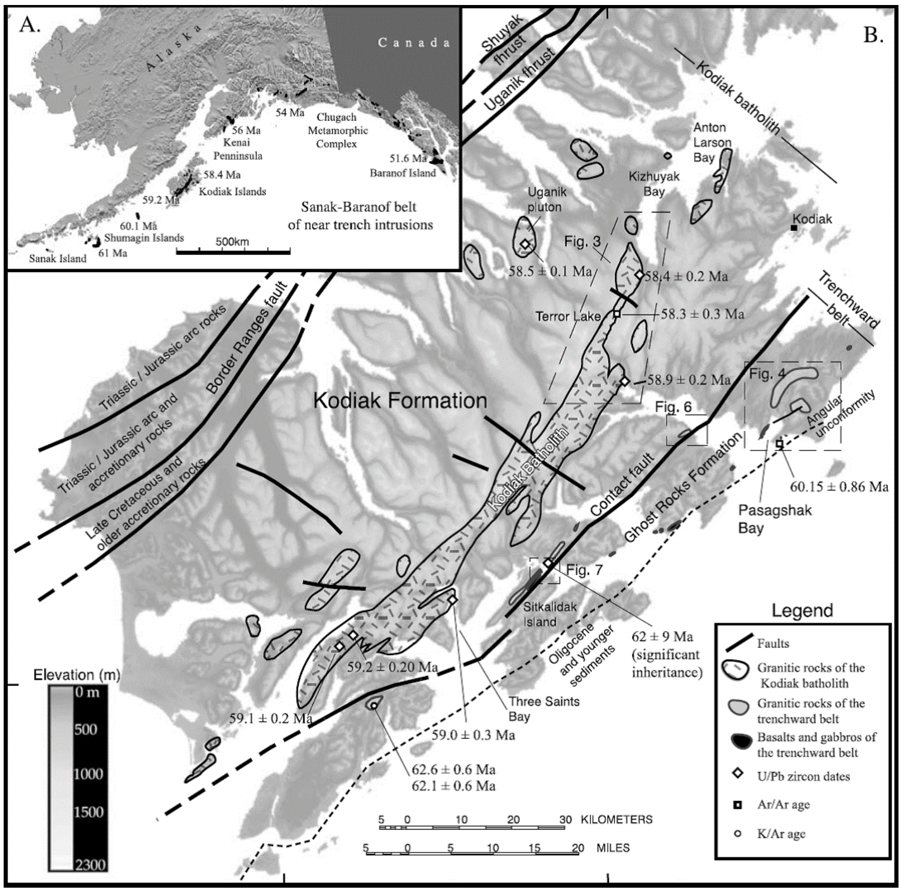

Figure 1.3. Geologic map of Kodiak. Source: Farris 2010: Figure 1.

1.1.1 Volcanic Activity

The Aleutian Range has been divided into two sections in order to separate the volcanoes by geologic formation: the western Aleutian Arc was formed on oceanic crust and the eastern Aleutian Arc volcanoes were formed on continental crust. The eastern Aleutian Arc begins near Unimak Pass on the Alaska Peninsula extends to Cook Inlet (Vallier et al. 1994:367, 384). This section of the Aleutian Arc contains 37 Quaternary volcanic centers, with 30 containing eruptive activity during the Holocene (Miller and Richter 1994:762-766). Since the Pleistocene, nine calderas have been produced by large scale eruptions; five of those eruptions contained bulk volumes of pyroclastic ejecta of more than 50km^3 (Miller and Richter 1994: 766). The central Alaska Peninsula contains volcanoes located close together, with a 200km long distance from the Ugashik-Mt. Peulik Volcano south of Becharof Lake northeast to Douglas Volcano at the northeastern coast of the Alaska Peninsula containing 14 volcanoes (Miller and Richter 1994). Within this area, the Kialagvik, Chiginigak, and Yantarni volcanoes are separated by 18km. Mount Katmai, Trident Volcano, Novarupta, Mount Griggs, Falling Mountain, Mount Cerberus, Mount Mageik, and Mount Martin are no more than 10km apart (Detterman et al. 1996:61). The eruptive history and number of volcanoes located in the Alaska Peninsula affected human populations (Dumond 2004; VanderHoek 2009; VanderHoek and Myron 2004). In particular, caldera-forming eruptions that may have directly impacted humans in late prehistory are: Veniaminof (3700 BP), Black Peak (4700-4100 BP) and Aniakchak (3430 BP) (Detterman et al 1996:62).

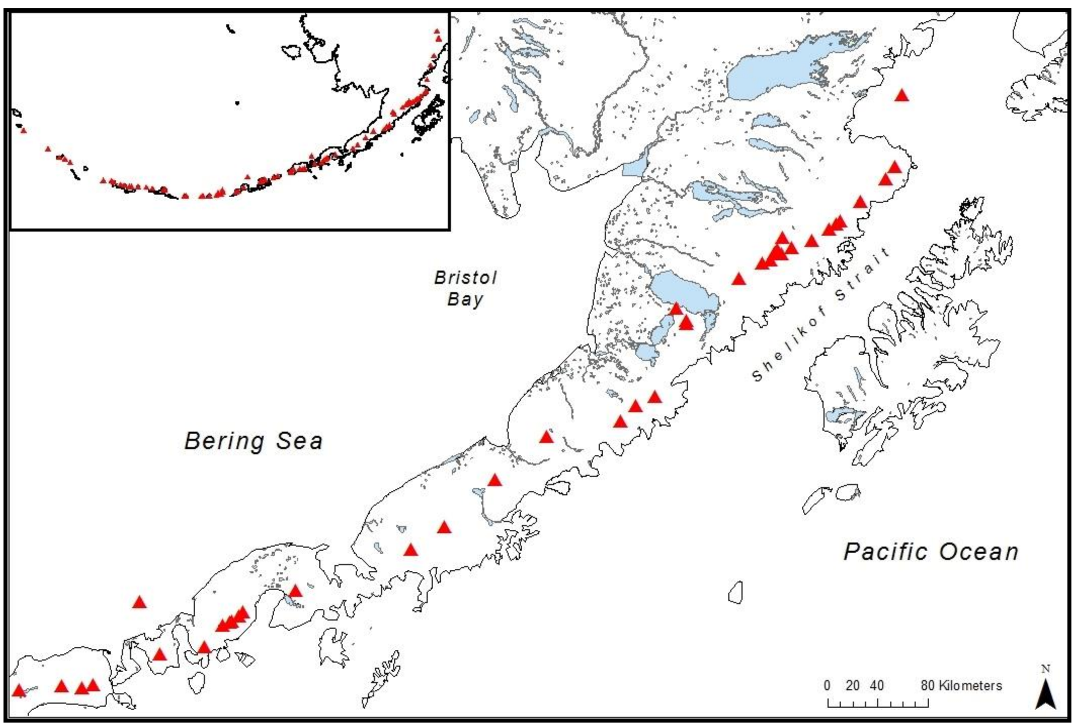

Figure 1.4. Location of Alaska Peninsula volcanoes.

1.1.2. Locations of Available Lithic Resources

From the above data, it is clear populations would have been able to access different types of lithics. Populations in the central Alaska Peninsula would have had local access to a range of igneous lithic materials throughout the peninsula, particularly near the Pacific coast. The area between the Meshik River valley north and the Ugashik River system is comprised "mainly of basalt and andesite flows, coarse volcanic rubble, breccia, and lahars" (Detterman et al 1996:46). Rhyolite (more than 70 percent of SiO_2) is relatively rare and present in Ugashik-Peulik, Aniakchak, and Valley of Ten Thousand Smokes post-caldera domes and ash flows, and ejecta from the 1912 Novarupta eruption (Miller and Richter 1994:769).

Populations living in Kodiak would have access to a variety of native sedimentary lithic materials. Past populations used slate throughout Kodiak which is most likely from the sedimentary Kodiak Formation that covers most of Kodiak (Vallier et al. 1994:379). Red and green cherts could be found in both western and eastern Kodiak, with white chert deposits reported in eastern Kodiak (Farris 2010:3; Fitzhugh 2004:28). Greywacke could be found in abundant quantities throughout Kodiak but particularly in the eastern coast (Farris 2010:2-3). Granite rock from the exposed Kodiak batholith in central Kodiak was available (Farris 2010:3). Some volcanic rock on Kodiak is available however its quantity and quality for toolmaking has been doubted (Fitzhugh 2004:30). Small numbers of basalt pillows and dikes are exposed in eastern Kodiak from the Sanaf-Baranof trenchward belt (Farris 2010:2, 5-6). The Kodiak batholith consists of more than 80 percent sedimentary rock including greywacke, with the remaining percent consisting of basalt (Farris 2010: 3, 17).

1.2 Archaeological Background

The late prehistoric archaeological traditions on the Alaska Peninsula and Kodiak are reviewed in this section. A brief overview of preceding cultural traditions is given in order to provide context for the late prehistoric cultural traditions. All dates are given in calibrated BP years following the revised dates from Mills (1994) because this more accurate method of dating changed the timeline of several cultural traditions, clarifying some topics regarding the origins of late prehistoric traditions. Ancient peoples in these regions were influenced from various neighboring areas, including northern and western Alaskan coastal areas, Cook Inlet, and the

Aleutian archipelago. The Norton tradition on the Alaska Peninsula and Kachemak tradition on Kodiak do not appear to have originated from the same place; however the similarities between the Norton tradition on the central Alaska Peninsula and Late Kachemak phase of the Kachemak tradition on Kodiak are numerous, suggesting some contact between the two populations. The subsequent Koniag tradition is present on both the peninsula and Kodiak which could be due to increasing interaction or population movements throughout the North Pacific region. The nature of these influences or interactions is not well resolved in the literature (Clark 1974, 1982, 1984, 1998; Dumond 1987, 2000, 2003; Dumond and Scott 1991; Harritt 1997; Jordan and Knecht 1988; VanderHoek 2009) and the various ideas on there are described below. Calibrated radiocarbon dates (BP) used in recent literature are taken from several sources and listed below (Hoffman 2009; Knecht and Davis 2001; Maschner 1999; Mills 1994; VanderHoek and Myron 2004; West 2011).

Table 1.1. Cultural Sequences in Late Prehistory in the Alaska Peninsula and Kodiak

BP	Aleutian Archipelago	Alaska Peninsula Naknek	Alaska Peninsula Ugashik	Alaska Peninsula Pacific Coast	Kodiak
0	Historic (200-0)	Historic (200-0)			Historic (200-0)
	Late Aleutian (1000-200)	Koniag (600-200)			Koniag (900-200)
		Thule (850-650)			Late Kachemak (2700-900)
		Norton (2300-950)			
1000	Amaknak (3000-1000)				
2000					
		Hiatus		Hiatus	
				OB II/Takli Birch (5000-2700)	Early Kachemak (4000-2700)
3000	Margaret Bay (4000-3000)				
		ASTt (4500-3300)			
4000	Late Anangula (7000-4000)				OB II (5000-4000)
		OBII (5000-4500)			
5000					OB I (7500-5000)
		Northern Archaic (6000-5500)			
6000				OB I/Takli Alder (7000-6200)	

1.2.1. The Norton Tradition in the Alaska Peninsula

The origin of the widespread Norton tradition, found across western and coastal Alaska in late prehistory is debated and discussed below. An occupation hiatus occurred in the Alaska Peninsula at the end of the Arctic Small Tool tradition (ASTt) which coincided with the 3400BP caldera-forming eruption of Aniakchak. ASTt is derived from western Alaska and ASTt assemblages are found from the Aleutians and Kodiak, likely migrating around Bristol Bay and arriving in the central Alaska Peninsula around 4500-400 BP (Dumond 1981, 1982; Henn 1978; Jordan and Maschner 2000:397; Steffian and Saltonstall 2005; VanderHoek 2009; Workman and Zollars 2002). During the time of the eruption, Port Moller and the Ugashik Narrows area were the only populated locations in central and southern Alaska Peninsula (Dumond 1998b; McGimsey et al 1994:59; Miller and Smith 1987:435; Steffian and Saltonstall 2005; VanderHoek 2009; VanderHoek and Myron 2004: 39). A colder climate ended in 2500BP that also roughly coincided with the appearance of the Norton tradition on the peninsula (Heusser 1963:81). The occupation hiatus lasted until the start of the Norton tradition around 2700 BP at CHK-00031 near Chignik Lake (McCartney 1974). Due to the eruption and climate change, the occupation hiatus has been interpreted as either a temporary hiatus of the existing population, or abandonment and the introduction of a new population. The similarities between the assemblages of ASTt and the Norton tradition in the Naknek region consist of house form, end blades, microblades, side scrapers, adzes, mitten-shaped burins, and knives (Dumond 1982:40, 1992, 1998a, 1998b; Henn 1978; Steffian and Saltonstall 2005; VanderHoek 2009). While technological continuity exists between ASTt and Norton traditions, similarities between the Norton and Kachemak traditions on Kodiak indicate some influence occurred with the Norton tradition on the Pacific coast (Clark 1996:226). The Kachemak tradition has been hypothesized as an in-situ development from the preceding Ocean Bay tradition (discussed in Section 1.2.2), which appeared as a local variant in Alaska Peninsula sites on the Pacific coast (Clark 1996:225). Kachemak influence is found in Norton sites located near the Pacific coast containing the presence of ground slate knives, polished slate ulus, stone lamps, labrets, net sinkers and harpoon dart heads, similar house structures, and increasing populations (Clark 1996:226; Dumond 1998b; Dumond and Scott 1991:91).

Norton assemblages and house structures in the Alaska Peninsula vary widely due to many influences in the surrounding region (Bundy 2007). In the Bristol Bay coast, local Naknek sequences contain influences from both the Norton tradition and Kachemak between 2300-950 BP. Here the evidence for a Norton derived regional sequence comes from the introduction of pottery and side-blades (Dumond 1982:40, 1992, 1998b: 15, 2000) while Kachemak influence is evidenced by the square house structure and chipped stone technology (Dumond and Scott 1991: 93). Meanwhile round house forms are found at sites also located in the Bristol Bay coast, Alagnak River, UGA-00052, and in the Aleutians during this time (Bundy 2007, Dumond 1981, Hoffman 2009:14, Maschner 1999: 94). Pottery, houses with cold-trap entrances and ground slate found in southern Alaska Peninsula sites indicate that the Norton tradition spread to the lower end of the peninsula, albeit with a slower transitioning to Norton material culture than in the Katmai region (Maschner 1999:94, 2004:104; McCartney 1974). Norton sites in the Alaska Peninsula generally contain predominantly chipped stone with some ground slate tools, with oil lamps and labrets present. Compared to previous archaeological traditions in the Alaska Peninsula, the Norton tradition is found in both the Bering Sea and Pacific coasts, representing the first time in which populations across the Alaska Peninsula may have interacted to a degree; the apparent contact between the two coasts are evidenced by the presence of pottery, chipped stone technology, and increasing populations indicated by an increase in the number of house pits (Dumond 1987, 1998b; Dumond and Scott 1991: 91, 93; Workman 1982:114). Due to this evidence of interaction, the Norton tradition contains evidence for an increase in mobility or social interactions between populations across the peninsula. However, local variations of Norton assemblages among sites in the peninsula exist and therefore the diagnostic artifacts for Norton in this region are broadly identified as net sinkers, ground slate ulus, and pottery (Bundy 2007:19).

During this time, seasonally available food resources were exploited by occupying a variety of locations across the peninsula that reflect local subsistence economies: summer fish camps are located along riverine settings, coastal sites focused on marine food procurement, and the interior contains both terrestrial and riverine food resources where many larger winter village sites are located (Bundy 2007; Dumond 1998b:194, 2000:5; McClenahan 2004:63-64). In the Chignik region, there is a progression from the Norton late prehistoric record of human populations increasingly relying on coastal subsistence strategies, seen in the increasing number of net sinkers from the sites (Dumond 1992). Local subsistence economies in the Alaska Peninsula do not appear to undergo significant changes throughout prehistory as discussed in Section 2.3 (Dumond 1998b:197).

While various influences are found in Norton sites, there is little evidence of trade items which contrasts with the contemporaneous Late Kachemak sites in Kodiak. It has been suggested that slate may have been a trade item due to its disproportionate presence at peninsula sites, for example while Pacific coastal sites contain slate tools, interior sites UGA-00049, UGA-00052, and DIL-00161 lack slate tools (Bundy 2007, Dumond 1998b:195-196; Saltonstall et al. 2012:113, 116-122). Labrets may have also been a trade item between Norton and Kachemak (Saltonstall et al. 2012). While trading does not appear to be a priority for Norton populations, Kachemak populations in Kodiak engaged in extensive trading as discussed below.

1.2.2 The Kachemak Tradition in the Kodiak Archipelago

While the Alaska Peninsula experienced influences from western Alaska, a transition from the preceding Ocean Bay II (OBII) tradition to the Early Kachemak phase of the Kachemak tradition occurred in Kodiak. Technological continuities and long term settlements provide evidence for a transition from OBII to Early Kachemak (Clark 1970, 1996:223; Steffian et al. 1998:99-101). Early Kachemak is generally defined as having plummet shaped grooved stone, oil lamps, labrets, and ground slate ulus (Clark 1996:221-222, 225). Food production increased during this time due to the increase in toolstone usage, storage pits, population density, and local subsistence procurement during the Early Kachemak which possibly led to an eventual resource depression at the end of the Late Kachemak phase (Steffian et al 2006:118-120, 121-123). This resource depression may be reflected in the dietary stress markers in Late Kachemak individuals (Steffian and Simon 1994).

The Late Kachemak phase (2700-900 BP) of the Kachemak tradition is characterized by the increase in population density and sedentism as evidenced by the increase in the number of large village sites and rounded house forms (Jordan and Knecht 1988). It has been suggested that populations from the Kenai Peninsula may have moved onto Kodiak during the Late Kachemak, increasing the population density in the archipelago (Workman and Workman 2010:95). Late Kachemak assemblages contain technological continuity from the Early Kachemak assemblages; however slate became the predominant toolstone with some flaked chert present at sites. Other differences between the Early and Late Kachemak phases include a decrease in size of notched pebbles and the appearance of heavy (about 40 kg) stone lamps (Clark 1970:92, 1998:179). A variety of personal adornment (pins, necklaces), elaborate designs and rituals for the dead evidenced in burials (drilled bones, secondary burials, and artificial eyes) are among the defining aspects of the Late Kachemak (Clark 1970:92, 1974, 1984:140; Jordan and Knecht 1988).

The settlement patterns during the Late Kachemak indicate sites were located in a variety of locations to obtain primarily coastal and riverine food resources, with large villages situated near bays close to the coast while short term summer camps are located farther inland near smaller streams (Fitzhugh 2003, Steffian 1992a). The food resources available on Kodiak vary according to location, with whales mostly migrating on the eastern coast while the productive salmon runs from Karluk River is located in the southwest (Steffian 1992a:142-144). Unequal access to food resources becomes more apparent during the Late Kachemak, as the increase in population density may have led to increased efforts to control rivers containing abundant fish runs, with large villages in southwest Kodiak located near bays (Steffian 1992a). Long term surplus food production and storage found in Kachemak sites are viewed as a precursor to the intensified social relations and emergence of possibly stratified societies that occurred the Koniag tradition (Fitzhugh 2003:320; Steffian et al 2006:118-120).

Late Kachemak populations engaged in trade/exchange with populations in surrounding regions particularly with the Alaska Peninsula. The evidence for trade and exchange during this time are non-native materials used for ceremonial or decorative purposes such as beads and coal (Clark 1970:85; Steffian 1992a; Steffian et al. 2006:15). In particular, the coal labrets present at Late Kachemak sites derived from the central Alaska Peninsula (Steffian 1992b). Similarities between Late Kachemak and Norton assemblages include labrets, net sinkers, ground slate ulus, barbed slate projectile points, pottery, and toggling harpoon heads, and the presence of food storage pits (Dumond 1981:143; Steffian et al. 2006; Hoffman 2009:24). These similarities indicate some contact or travel onto the peninsula in order to obtain resources (Steffian 1992b).

The data above indicate maintaining social relations were increasingly important during the Late Kachemak. Treatment of the dead indicates the possibility of an emerging hierarchical social structure or community/territoriality markers however other evidence for stratified societies such as unequal distributions of non-local materials and different house sizes are not observed in southwest Late Kachemak village sites (Fitzhugh 2003:225; Steffian 1992a:159-161; Steffian and Simon 1994:90). An increase in population density, possible unequal access to seasonal food resources, increasing use of personal adornment, the presence of non-local materials, and preferential treatment of the dead indicate a changing social climate on Kodiak during the Late Kachemak.

1.2.3 The Thule/Koniag Traditions in the Alaska Peninsula

The local sequence (Brooks River Camp and Ugashik River phases) on the central Alaska Peninsula are derived from the northern coastal Thule tradition, which arrived on the peninsula either by diffusion or migration between 850-650 BP. Comparative analysis between two crania from Brooks River Camp phase sites, and crania from other parts of Alaska found that the Brooks River crania were most similar to crania from Ipiutak, Tigara, and Norton Sound, while being the most dissimilar to crania from the Yukon, Barrow, and St. Lawrence Island (Hughes 1981:230-231). This would indicate the Camp phase populations on the Alaska Peninsula derive from the northwest coast of Alaska. Similar artifact typology, identical house structures, side blades, gravel-tempered pottery (possibly from St. Lawrence Island), and ground stone tool technology are evidence for the Camp and Ugashik River phases being included in the Thule tradition (Dumond 1969; Henn 1978; VanderHoek 2009; VanderHoek and Myron 2004:197; Yarborough 1974). In addition to these characteristics, the assemblages in the peninsula generally contain of ground slate tools, barbed slate points, and the introduction of ceramic/unbaked clay lamps. Similarities between northern and southern Alaska Peninsula sites persist during the Thule time period, with pottery, ground slate, and polished slate found on the southern Alaska Peninsula (Maschner 2004:104-105).

A layer of tephra ash ("Ash C") that fell around 650 BP separates these two phases across most of the sites on the central Peninsula during this time, with apparent site abandonment and re-occupation beginning between 600 BP in the central peninsula. A possible migration or some outside influence from Kodiak is attributed to the re-occupation of the central Alaska Peninsula with the appearance of the Koniag tradition; the many similarities between the Koniag tradition in Kodiak and the Alaska Peninsula include the presence of incised pebbles, ground and polished slate tool manufacturing, pottery, steam baths, triangular slate blades, and multiroom house styles (Bundy et al. 2005, Dumond 1981, 1992, 2003:102-109, 2005:36, 41-45; Harritt 1988;

Hoffman 2009:102-104; VanderHoek 2009:46; VanderHoek and Myron 2004:197; Yesner 1985). Still others believe this developed Koniag tradition represents a singular social entity that may have de-populated the area for a short time after Ash C fell, and later returned, as evidenced by the very similar assemblages between the Camp (Thule) and Bluffs (Koniag) phases including slate grinding (Dumond 1994, 2003:110; Harritt 1997:104).

Due to the abrupt changes in archaeological assemblages from Norton, Thule and Koniag traditions in the central Alaska Peninsula migratory events have been hypothesized in previous research. Migration from northern coastal Alaska to bring the Thule tradition could have experienced an "ecological pull" to the more food productive Pacific coast (Dumond 1998a:71). A genetic study shows individuals with different haplogroups, possibly from the Bering Sea or the northern Alaska Peninsula, appeared at Katmai and moved down in peninsula and west to the central and western Aleutians after 1000 BP (Raff et al. 2010:689).

In contrast to Koniag populations in Kodiak, Alaska Peninsula populations did not appear to significantly change subsistence strategies during this time. Data from late prehistoric individuals from sites located in the Alaska Peninsula yield diets comprised of locally available food resources (Coltrain 2010). The presence of non-local materials indicates trading was not as extensive in the Alaska Peninsula as Kodiak. While incised pebbles are found in site XMK-00016 and ethnographic accounts state amber was traded from Kodiak, the quantity of non-local items and number of outside influences is less in Alaska Peninsula sites than Kodiak during this time (Bundy et al. 2005; Dumond 1994; Hrdlicka 1944:80). Maintaining local subsistence patterns may have been reinforced by ethnic boundaries on the peninsula, which occurred during the time of Russian and American contact according to ethnographic accounts (Black 1977; Dumond 1998a:65-72). If subsistence patterns did not significantly change over time, Alaska Peninsula populations may not have experienced the same degree of resource consolidation that Kodiak populations engaged in during the Koniag tradition as discussed in Section 2. Population density remained relatively sparse on the Alaska Peninsula throughout the late prehistory, with the largest population centers located around the Ugashik River drainage system (Dumond 1987, 1991:103, 1998b). As explained by Hoffman (2009:102-104), locally available tool materials may have been easily accessible to new people occupying older sites if population movements occurred in late prehistory. At the same time, cultural influences instead of migration episodes could exhibit the same local toolstone procurement patterns.

1.2.4 The Koniag Tradition in the Kodiak Archipelago

The Koniag tradition begins around 900 BP, with a change in material culture characterized by ground slate, toggling and barbed harpoon heads, grooved splitting adze, and ulus along with changes in social structure discussed below (Clark 1974). The Koniag tradition has been divided into phases (Transitional: 900-700 BP, Early:700-550 BP. and Late: 550-200 BP) with the Late Koniag phase focusing on intensified fishing and increasing social stratification; these changes coincided with an apparent climate change (Jordan and Knecht 1988; Knecht 1995; West 2011); however the separation of Early and Late phases of the Koniag has been called into question, with new dates and research pointing toward slow changes occurring over time on Kodiak (Steffian et al. 2006, 2010; West 2011).

Due to the presence of Koniag material culture found in the North Pacific region and aspects of the Koniag traditions which derived from multiple locations across the North Pacific region and the Northwest coast, there are multiple theories on the origin of the Koniag tradition in the Kodiak Archipelago. Some see a movement of Koniag populations from the Alaska Peninsula to southern Kodiak, due to the older age of Koniag peninsula sites and the presence of Brooks River Camp phase (Thule) pottery found on southern Kodiak (Clark 1974:182; Dumond 1991, Dumond 1994:1-2; Oswalt 1967:245-246). Others observe an in-situ development into Koniag, seen in early Koniag sites which contain a similar tool assemblage to Late Kachemak, primarily heavy grooved splitting adzes, the use of the sweat bath, and spruce root baskets as well as physical anthropology comparisons between Late Kachemak and Koniag skeletal remains (Clark 1998:9; Jordan and Knecht 1988; Knecht 1995; Steffian et al. 2006:95; Scott 1992; Simon and Steffian 1994). There is evidence linking Koniag populations being in contact with southern Alaska, the Northwest coast and Aleutian archipelago due to the presence of petroglyphs, puffin beak personal adornment, and the similar treatment of the dead found in these locations (Clark 1974:151, 1970:14-16; Dumond 2003:105; Heizer 1956). Other research has been conducted which present a possible migration from Cook Inlet onto northern Kodiak from which the sweatbath, woodworking, and splitting adzes were introduced (Clark 1984:147; Workman and

Workman 2010). Other researchers believe Koniag is neither wholly in-situ nor a result of population replacement, but a combination of old and new elements with technological "updates" aided by mobile populations that traveled great distances (Clark 1984:148; Bundy et al. 2005:77).

While the Koniag tradition spread throughout the North Pacific region, there are additional lines of evidence that show unique connections existed between Kodiak and the central Alaska Peninsula during this time. Non-local materials from the Alaska Peninsula are found in Koniag sites (Clark 1997:45; Knecht 1995:732; Steffian 1992b). Ethnographic accounts of Koniag residents in Kodiak at the time of Russian contact claim they descended from people living on the Kvichak River on the northern Alaska Peninsula (Black 1977:98). Today the Alutiiq language is spoken by present day populations on the Alaska Peninsula and Kodiak, and linguistic data show that the appearance of the Camp phase (Thule tradition) on the peninsula coincides with the similar linguistics from Kodiak (Dumond 2005:40; Leer 2001:31). Genetic data shows populations on the Alaska Peninsula and Kodiak contain more similar genetic affinity than from other parts of Alaska: Mitochondrial DNA samples from Brooks River Koniag individuals on the Alaska Peninsula yield an affinity with Kodiak Island and Pacific coast populations (Raff et al. 2010:686-687).

Patchy resources were available in and off the coast of Kodiak, and the availability of food resources and efforts to procure resources reflects geographic boundaries in material culture and linguistics. Differences exist between site assemblages in the northeast and south/southwest Kodiak: tri-notched cobble weights were common in the northeast while stone lamps from southwestern Kodiak were distinct in style from other parts of the island, and ceramics have been found in southern Kodiak sites (Clark 1974:182, 1998, Hrdlicka 1944:327). The local variants of the Koniag tradition reflect the geographic division between differences in linguistics in Kodiak. "The slowness with which pottery spread at 1200 AD may even indicate that on Kodiak they were split into two groups, with the southwest having more in common with the Bering Sea Eskimos. There are even hints of linguistic differences" (Clark 1974:182). These linguistic differences are divided roughly into two areas on Kodiak, from the north and northeast parts of Kodiak, and the southern and southwestern coast (Black 1992:173). Koniag populations located in different parts of Kodiak focused on raiding adjacent off-island locations; the northeastern Kodiak populations raided the Kenai and Chugach populations while the south and southwest Kodiak dealt with the Alaska Peninsula and Aleutian populations (Black 1977:86, 92, 2004:140-141). The increasingly geographically fragmented Koniag populations have been attributed as a result of the development of hierarchical complex social structures (Fitzhugh 2004).

The Koniag tradition contains evidence for socially stratified societies. Ceremonial, ranked/status or ritual items were utilized during the Koniag tradition such as labrets, incised pebbles, petroglyphs; a diversity of burial practices indicate unequal wealth or division of labor among individuals. The unequal distribution of seasonal food resources led to possible control of food procurement locations that increased over time. Food procurement intensification, population growth, and possibly the changing nature of extended family relationships led to the formation of multiroom houses for additional storage, harvesting space, and sleeping quarters (Fitzhugh 2004; Steffian et al. 2006:96). While Kachemak sites vary in size (from one feature to almost 30), Koniag sites typically are village sites with a greater number of structures (Fitzhugh 2003:293-297; Jordan and Knecht 1988:232). In addition, house size doubles from the Kachemak to Koniag (Fitzhugh 2003:302-314; Jordan and Knecht 1988). The single room houses of the Late Kachemak contrast with the multiroom house form used during the Koniag in Kodiak to accommodate greater population density, with extended family relationships (Fitzhugh 2003:303, 373). The many house types found at Koniag village sites allowed for a wider variety of site functions including the kashim, meeting houses, and potential storage for redistribution and consolidation of resources (Fitzhugh 2003; West 2011). Small defensive sites located off the coast of Kodiak appear during the Late Kachemak and the size and frequency of these defensive sites increase over time, indicating more raiding efforts (Fitzhugh 2003:371; Knecht 1995:735-740). Like Late Kachemak sites, Koniag sites are located near similar locations in order to obtain seasonal food resources: salmon harvesting along riverine settings and sea mammal and whale hunting occurred at sites on the eastern coast. However sites located in riverine settings appear to belong to outside communities, suggesting some interaction took place between Koniag populations. The presence of “extraterritorial” summer fish camps located within inland riverine settings were possibly used by communities located elsewhere; this would indicate these populations /communities needed to go through the territory of pre-existing communities with villages located near the mouth of the river (Clark 1998; Jordan and Knecht 1988). This data along with ethnographic accounts of potlatches are indicative of stratified societies on Kodiak and throughout the North Pacific region (Black 1977:93; Clark 1974:153; Fitzhugh 1996:377-378, Jordan 1994; Steffian et al. 2006:96).

2.0 Research Design

Given the increase in population density, intensified efforts for food resource procurement and storage, and ethnographic accounts and archaeological evidence for intensified raiding/warfare, it is reasonable to hypothesize non-local toolstone procurement would have been different during the Koniag tradition than the Late Kachemak phase. Mafic and intermediate (basaltic/andesitic volcanics) raw material from frequent volcanic activity in the Alaska Peninsula has provided ample toolstone for prehistoric populations, whereas basalt has not been found naturally occurring on Kodiak Island in quantities sufficient for tool making; the presence of volcanic artifacts on Kodiak indicate access to sources (Fitzhugh 2003:348, 2004; Tennessen 2009:54-55, 95). While ethnographic accounts report conflict between Kodiak and Alaska Peninsula populations occurred, tools made from volcanic materials found on Kodiak during the Koniag are similar to Alaska Peninsula toolstone during both the Late Kachemak and Koniag traditions (Fitzhugh 2004; Saltonstall 1997:45; Steffian et al. 2006; Tennessen 2009:54-55, 95). Since geographic proximity to off-archipelago locations appeared to play a large role at Kodiak sites with regard to resource acquisition, the short distance between the Alaska Peninsula and Kodiak would have provided easy opportunities for Kodiak populations to obtain toolstone. With the Alaska Peninsula and Kodiak being separated by 40.2km by the Shelikof Strait at its closest distance, it is apparent toolstone was procured from the peninsula and used by Kodiak residents in late prehistory. The raiding and apparent food resource depression that Kodiak populations experienced contrasts with Alaska Peninsula Koniag sites which do not contain the same evidence and indicates relatively stable food resources in late prehistory.

The following sections provide specific data from Kodiak and Alaska Peninsula late prehistoric sites in order to make predictions about volcanic toolstone procurement over time in this region. The appearance of the Koniag tradition in the central Alaska Peninsula represents the first time a unified archaeological tradition is present in both the Alaska Peninsula and the Kodiak archipelago. While Late Kachemak sites contain evidence for trade and interaction with other North Pacific populations, the Koniag tradition in Kodiak represents intensified focus on obtaining resources by raiding or trade, and a changing pattern of obtaining and storing food resources. In contrast, Alaska Peninsula late prehistoric populations did not appear to significantly change subsistence strategies or engage in extensive trading in the late prehistory. Several approaches to examining changes in procurement patterns over time are discussed in Sections 2.1 and 2.2. Section 2.3 summarizes several changes that occurred in Kodiak from the Late Kachemak to the Koniag tradition suggesting Kodiak populations had multiple reasons to travel off-shore more frequently during the Koniag tradition. Section 2.4 lists hypotheses formed by the evidence suggesting Alaska Peninsula late prehistoric populations did not significantly alter subsistence patterns.

2.1 Recognizing Procurement Patterns According to Artifact Abundance and Weight

Examining the types of tools and debitage can reveal changes in the procurement strategies (Andrefsky 2009). In particular evidence in lithic assemblages can indicate where raw material is more or less abundant, and the proximity of a site to a source. Embedded procurement of toolstone is directly related to subsistence practices for prehistoric hunter-gatherers (Binford 1979:259-261). Determining whether populations conserved non-local lithic material over time in Kodiak can reflect changes in subsistence strategies, as procurement would have occurred during raids or seasonal rounds (Black 1977; Binford 1980). As discussed in Section 1.2.4, Koniag populations increased efforts to gain access or control of food resources which included raiding adjacent off-archipelago locations, possibly due to a resource depression from the mass harvesting of marine and riverine food resources during the Kachemak tradition (Fitzhugh 2003; Kopperl 2003). More frequent off-archipelago travel suggests Koniag populations would have conserved non-local material less than Late Kachemak populations. Conserving lithic materials can be measured in several ways. In a lithic assemblage, the relative weight of tools can be considered an indicator that residents maximized non-local lithic materials: tools and flakes will be heavier the closer a site is found to a source, if that source is easily accessible (Odell 2004:63). Flake weight in particular can reveal reduction stages of a tool, with primary and secondary flakes being heavier and most often found closer to a source (Eerkens et al. 2007). Additionally the abundance of a particular toolstone will decrease the farther away an assemblage is from a source (Mitchell and Shackley 1995; Odell 2004). If a change in the relative size and abundance of a particular toolstone occurred over time on Kodiak in late prehistory, it would reinforce previous research that showed Koniag populations had a different social structure/subsistence economy than Late Kachemak populations.

Hypothesis 1: Late Kachemak populations conserved Alaska Peninsula toolstone more than Koniag populations in Kodiak.

2.2 Raw Material Procurement According to Site Type

Sites with short term occupations are located in different places than long term occupations in the Alaska Peninsula according to the seasonality of food resources. During the Norton and Koniag traditions, winter settlements typically consist of large villages located in coastal or riverine settings while short term (usually summer fish camps) sites are oriented toward fish producing streams and rivers. Both Norton and Koniag village sites exhibit greater sedentism with year-round or semi-annual occupations suggesting logistical mobility occurred. Short term sites are expected to contain toolstone from fewer source areas; for example CHK-00005 is a seasonal fishing site, indicating people did not travel far distances (Shirar et al. 2011:17-22, 117-128). It is expected sites with short term occupations contain toolstone from fewer sources than year-round occupations. Alaska Peninsula sites will be used for this study because Kodiak sites contain evidence that populations engaged in primarily maritime/fishing economies while Alaska Peninsula sites are occupied according to the seasonality of a variety of mammals not present in Kodiak such as caribou.

Hypothesis 2: Alaska Peninsula sites with short term occupations contain less variety of volcanic toolstone than year-round occupations.

2.3 Evidence for Non-Local Toolstone Procurement Pattern Changes in Late Prehistoric Kodiak Sites

Data presented in Section 1.2 shows many differences between Late Kachemak and Koniag sites indicate the two populations engaged in embedded procurement patterns differently. The data is briefly summarized here. The differences in site location, size, and house form can be attributed to changes in subsistence practices. Late Kachemak sites contain both year-round villages and seasonal sites used with frequent re-occupation while Koniag sites consist of "large to huge winter villages, disaggregated seasonal settlements, and short term camps or locations" indicating greater sedentism and logistical mobility (Fitzhugh 2003:288, 291, 332, 369). The different sizes and forms of houses at Koniag villages show a variety of specific functions such as the kashim and storage pits for potential redistribution and consolidation of resources (Fitzhugh 2003; West 2011).

The geographic distribution of available food resources in Kodiak is further evidence for a shift in subsistence strategies over time. Koniag subsistence became more geographically segregated with food resources possibly unevenly distributed as Koniag society became increasingly hierarchical (Fitzhugh 2004; Petroff 1881:27). During the Koniag tradition, whale hunting occurred mostly in southeast Kodiak, while whaling or sea mammal remains are uncommon in Northwest and southwest Kodiak sites; this could be explained by the enormously productive salmon runs at Karluk River (Fitzhugh 2003:212, 379-380; Knecht 1995:728-730; West 2009). Bioarchaeological data of dietary stress from Late Kachemak individuals reflect times of food storages (Steffian and Simon 1994). If local food resources were insufficient for a growing population by the end of the Late Kachemak, competition for non-local resources would have increased.

This competition may have led to an increase in warfare or raiding off-shore locations from archaeological evidence and ethnographic data. The geographic separation of Kodiak subsistence practices is reflected in ethnographic accounts of fighting with geographically proximate off-shore populations (Black 1977:86, 92, 2004:140-142, 149) as well as the appearance of wooden headgear and armor artifacts occur from Koniag site KAR-00001 (Black 1994:37; Clark 1998:10-11; Hrdlicka 1944; Knecht 1995:696-699). Small defensive sites located off the coast of Kodiak appear during the Late Kachemak, with the average size consisting of one to three houses, which was used for small-scale fighting (Fitzhugh 2003:371). The size and frequency of these defensive or refuge site locations increase over time, with a Koniag refuge site near Sitkalidak Island consisting of 27 structures, indicating conflict was common (Fitzhugh 2003:332; Knecht 1995:735-740). While warfare may have taken place prior to the Koniag, increased population density would have necessitated greater efforts to obtain resources. If the Koniag engaged in more frequent travel to areas located at greater distances, Koniag populations in Kodiak would have obtained a greater proportion of non-local toolstone from places farther away than Late Kachemak populations. Village sites are compared in order to reflect a range of site activities that may have influenced toolstone procurement patterns.

Hypothesis 3: Koniag village sites contain a greater proportion of toolstone found at a greater distance in the central Alaska Peninsula than Late Kachemak village sites.

2.3.1 A Comparison of Raw Material Variability According to Late Prehistoric Cultural Traditions in Kodiak

The relatively homogenous Late Kachemak phase in Kodiak indicates populations may have obtained resources from similar locations or had more equal access to food resources. While Late Kachemak sites contain evidence of community boundaries/family identity from modified and disarticulated scattered human bones found in sites during the Late Kachemak phase (Simon and Steffian 1994), evidence for a hierarchical social structure is not as apparent as during the Koniag tradition as discussed in Sections 1.2.4 and 2.3. Late Kachemak sites do not widely vary in size according to site function, contain evidence for smaller populations and contain evidence that raiding or warfare was not a common occurrence (Fitzhugh 2004; Steffian 1992a). If Late Kachemak populations did not practice social stratification or frequently raid adjacent areas, northeast and southwest Kodiak should be obtaining volcanic materials from similar sources. Coal labrets found in the southwest Late Kachemak site KOD-00145 and the northeast Late Kachemak site KOD-00044 that are derived from Alaska Peninsula are evidence that people living in these two contemporaneous sites used material from the peninsula. Therefore these two sites are sampled to test the following hypothesis.

Hypothesis: 4 Site KOD-00044 does not contain a significantly larger proportion of volcanic materials from the Alaska Peninsula than site KOD-00145.

Based on the above data presented that northeast and southwest Kodiak populations were focused on raiding adjacent off-shore locations during the Koniag tradition, it can be expected that Koniag sites located in these two places will contain volcanic materials from different locations. If geographic proximity determines the source for non-local toolstone, sites in southwest Kodiak should contain a higher proportion of volcanic material from the Alaska Peninsula than sites in northeast Kodiak. Site KAR-00001 will represent southwest Kodiak and site AFG-00015 will be sampled for the northeast. These sites were chosen because non-local materials including coal, basalt, chalcedony and caribou bone found at AFG-00015 are described as originating from the Alaska Peninsula. The KAR-00001 site contained white chalcedony which derived from the Alaska Peninsula (Knecht 1995:732).

Hypothesis 5: Site KAR-00001 contains a larger proportion of volcanic lithic materials from the Alaska Peninsula than site AFG-00015.

In order to test these hypotheses, sites located in the southwest and northeast Kodiak are used in order to find geographic variability of volcanic toolstone procured in late prehistory. While some differences in material culture exist between the two areas of the Kodiak archipelago, non-local raw materials on Kodiak have been assumed to derive from the Alaska Peninsula regardless of the location of the Kodiak site. The Kodiak sites provide both geographic and assemblage variability of late prehistoric sites in Kodiak. Contrasting Koniag sites with Late Kachemak sites located in the same areas can reflect potential changes in the direction from where toolstone was originating. Therefore, Late Kachemak site KOD-00145, located near KAR-00001 is used for comparative analysis for southwest Kodiak sites and Late Kachemak sites. Similarly, Late Kachemak site KOD-00044 is located near Koniag site AFG-00015. Site descriptions are listed in Section 4.

2.4 Evidence for Static Local Toolstone Use in Late Prehistoric Central Alaska Peninsula Sites

In contrast to uneven distributions of food resources across Kodiak, Alaska Peninsula populations encountered relatively stable available food resources in late prehistory as archaeological, bioarchaeological and ethnographic data yield. Coupled with low population density, Alaska Peninsula populations may not have experienced the same degree of food competition or need for food consolidation as Kodiak residents experienced and therefore longer distance travel or changing procurement patterns for toolstone may not have taken place. This section summarizes the several lines of evidence that show toolstone procurement locations would not have significantly changed over time.

Data from previous research supports a static local subsistence economy throughout the late prehistory. Analyzing nitrogen and carbon stable isotopes from individuals in Mink Island

(XMK-00030) during the Koniag tradition, at Brooks River (XMK-00001) during the Thule tradition, and Port Moller (XPM-00001) dated to the last 3000 years yielded evidence of diets that reflect localized subsistence strategies. The results from this study found that Koniag individuals in Mink Island subsisted almost exclusively on marine food, and the Thule Brooks River individuals experienced a more balanced diet of terrestrial and marine food. The Port Moller samples yielded a reliance on marine food, however not as heavily as eastern Aleutian individuals (Coltrain 2010). The Thule XMK-00001 and Koniag XMK-00030 individuals represent local or seasonal subsistence economies. Additionally, faunal and ethnographic data show relatively static subsistence patterns for Alaska Peninsula populations in late prehistory. Faunal remains from Brooks River, Naknek River and upriver sites in the north-central Alaska Peninsula show populations ate a varied diet and include terrestrial, bird, sea mammal, and fish with no significant change in diet between Norton and Thule/Koniag components (Dumond 1998b:197). Ethnographic accounts show local subsistence strategies may have been segregated according to ethnic boundaries: frequent warfare among communities and migrating populations occurred at the time of Russian and American contact (Black 1977; Dumond 1998a:65-72). One seasonal round from the Naknek drainage has been recorded by early twentieth century accounts as moving across the passes of the Aleutian Range to hunt sea mammals on the Pacific Coast each winter, and that this winter movement was established prior to Russian contact; similar assemblages between the Pacific coast and Bering coast Norton populations show interaction (Davis 1954; Dumond 1969:1111). Regarding food resource stability in late prehistory, Dumond (1998b:189) states: "fauna that ethnographic and archaeological evidence indicate were sought consistently enough by humans to have had an impact upon the placement of settlements appear to have been stable over time." Since raw material abundance is related to seasonal subsistence strategies, it is expected no changes in raw material availability occurs over time in the central Alaska Peninsula (Odell 2004:85).

While Norton sites contain some influence from other archaeological traditions and the Koniag tradition spread across the Alaska Peninsula as time progressed, the relative lack of trade items and smaller population in the central Alaska Peninsula gives further evidence that long distance travel by central peninsula populations did not occur in a similar way Kodiak populations engaged in. While pottery from northern Alaska is present in northern and Bering Sea coast

Norton sites, Pacific coast sites contain polished slate ulus and kashims, indicating some influence from Late Kachemak (Dumond 1998b:195-196). In the lower central Alaska Peninsula, the possibility of similar influences from the Aleutian and Kachemak cultural traditions, including UGA-00052 and SUT sites, has been raised by researchers (Maschner 2004; Hoffman 2009:108; VanderHoek and Myron 2004). During the Koniag tradition, influence from Kodiak is apparent from information discussed in Section 2.2.4 and possible trade or prestige items during this time includes incised pebbles found at site XMK-00016 with ethnographic accounts of trade items such as amber from Kodiak occurred (Bundy et al. 2005; Dumond 1994; Hrdlicka 1944:80). However the same frequency of elaborate designs and ornate creations from non-local materials found in Kodiak during the Late Kachemak and Koniag are not found in the central Alaska Peninsula. The lack of extensive trade and hierarchical societal structure in the central Alaskan Peninsula may be partially explained by a relatively smaller population density than Kodiak (Dumond 1991, 2003:105-106).

Possible migratory events occurring in the Alaska Peninsula in late prehistory (Dumond 1998a:71, 2003; Raff et al. 2010) have been theories for the appearance of different cultural traditions and haplogroups in the peninsula however abrupt changes in faunal remains are not recorded. If populations moved across the peninsula or to different locations, finding immediately available toolstone in the vicinity of terrestrial food would have not been difficult (Hoffman 2009:102-104). The possible migration of Kodiak populations onto the central Alaska Peninsula that brought the Koniag tradition could have been possible due to low population density of pre-existing peninsula residents. Given the static food resources, similar subsistence strategies, relatively low population density, and possible waves of migrations and re-settlements in the central Alaska Peninsula throughout the late prehistory, it is expected that no difference in local toolstone procurement over time.

Hypothesis 6: There is no significant difference in the direction from where toolstone was originating between Norton and Thule/Koniag aged central Alaska Peninsula sites.

2.4.1 A Comparison of Raw Material Variability According to Late Prehistoric Cultural Traditions in the central Alaska Peninsula

Based on the above data, it is expected Norton populations used locally available lithic materials; the locations of these materials are a result of the locations of lava flows and areas where pyroclastic ejecta were produced from eruptive events. The frequent eruptions in late prehistory in the Alaska Peninsula (discussed in Section 1.1.1) resulted in pyroclastic flows and debris that became potential volcanic lithic materials for Alaska Peninsula populations. The large-scale eruptions of Aniakchak (3500 BP) and Mount Veniaminof (3700-3500 BP) created zones of pyroclastic flow; the geographic boundary zones of the flows (VanderHoek and Myron 2004:Figure 7-4). Other sites are located near river drainage systems, which transport sediment and cobbles from the Aleutian Range. Populations located near these flows and lithic materials would have used different types and sources of volcanic lithic materials than those located farther away (Section 1.1.3). Therefore the abundance of volcanic material on the Alaska Peninsula has remained static and readily accessible to late prehistoric populations.

Hypothesis 7: All Norton sites do not contain the same proportions of toolstone from the same likely sources.

During the Koniag tradition, influence from Kodiak is apparent from data from previous research discussed in Section 1.2.4 and possible trade or prestige items during this time includes incised pebbles found at site XMK-00016 and ethnographic accounts of trade items such as amber from Kodiak (Bundy et al. 2005; Dumond 1994; Hrdlicka 1944:80). However the same frequency of elaborate designs and ornate creations from non-local materials found in Kodiak during the Late Kachemak and Koniag are not found in the central Alaska Peninsula. The lack of extensive trade and hierarchical societal structure in the central Alaskan Peninsula may be partially explained by a relatively smaller population density than Kodiak (Dumond 1991, 2003:105-106). It is expected Koniag populations in the Alaska Peninsula used the same available volcanic lithic materials according to proximity to a source.

Hypothesis 8: All Koniag sites in the Alaska Peninsula do not contain the same proportions of toolstone from the same likely sources.

Selected Norton and Thule/Koniag aged sites were chosen from various locations across the central Alaska Peninsula and is expected to represent the variability of volcanic raw material element values. Norton sites used for this study are DIL-00161, UGA-00052, and CHK-00005 .The different influences from sites SUT-00024 and SUT-00027 includes Aleutian and Kachemak traditions, and will be used as a contrast to the other Norton sites. Sampling from the lower central Alaska Peninsula Pacific coastal areas (Ugashik, Sutwik, and Chignik quadrangles) was performed in order to obtain ranges of element values from this area near Aniakchak and Black Peak, where caldera forming eruptions occurred in late prehistory (Section 1.1). Sites located in the Katmai National Park and Preserve, XMK-00007 and XMK-00016, represent a sample of toolstone used in the Katmai area and are expected to contain different toolstone element values than sites located farther south.

If the Koniag tradition on Kodiak represented of greater access to a wider geographic range than the Late Kachemak tradition and it is reflected in volcanic material procurement, it would be expected that Late Kachemak populations obtained toolstone from a smaller geographic range than Koniag populations in Kodiak. Additionally lithic conservation is expected to increase in sites located farther away from a likely source. However lithic procurement patterns may not have significantly changed during over time in Kodiak; a greater variety of outside influences or increasingly hierarchical social structures may have occurred during the Koniag tradition, but may not be observed through differences in toolstone procurement locations. From this perspective, Koniag populations in Kodiak would not have obtained volcanic toolstone from the Alaska Peninsula more frequently from greater distances than Late Kachemak populations and no clear pattern would emerge from examining the volcanic raw materials found at sites.

3.0 Methods

This section contains an overview of all methods used for this study. Theoretical and technical issues with using PXRF are discussed first, followed by an explanation of the sampling strategy and the ways data was collected. Maps of sites and a list of site information are found in section 3.2. The end of this section contains an outline of the methods employed for subsequent statistical tests and the ways XRF data was analyzed.

3.0.1 Measuring Changes in Toolstone Procurement Location

X-ray florescence (XRF) is a non-destructive method in which artifacts can be sampled to find proportions of elements (Pollard et al. 2007). Differences in element proportions among samples can be used in order to find sources where lithic materials originated. While most XRF studies rely on geological sources for provenance studies, this study uses volcanic toolstone found at contemporaneous Alaska Peninsula sites in order to compare contemporaneous toolstone used at Kodiak sites. Out of the 80 established volcanoes on the Aleutian Arc, obtaining geological data from volcanic activity can obscure tool-quality raw material. Samples are grouped together by similar element values and are used as proxy source material; this topic discussed further in Section 3.1. Comparing element values from volcanic toolstone on Kodiak to the Alaska Peninsula was performed in order to find possible differences over time.

In order to evaluate the hypotheses, several tests were performed. XRF assays were performed on samples from Norton and Koniag aged sites on the Alaska Peninsula. The elemental data from each sample was taken and clustered into “groups” by finding similar values for 5 elements: Sr, Rb, Zr, Y, and Nb using hierarchical cluster dendrograms and statistical analysis. Each Alaska Peninsula sample belonged to a group; these groups formed the variability of volcanic toolstone in the central Alaska Peninsula. Late Kachemak and Kodiak aged samples from Kodiak underwent the same XRF measurements and these samples were subsequently filtered into an appropriate group if possible.

3.1 XRF and Provenance Studies

Using XRF technology for the purpose of obtaining element values from a sample and comparing it to the element values of a geological source is the main method for conducting provenance studies. Prior to analyzing artifact samples, XRF data is obtained from source samples in order to find the variation of element values within a source. This method has proved particularly successful with obsidian provenance studies. While obsidian trace element values tend to neatly cluster per source, the many sources for volcanic material in the central Alaska Peninsula can obscure discrete ranges of element values when using only source data to find procurement patterns in this region. While 44 of the 54 active volcanoes in the U.S. are found in the Aleutian Range, there are multiple smaller sources of volcanic material including rear-arc volcanoes, domes, outcrops and other mafic units in the central Alaska Peninsula (Hildreth et al. 2006). The 2500 km long Aleutian Range has contained over 100 eruptions since 1760 (Kiehle and Nye 1990:10; Miller and Richter 1994:776).

Rather than yield a discrete cluster, mafic and intermediate sources located in close proximity contain gradients of change among trace element values due to expansive basalt plains (Kienle and Nye 1990). Johnson et al (1996:107, Table 7) shows that the differences in trace element ratios become larger as the distance between the two volcanoes is greater. The closer the volcano, the less difference in trace elements they are.

> From (mount) Fisher to Veniaminof, post-caldera volcanism is mafic, whereas from Black Peak to Kaguyak, post-caldera volcanism is intermediate to silicic. The abrupt change in two different compositional trends in the same area suggests a common cause, which we believe is related to the nature and extent of continental crust [Miller and Richter 1994:770].

Therefore the thickness of the continental crust impacts magma composition; the central Alaska Peninsula represents a small geographic part of the Aleutian Arc. Wide geographic sections of the Aleutian Arc contain different types of magmas perhaps due to the different thickness in the continental crust, with the eastern portion of the arc being dominantly calc-alkaine andesite while the central portion contains mostly tholeiitic basalt and basaltic andesite (Kienle and Nye 1990:13). Representing the western portion of the Aleutian Arc, the magmas from volcanoes in the Aleutian Archipelago were compared by Johnson et al. (1996:96) and were found to be comprised of similar compositions: “The absence of significant isotopic and trace element differences between lavas from the eastern and western Aleutians also supports the derivation of parental melts from similar mantle sources.” (Johnson et.al 1996:96). Additionally, magma sources for eruptions in this region have been documented as moving from sources underground and affecting other volcanoes in this area.

> Wallman et al. (1990) conclude that the direction of maximum regional stress, the strike of regional joint systems, and the line of fractures between Mt. Trident and Novarupta favor the hypothesis that magma for the 1912 eruption moved from Trident to Novarupta and that collapse of the summit of Mt. Katmai was related to withdrawal of magma towards Mt. Trident rather than directly towards Novarupta. Thus the magma source for the 1912 eruption may well have been the edge of the magma body inferred in this paper [Ward and Pitt 1991:1539].

Therefore several volcanoes may share parental magma source, and these magma bodies can shift over time.

Different lava flows from the same source can be overlapped over time and can obscure eruptive history if only comparing element compositions. A study by Forbes et al. (1969) analyzed six andesite flows from the six eruptions between 1953-1960 from the Trident volcano located in the Katmai National Park and Preserve that two “batches” of magma were produced during this time and (Forbes et al. 1969:110). Additionally Hildreth and Fierstein (2003: Figure 3) presents data that show element values of materials from volcanoes in the Katmai region overlap.

Pinpointing which specific outcrop or source that populations used would require trace element values to be obtained for each possible source/flow in order to find a range of values; this would depend on the assumptions that the landscape was not altered by volcanic activity and that the specific sources produced tool quality volcanic materials. This particular topic has been addressed in XRF basalt studies from Hawaii and reflects the difficulties in matching one source to an artifact:

> Major and trace element concentrations in basalts tend to be more heterogeneous than in obsidian and also exhibit less geographic distinctiveness because of the more continuous and expansive nature of mafic eruptions. Major Polynesian basalt quarry sites have been characterized and compared (Sinton and Sinoto 1997; Mills et al. 2008), but minor sources with similar geochemical signatures, such as cobbles from gulches or dense basalt from dikes, confound our ability to make exclusive associations with specific sources. There have been a number of extensive geochemical datasets published for Hawai'i…but these studies are not focused on the specific flows that Hawaiians used to make tools [Lundblad et al. 2011:66].

Due to the reasons listed above, it is more productive to compare contemporaneous archaeological artifacts within the Alaska Peninsula in order to find larger trends in the element data rather than pinpoint exactly which source the samples may have originated. Many believe the volcanic lithic raw materials found on Kodiak came from the Alaska Peninsula due to the ubiquity of volcanoes, the frequent volcanic activity, and the close proximity between Kodiak and the peninsula (Fitzhugh 2004:29-34; Steffian et al. 1998:82-83; Steffian et al.2006:118-120). Assuming Alaska Peninsula populations used locally available volcanic toolstone, comparisons are made with volcanic toolstone found in Kodiak sites in order to find associations in element data.

3.2 Sample Selection

Samples were selected for a variety of reasons, controlling for time, cultural affiliation, geographic regions within the study area, and site function. Sites on Kodiak were selected according to southwest/northeast geographic locations in order to compare local variants of Late Kachemak and Koniag traditions, while Alaska Peninsula sites were selected according to the appearance of Norton and Thule/Koniag tradition and local variants. Sites from Kodiak were chosen because they contain stone from the Alaska Peninsula; See Section 4 for site descriptions. Sampling from the lower central Alaska Peninsula coastal areas (in Ugashik, Chignik, and Sutwik Island quadrangles) was performed in order to examine locations where potential migrations took place (Dumond and Scott 1991). Two Alaska Peninsula sites, SUT-00024 and SUT-00027 are not defined by researchers as either Norton or Koniag but as a combination of Port Moller/Aleutian and Kachemak influences (Vanderhoek and Myron 2004:197-198). Therefore these two sites are not defined in this study as either a Norton or Koniag component but were used in order to look for potential variability in toolstone during the Norton tradition time period. Year-round and seasonal sites (villages and fishing camps) were sampled in order to compare differences in procurement patterns according to site functions. Sites are located within a wide geographic spread of Alaska Peninsula sites from the Alagnak River to Chignik for two reasons: to find the variability of element values among late prehistoric central Alaska Peninsula sites, and to determine if tools remained locally procured over time. Discussion of site selection is also found in Sections 2.3 and 2.4.

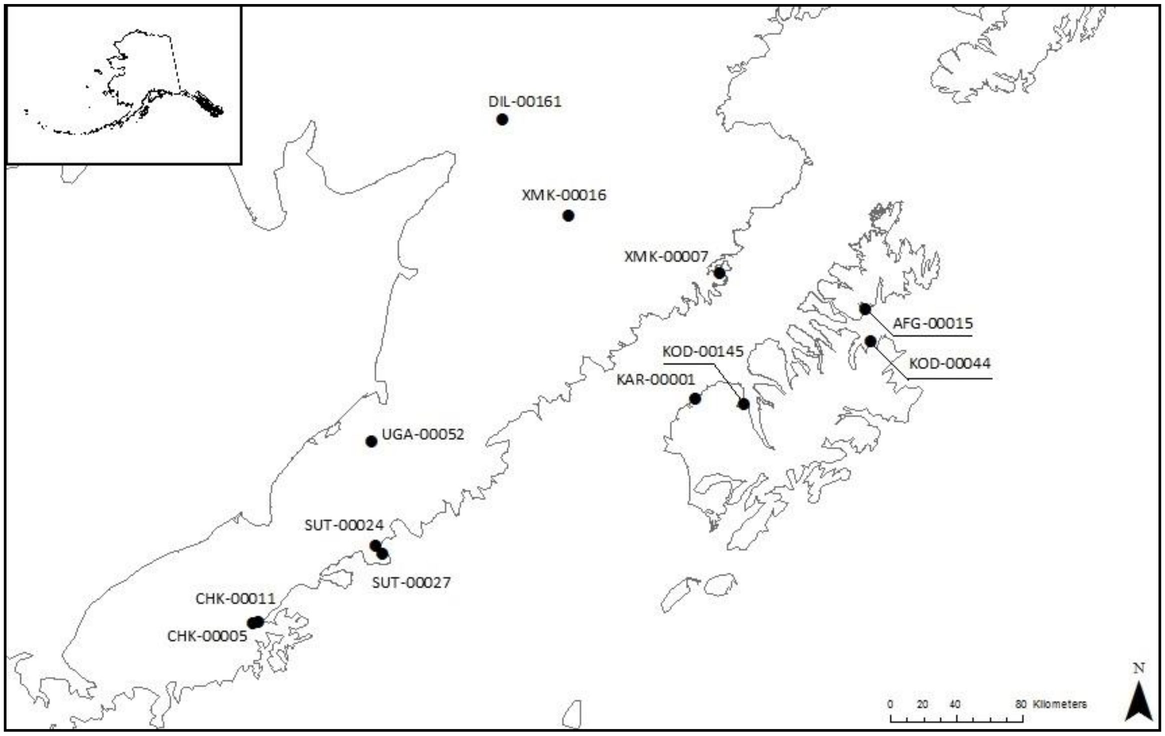

Figure 3.1. Sites used for this study.

In total, 188 samples were used for this study: there are 103 artifacts sampled from the Alaska Peninsula (from 8 sites) and 70 samples from Kodiak and Afognak Islands (from 4 sites). In addition to the artifacts, 15 geological samples taken from the ground surface from the Aniakchak National Monument and Preserve during the 2010 field season were used. Twenty eight samples are contained within Koniag components or sites on Kodiak, 45 from Alaska Peninsula Koniag/Thule sites, 42 from Late Kachemak components or sites, 44 from Norton components or sites, and 14 samples from SUT-00024 and SUT-00027. Flakes represent 72.6 percent of the total sample number with samples not selected according to the presence of cortex. Descriptions of artifact type for each sample consist of both previous identifications found in catalogs and site reports, as well as new identifications provided by several researchers including myself.

Samples were selected if its surface area had the following requirements for PXRF: relatively flat surface, no dirt/contaminants, no phenocrysts, and large enough for the beam but not too heavy for the platform. Additionally each sample contains a value of >5000ppm of Fe, per the observation by Dr. Jeff Rasic that 923 of 955 basalt and 1021 of 1124 andesite samples from Alaska contain more than 5 percent FeO.

Table 3.1 contains information from each site used in this study. Information was gathered from site reports, artifact catalogs, previous research, and the AHRS. The dataset in Appendix C displays additional information for each sample.

Table 3.1. Site and Sample Information

Site	Component (age, BP)	Type	Feature	Season	N samples
			Alaska Peninsula		
CHK 005	Norton (2000-1800)	Fishing station	House	Seasonal	31
CHK-011	Koniag (600-400)	Lithics	Scatter	Unknown	21
DIL-161	Norton (2400-1200)	Village	House	Year-round	17
SUT-024	Port Moller/ Aleutian/ Kachemak (1600-1100)	Village	House, Kashim	Unknown	10
SUT-027	Port Moller/ Aleutian/ Kachemak (1600-1100)	Village	Shell midden, house, storage pits	Unknown	4
UGA-052	Koniag (600-400)	Settlement	House	Year-round	2
UGA-052	Norton (1500-1000)	Village	House	Year-round	17
XMK-007	Koniag (400-0)	Fishing station	House	Seasonal	12
XMK-016	Koniag (600-0)	Settlement	House, burial	Year-round	20
			Kodiak		
AFG-015	Koniag (800-400)	Village	Houses	Year-round	24
KAR-001	Koniag (550-100)	Village	Houses	Year-round	13
KOD-044	Late Kachemak (2200-1800)	Village	House	Seasonal	16
KOD-145	Late Kachemak (1400-1000)	Village	House	Year-round	34

Table 3.2. Additional Site and Sample Information

Site	Component (BP)	Artifact type
Alaska Peninsula		
CHK-00005	Norton (2000-1800)	Flake (4), interior flake (10)
CHK-00011	Koniag (600-400)	Biface (1), biface fragment (3), flake (1), flake tool (1), interior flake (12), uniface (1)
DIL-00161	Norton (2400-1200)	Biface (1), cobble (1), flake (14)
SUT-00024	Port Moller/ Aleutian/ Kachemak (1600-1100)	Biface (2), flake (8)
SUT-00027	Port Moller/ Aleutian/ Kachemak (1600-1100)	Flake (4)
UGA-00052	Koniag (600-400)	Flake (4)
UGA-00052	Norton (1500-1000)	Flake (7), waste flake (3)
XMK-00007	Koniag (400-0)	Biface (1), biface fragment (1), flake (4), flake tool (1), interior flake (1), uniface (2)
XMK-00016	Koniag (600-0)	Flake (12)
Kodiak		
AFG-00015	Koniag (800-400)	Adze part (3), biface (1), biface blank (1), core (1), flake (7), secondary flake (1), thinning flake (1)
KAR-00001	Koniag (550-100)	Core (1), flake (11), stemmed projectile point (1)
KOD-00044	Late Kachemak (2200-1800)	Biface (5), ground tool (6), interior flake (2), projectile point (3)
KOD-00145	Late Kachemak (1400-1000)	Biface (6), biface preform (1), core (2), flake (14), projectile point (1), stemmed projectile point (1), utilized flake (1)

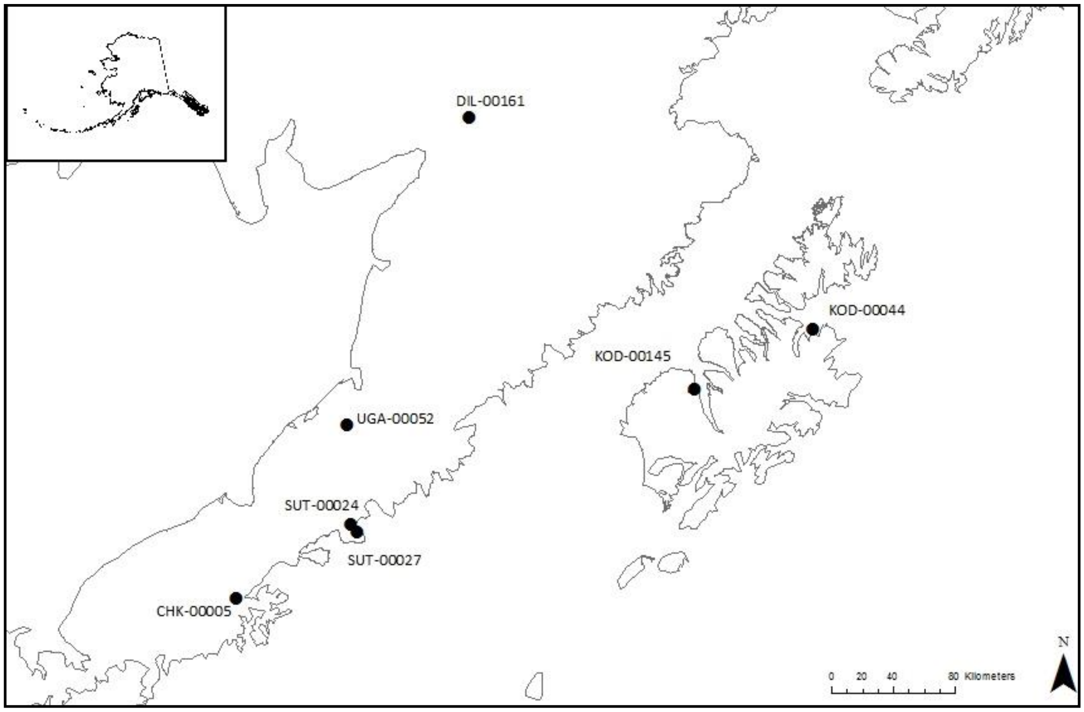

Figure 3.2. Norton, Late Kachemak and contemporaneous sites.

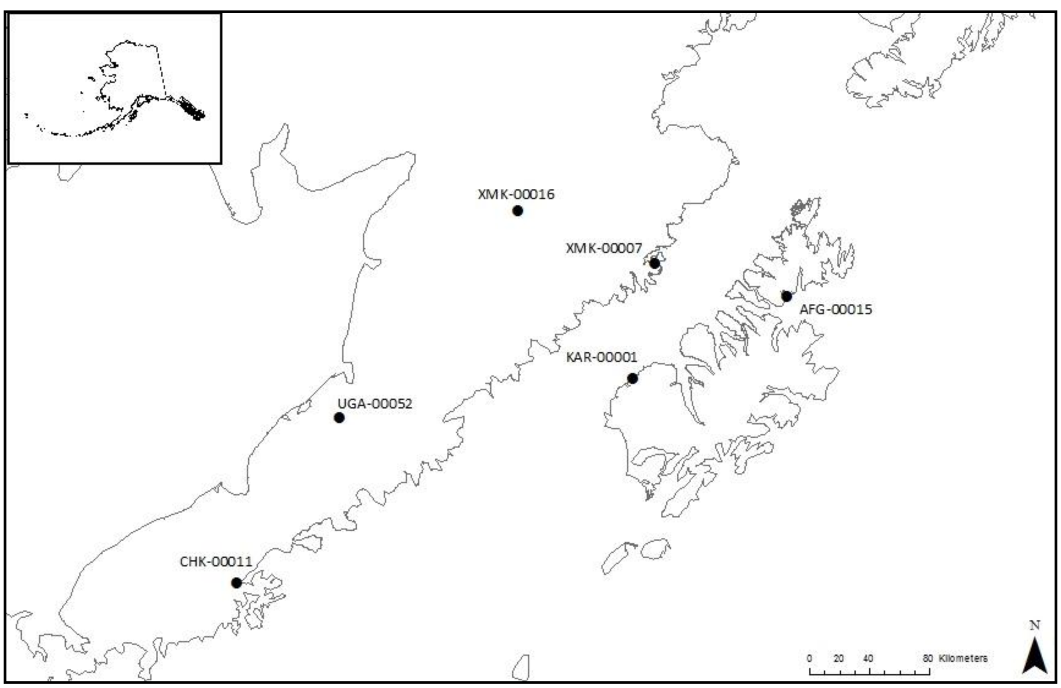

Figure 3.3. Koniag sites.

3.3 Data Collection

The Bruker 510 Tracer 3-V portable x-ray fluorescence instrument housed at the University of Alaska Museum of the North was used to generate all XRF values. The instrument was set for the following parameters: 40keV, 15 nA, and 300 live seconds (lsec) with an Al-Ti filter for each sample. 300 lsec was chosen due to the dense and heterogeneous nature of the rock types (Liritzis and Zacharias 2011:127-131). The S1SPXRF software (Bruker) collected raw x-ray intensities (counts) which were converted to concentrations (parts per million, ppm) with the KTIS1 Calibration excel macro. The elements used for analysis in this project were Sr, Rb, Zr, Y and Nb. See Appendix A for a more in-depth explanation of elements chosen for analysis. The dataset contains the elemental concentration data (in ppm). Next to each element listed on the spreadsheet is the energy line from which the photoelectrons are emitted from the samples (the photons from each element was obtained from the first k energy shell of a particle, "Ka1").

All samples were analyzed non-destructively. The most flat surface of the sample devoid of macroscopic inclusions with a surface large enough for the 4mm diameter beam was placed onto the platform of the PXRF instrument. Each sample was removed from its artifact bag or container and placed directly onto the platform/in the path of the beam for 300ls.

3.3.1 Calibration Co-efficient

Precision of an XRF machine is commonly calculated by measuring standards on the machine and comparing the results (Hughes 1998:108). The calibration co-efficient was created with seven USGS pressed powder standards obtained from the UAF Geology department in the AXIOS XRF laboratory. The standards consisted of six basalt (BCR, BE-N, BR, BIR-1, JB-2, and NBS-688) and one andesite sample (AGV-1). The andesite sample was chosen in order to keep the regression line from being limited strictly to mafic element values. As intermediate and mafic rocks are defined in a range of values, adding a variety of rock types ensures more samples can be more accurately defined. Using the KTIS1 excel macro, the counts obtained from running each standard under the beam for 300 lsec were compared to the published, known values for each. The discrepancies between the two numbers were shown for each element to be analyzed, and some elements had one standard removed if it was an outlier that significantly changed the fitness of the line. Interferences and backgrounds were automatically taken into account by the software (for example SrKb interferes with the ZrKa peak). Once the co-efficient was created, it was applied to each sample by converting each pulse count per element into ppm data using regression lines. See Appendix B for a comparison of different Compton energy ranges from samples used for this study.

3.4 Statistical Methods

This section details the steps taken to establish likely local toolstone sources using Alaska Peninsula samples and subsequent statistical tests performed in order to compare all samples (including Kodiak samples) across space and time. The results from these tests form the discussion and are used to evaluate the hypotheses.

3.4.1 Determining Groups using XRF Data

Comparing element values from Alaska Peninsula samples was performed in order to create groups of similar element values. There are several methods researchers have used to create groups from samples containing similar element values. Biplots and triplots can illustrate differences among element values of samples depending on which elements are analyzed and can be helpful visualizations of the data (Shackley 1988:763-764). There has been some debate regarding the importance of creating clusters or groups by statistical methods versus visual inspection by the researcher in order to create groups (Shackley 2010). In order to test the difference between grouping samples based on similar values by visual observation and samples grouped together from SPSS-generated cluster output, samples were manually inserted into groups from my own visual observation. The group assignments of samples using SPSS and results from manually created groups were subsequently compared and discussed in Section 5.1.

Cluster analysis can result in useful groupings of samples with similar values, as can discriminant and factor analysis (Glascock et al. 1998; Shackley 2010). Hierarchical clustering was performed using several methods. Discriminant cluster analysis is the most common method using XRF data in archaeological studies and is useful for comparing discrete sources from distant locations, however this particular method was not chosen for this study due to the ubiquity of many possible sources within a relatively small geographic range. Therefore hierarchical cluster analysis is used in order to find differences among relatively homogenous values. Additionally, discriminant cluster was not used because the predictor variables needed were already established (the five elements). Three cluster analysis tests were subsequently performed using the following hierarchical methods: within group linkage, complete linkage, and Ward's Method for the samples from the Alaska Peninsula. The median method was used because the clusters are combined without taking the number of cases per cluster into account; since this clustering is exploratory, it is important to include a cluster method that weighs each cluster evenly. A different clustering method, complete linkage (furthest neighbor),computes the distance between two clusters as the distance between the furthest two points, allowing the differences between clusters to be represented by the distance. Ward's method is the third method used because it allows for the least amount of variance (Norusis 2011:387-388). The dendrograms from methods provided useful comparisons of the results. The goal of interpreting the output of the dendrograms was to find the greatest dissimilarity between all clustered samples. The results of these methods were correlated together in order to arrive at a final group arrangement; using several cluster analysis methods and finding positive correlations between each method strengthen the 'true' validity of the groups. The cluster results from Ward's method were chosen as the final group designation for samples because this method allows for the least amount of variance. The results of the cluster analyses formed six groups based on similar element values. Kodiak samples were subsequently fit into the groups formed by the Alaska Peninsula using the same Ward's method in SPSS.

3.4.2 Comparing Samples According to Assigned Groups

After establishing a group number for every sample, the samples were compared according to size of tool type, site location, component, and time period. The purpose of these tests was to determine if differences exist in the abundance and variability of toolstone element values across space and time on Kodiak and the Alaska Peninsula. Two-tailed (α=0.05) chi-square (and Yate's continuity when applicable) tests were performed. Chi-square tests were used for these tests in order to determine if samples were evenly distributed. If the expected cell size of less than 5, Yate's Continuity Correction was calculated for that particular cell. Fisher's exact test was used when samples with an expected cell size of 5 or less on a 2x2 contingency table when applicable. ANOVA is used for sites with more than 30 samples even if an expected cell count is <5 because it allows for expected cells of zero by comparing means between groups/sites in this study. In the chi-square tables in Section 5, the rows labeled “Obs.”=Observed frequency and “Exp.”= Expected frequency.

In order to compare the samples by time period, the Alaska Peninsula samples were separated into two periods: Early and Late. This was done in order to include dated samples with no component/cultural affiliation information given, and in order to group contemporaneous samples together with different components/cultural affiliations. Samples were defined as either “Early” or “Late” time periods by their cultural affiliation or dating information. The “Early” time period consists of samples with the following components: Early Kachemak, Late Kachemak, Norton, SUT-0024, and SUT-0027. The “Late” time period consists of Koniag samples on the Alaska Peninsula and Kodiak, as well as nine samples with components labeled as ‘Eskimo’ in AHRS from XMK-00007 with a Koniag-aged date from AHRS. The geological samples were used for comparative purposes in Section 6.

4.0 Site Descriptions

In order to provide context of the sites used for this study, this section contains a brief summary of each site. Each area within this study region contained different influences throughout the late prehistory, and these influences are represented in each site according to location. While some sites have been widely researched, other sites are relatively recent and have not undergone extensive analysis by multiple researchers. Therefore some site summaries contain less information than others; however most key characteristics of each site including site function, seasonality, and lithic assemblages are listed. Data compiled from site reports, publications, repository catalogs, and AHRS comprise the summaries.

AFG-00015

This Koniag winter settlement was excavated for the Afognak Native Corporation from 1994 to 1997. One multiroom house and sections of six other multiroom houses were excavated. Clay lined pits and slate boxes were used for salmon storage and cooking. Key Koniag artifacts were found including greenstone adzes and incised pebbles (Saltonstall 1997:43). Marine fishing and sea mammal hunting were practiced at the site, with harpoons and fishhooks present with few net sinkers for shallow water fishing. Faunal remains indicate residents ate a varied diet at this site: cod, scuplin, and salmon fish with sea mammals (seals, sea otters, whales), and birds, and shellfish (Saltonstall 1997:47).

Non-local artifacts were found such as red shale (Kenai Peninsula), one dentalium shell (from the southeast), and a Punuk style harpoon (St. Lawrence Island). The presence of coal, basalt, chalcedony, and caribou bone were attributed as coming from the Alaska Peninsula (Saltonstall 1997:45). The site was subjected to tidal waves due to its location and subsequently its abandonment has been attributed to a probable tidal wave (Saltonstall 1997:4).

CHK-00005

This Norton site is located at the confluence of Chignik Lake and the Chignik River. Dumond recorded the site in 1975 and a 2010 survey by the National Park Service and the Museum of the North, four cultural depressions are found at the site featuring at least two single room houses (Shirar et al. 2011:17, 113). The relatively large quantity of artifacts for this area and the depth of artifacts indicate a long occupation. Fishing was the primary subsistence activity, evidenced by the majority of artifacts consisting of flakes and net sinkers, and basalt is the predominant tool material (Dumond 1975:10, 1992:93; Shirar et al. 2011:17-22, 117-120).

CHK-00011

Dumond recorded this site along with CHK-00005 in 1975; among the artifacts were polished slate ulus and blades (Dumond 1975:12). No house depressions were found but local reports of artifacts led Dumond to survey the area. Overall few artifacts were found, with the majority consisting of slate flakes. This site has been attributed to the Koniag tradition on Kodiak due to the presence of polished slate (Dumond 1992:100).

DIL-00161

DIL-00161 is a large winter Norton village site located on the Alagnak River in the central Alaska Peninsula containing numerous cultural depressions (Hilton 2002). The house forms are Norton: single rooms containing a central hearth. The majority of artifacts are flakes and ceramic sherds (Hilton 2002:82). Chipped stone tools were predominant, with few ground stone tools present. Projectile points share similarities with those of the Naknek drainage phases of the Norton tradition (Bundy 2007).

KAR-00001

This large village site located in southwest Kodiak has been considered the most important site in defining the Koniag tradition. Hrdlicka first discovered this site in 1932 and (Hrdlicka 1944:102-104) it has been subsequently surveyed and excavated numerous times, revealing a long history of occupation (Jordan and Knecht 1988; West 2011). Situated on the coast facing the Katmai area of the Alaska Peninsula, KAR-00001 is advantageous located within the North Pacific region, allowing for easy access to both the Karluk River system on Kodiak and the Pacific Ocean. Fishing implements, harpoon heads, fish fauna, and ulus shows intensive fishing from the Karluk River occurred throughout the site occupations (Jordan and Knecht 1988:382-400).

The variety of artifacts has led to a wealth of knowledge regarding Koniag subsistence and ceremonial practices. Incised pebbles, figurines, labrets, ceramics, bentwood boxes, toys, and masks are among the items now known to be key artifacts of the Koniag tradition (Jordan and Knecht 1988:386-400). Factors involved in late prehistoric life from this time period has been examined in order to find possible catalysts for the emergence of the Koniag tradition on Kodiak, including climate change, social relations, and subsistence strategies (Clark 1998; Fitzhugh 2003; Jordan and Knecht 1988; Knecht 1995; West 2011).

KOD-00044

KOD-00044 is a seasonal village site on northeast Kodiak Island is located at the mouth of Anton Larsen Bay. Its location near salmon streams and predominance of net sinkers and fishing gear at the site is evidence that residents of the site engaged in intensified fishing. Frequent re-occupation of the site is observed by its many house floors and high density of artifacts, with Ocean Bay, Kachemak, and Koniag traditions at the site (Clark 1970, 1974:79). Human remains reveal nutritional stress was encountered at the site during the Late Kachemak phase (Steffian and Simon 1994). Due to the many dates from this site, samples within levels L-1 and L-2 dated to the Late Kachemak are used for this study (Jordan and Knecht 1988:272; Mills 1994:143).

KOD-00145

This year-round village site is located at the mouth of Larsen Bay and contains roughly 45 cultural depressions. This site has a long history of archaeological research, with discovery by Hrdlicka in 1931. The history of research at this site includes determining the differences between Koniag and pre-Koniag components, with various names attributed to components differently as time progressed. Hunting and fishing equipment, personal adornment, and food production equipment is present at the site. KOD-00044 does not contain net sinkers, and marine or deep sea fishing was likely occurring at this site similar to site AFG-00015 discussed above (Hrdlicka 1944:99-101, 135; Heizer 1956). Due to its larger size and evidence for a wide range of activities including burial practices, this site functioned as a logistical foraging base and as a way to control resources at Uyak Bay (Steffian and Simon 1994:90).

SUT-00024

This site was investigated as part of the National Park Service Archaeological Survey of Aniakchak from 1997-2000 (VanderHoek and Myron 2004:3-10). This seasonal site is located near the northwest shoreline of Aniakchak Lagoon, with 20 houses occupied between 1900-1100 BP containing seasonal riverine and marine fauna. Evidence for Aleutian and Port Moller influences lie in the tool technology (chipped stone flakes and large knives derive from the Aleutian traditions, while the men's houses and tunnel entrances show affinity to the Norton tradition). In addition to the Aleutian and Norton influences, non-local obsidian was found (VanderHoek and Myron 2004:80-85).

SUT-00027

This large village site was included in the Aniakchak survey along with SUT-00024, and was occupied between 1600-1100 BP. While many cultural depressions were found, fifteen depressions are identified as houses; they exhibit a variety of house forms that include Aleutian, Norton, and Koniag styles. Flakes, harpoons, and projectile points are among the artifacts recovered. The significance of the recovered materials lies in the numerous faunal and shellfish remains: the variety of faunal remains includes cod, salmon, bird, unidentifiable sea mammal, shellfish, seal, and fox. Due to it close proximity to SUT-00024 it is likely the same food resources were utilized at the site (VanderHoek and Myron 2004:89-95).

UGA-00052

This multicomponent village site was occupied during the Norton period and thirteen houses from this component were excavated by the BIA and Hamline University from 2003-2004. Chipped stone tools and terrestrial game hunting tools comprise most of the Norton assemblage. Basalt comprises over 44 percent of the chipped stone flakes in the Norton component. No slate is found at the site, which is uncommon for Norton sites. The houses are round and not rectangular, although none appeared to have a special function (Hoffman 2009:14). Hoffman notes that since 3.9 percent of flakes contain cortex, the basalt source may have been closer to the Aleutian Range (Hoffman 2009:55-56). Like the location of the Norton site DIL-00161, the Ugashik River flows from the Aleutian Range into Bristol Bay. The round house style, lack of slate, and abundance of basalt points to Aleutian influence in the Ugashik region (Hoffman

2009:100-101).Abandonment occurs after the Norton, and re-occupation at the site begins about 1400 AD with the Koniag culture. It is suggested that the Norton component of UGA-00052 represents a sudden migration of “displaced peoples” into the Ugashik region, as evidenced by a lack of fine quality slate and clay (Hoffman 2009:102-104).

XMK-00007

Teams from the University of Oregon and the University of Alaska excavated in the Naknek drainage and at Kukak and Kaflia Bay as part of a 2-year study in conjunction with the National Park service from 1953-1555. As a result, site XMK-00007 was discovered, consisting of four single room late prehistoric house pits from the Koniag tradition. Ground slate blades and ulus present at the site are evidence for some degree of non-local influences. Both marine and terrestrial fauna were recovered, with seal fauna used for ceremonial practices (Oswalt 1955).

XMK-00016

Fifteen multiroom houses comprise XMK-00016, a Koniag (Brooks River Bluffs phase) village site located on the south bank of the Brooks River, among the Brooks River Archaeological District National Historic Landmark. This site has experienced multiple surveys and excavations since 1960. Basalt was the most utilized material, while slate was the second most common. While flakes comprised the majority of artifacts at the site, artifacts that are shared with the Koniag tradition consist of: slate ulus, incised pebbles, and slate projectile points. The site contained avian, shellfish and terrestrial fauna which shows that seasonal rounds encompassed the coast. The similarities in assemblages and house forms between this site and Koniag sites in Kodiak indicate a great degree of interaction or influence occurred from Kodiak contemporaneous populations (Bundy et al. 2005).

5.0 Results

This section lists the results of statistical tests performed for this study. Section 5.1 provides a discussion of the results for creating the proxy source groups from Alaska Peninsula samples. Section 5.2 details the geographic distributions of the group assignments on the Alaska Peninsula and Kodiak while Section 5.3 compares flake weights in order to explore changes in procurement patterns. Sections 5.4- 5.6 contain tests performed among Alaska Peninsula samples comparing site occupations, and components/time periods. Sections 5.7 compares Kodiak samples over time, while Section 5.8 compares Kodiak and Alaska Peninsula samples over time. This section contains all tests necessary in order to evaluate each hypothesis as discussed in Section 6.

5.1 Clustering Results of Alaska Peninsula Samples

This section details the first steps in addressing the hypotheses from Section 2. Two methods of forming likely source groups were compared because older methods use biplots or visual observation of element values as discussed in section 3.4.1. This method involved creating dendrograms using three hierarchical clustering methods in order to find 'true' groups; the three methods were tested for correlations in order to determine the validity of the group assignments.

5.1.1 Comparing Two Methods of Forming Groups Containing Samples with Similar Element Values

Two methods were performed that grouped samples containing similar element values together. Six groups consisting of samples containing similar element values were manually created from the 118 Alaska Peninsula samples through visual observation of the five element values per sample. The second method consisted of using SPSS hierarchical cluster analyses (discussed below) using the same 118 samples. Results of both methods per sample are listed in Appendix D. A comparison between the two methods shows 80.5 percent of all samples were assigned to the same group, with 23 out of the 118 samples assigned to different groups.

Table 5.1. Correlation of Group Assignments between Visual Observation and SPSS

Method		SPSS	Manual
SPSS	Pearson Correlation	1	.547**
	Sig. (2-tailed)		.000
	N	118	118
Manual	Pearson Correlation	.547**	1
	Sig. (2-tailed)	.000	
	N	118	118
**. Correlation is significant at the 0.01 level (2-tailed).			

The range of values for each element per group between SPSS and manually created groups are statistically similar. The results from Table 5.1 show that while statistical tests are useful and bring reliability to XRF studies in archaeology, visual observation and manual assignment of samples into groups can produce similar results. Due to the significant correlation and the common use of statistical clustering in provenance studies, the SPSS generated group assignments was used for the remainder of this study.

5.1.2 Forming groups using SPSS

The dendrograms of three hierarchical cluster methods were compared in order to determine which samples clustered together to create groups. The clustering methods used (median linkage, complete linkage, and Ward method) are discussed in Section 3.4.1. The three dendrograms displayed the greatest similarities among group number and samples within each group at a distance of 5. Using the distance of 5 as the cutoff point for determining groups was an optimal distance for several reasons. For the complete and median method, most of the first-order clustering had been performed prior to distance 5: the only samples not included in a group at distance 5 were found in the median method dendrogram: samples BD-00357 and BD-1011 were included as part of group 6 and BD-00265 and BD-1010 were included in group 4 (Figure 5.3). Selecting a distance of 5 to determine group numbers also established a conservative range of element values per group that reflects the goals of this study: the greater the distance, the more dissimilar clusters are combined (Norusis 2011:371) and since the range of volcanic toolstone in the Alaska Peninsula samples are expected to produce relatively homogenous element values (as discussed in Section 3.1), determining groups at a closer distance is expected to yield geographically discrete clusters. If a greater distance for determining group numbers was used, it might obscure the small-scale differences in toolstone element values across the small geographic range of site locations.

The results from each method produced the following number of groups at a distance of 5 or below 5: six groups from the complete method, six groups from the median method, and six groups from Ward method. No assumptions were made about the source/origin of toolstone and no attempt was made to lump samples together into groups based on site or age. Every sample was assigned to a group number. A correlation test was subsequently performed using the grouping results of all three methods. The positive correlations between each method are shown below in Table 5.2.

Table 5.2. Correlations among Cluster Methods

Method		Complete	Ward	Median
complete	Pearson Correlation	1	.962**	.949**
	Sig. (2-tailed)		.000	.000
	N	118	118	118
ward	Pearson Correlation	.962**	1	.984**
	Sig. (2-tailed)	.000		.000
	N	118	118	118
median	Pearson Correlation	.949**	.984**	1
	Sig. (2-tailed)	.000	.000	
	N	118	118	118

**. Correlation is significant at the 0.01 level (2-tailed).

All three methods show strong positive correlations between group assignments of samples. The six groups created by Ward's Method are ultimately chosen as the group assignments for Alaska Peninsula samples for three reasons: this method allows for the least amount of variance, the results which showed significant correlations between all three SPSS cluster methods (Table 5.2), and the result showing significant association between groupings created by visual observation and the Ward's Method dendrogram (Table 6.1). Figures 5.1-5.3 lists the dendrograms from all three methods with the six groups labeled and color coded; a line at distance 5 in each dendrogram illustrates the similarities between all three methods.

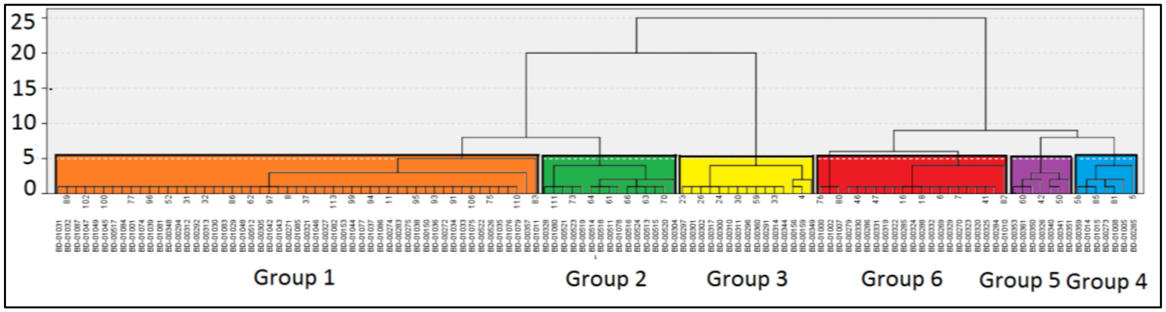

Figure 5.1. Dendrogram using Complete method.

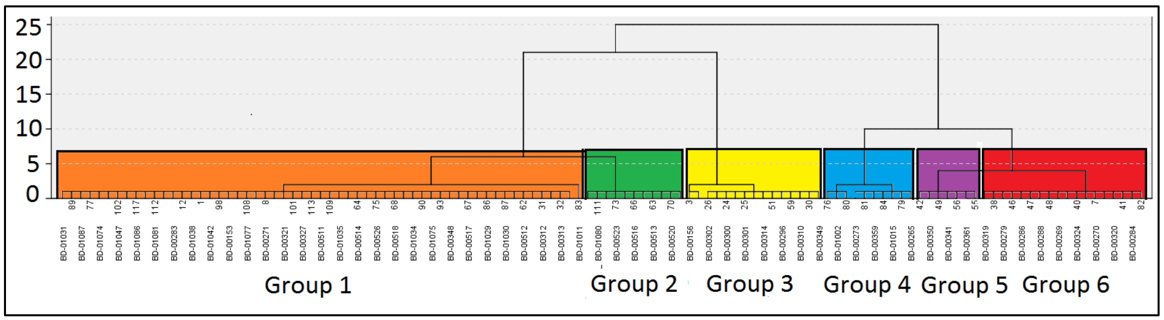

Figure 5.2. Dendrogram using Ward method.

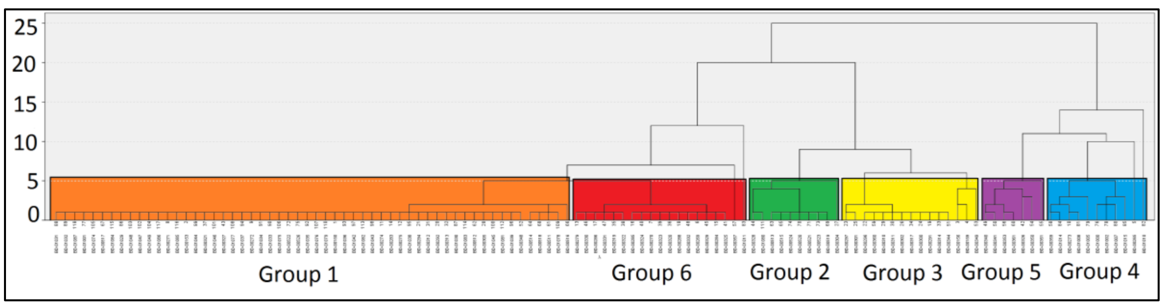

Figure 5.3. Dendrogram using Median method.

The group assignment of each sample is listed in Appendix D. The mean concentration values and standard deviation of each element are listed in Table 5.3 using the results from Ward method.

Table 5.3. Mean and Standard Deviation of each Element per Group Number

Group Number	Sr		Zr		Y		Rb		Nb	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Group 1 n=57	377	45	225	7	64	4	48	4	18	2
Group 2 n=11	396	39	216	10	52	6	37	5	12	2
Group 3 n=15	411	37	179	16	39	4	65	7	9	1
Group 4 n=10	211	65	189	19	47	7	103	13	14	2
Group 5 n=7	200	43	224	10	74	11	90	11	27	3
Group 6 n=18	328	11	231	2	68	8	70	1	21	2

The samples are visually represented in Figure 5.4 according to group number. The six groups were inserted into a discriminant function analysis in SPSS and all five elements were included in creating the two functions measured for each sample.

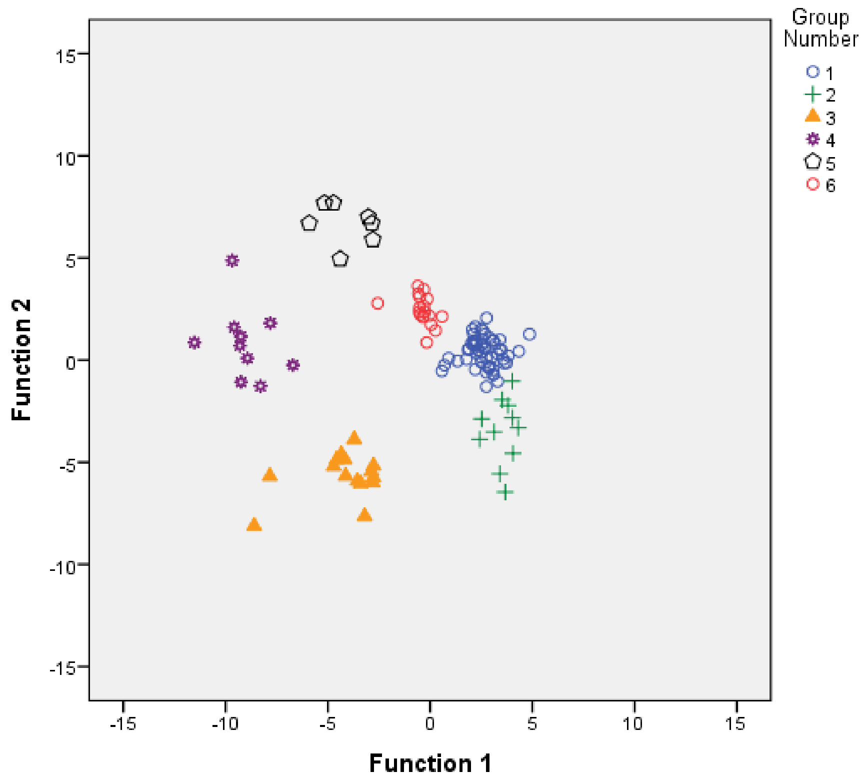

Figure 5.4. Scatterplot of discriminant function analysis using Alaska Peninsula samples.

98.2 percent of all variability found in the five elements is contained within the two functions. The concentration values per element for each sample are log (base 10) values. The standardized discriminant function coefficients of Function 1 are: -.984(Rb) +.284(Sr) +.786(Y) +.422(Zr) +.146(Nb). The standardized discriminant function coefficients of Function 2 are: .251(Rb)-.602(Sr)+.322(Y)-.237(Zr)+.836(Nb). This graph shows each group is located close together according to proximity in the Alaska Peninsula. Groups 1 and 2 are found in the lower Alaska Peninsula; they are located closer in Figure 5.4 than Groups 3 and 4 which are predominantly found in the north-central sites.

In order to illustrate the clustering of each group according to specific elements, Figures 5.5 and 5.6 show biplots of selected elements (with logged values) using the Alaska Peninsula samples.

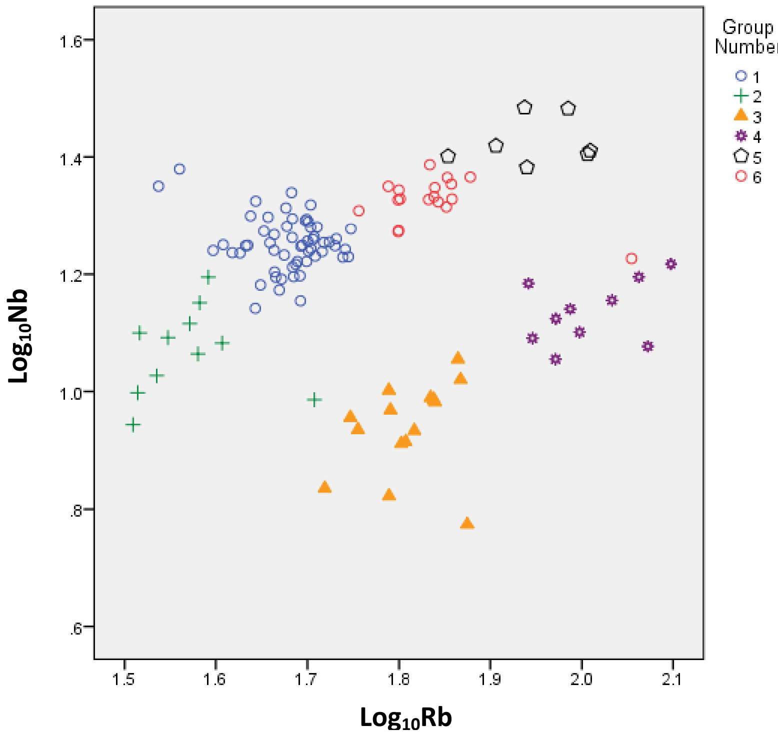

Figure 5.5. Log_{10}(Nb) vs. Log_{10}(Rb) scatterplot of Alaska Peninsula samples.

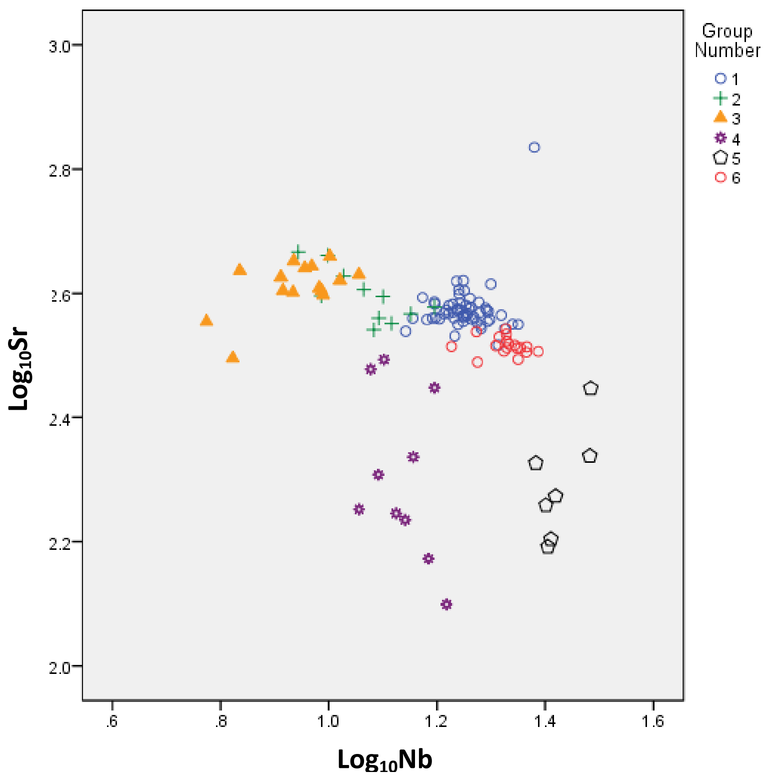

Figure 5.6. Log_{10}(Sr) vs. Log_{10}(Nb) scatterplot of Alaska Peninsula samples.

As expected the biplots consistently show a range of differences in element values between each group rather than each group forming a tight discrete cluster for each biplot; this supports the previous dendrogram and discriminant function graph results that reflect geographic proximity determines relative differences in element values.

Table 5.4 lists the number and percentage of samples within each group per site including the geologic samples used for comparison.

Table 5.4. Group Assignments for Alaska Peninsula Samples per Site

		Group Number						Total
		1	2	3	4	5	6	
CHK-00005	Count	15	1	2	0	0	0	18
	% within site	83.3%	5.6%	11.1%	0.0%	0.0%	0.0%	100.0%
	% within group	26.3%	9.1%	13.3%	0.0%	0.0%	0.0%	15.3%
CHK-00011	Count	19	0	0	0	0	0	19
	% within site	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	% within group	33.3%	0.0%	0.0%	0.0%	0.0%	0.0%	16.1%
DIL-00161	Count	5	1	10	0	0	0	16
	% within site	31.3%	6.3%	62.5%	0.0%	0.0%	0.0%	100.0%
	% within group	8.8%	9.1%	66.7%	0.0%	0.0%	0.0%	13.6%
SUT-00024	Count	1	1	0	0	1	7	10
	% within site	10.0%	10.0%	0.0%	0.0%	10.0%	70.0%	100.0%
	% within group	1.8%	9.1%	0.0%	0.0%	14.3%	38.9%	8.5%
SUT-00027	Count	1	0	0	0	0	3	4
	% within site	25.0%	0.0%	0.0%	0.0%	0.0%	75.0%	100.0%
	% within group	1.8%	0.0%	0.0%	0.0%	0.0%	16.7%	3.4%
UGA-00052	Count	5	0	0	2	0	7	14
	% within site	35.7%	0.0%	0.0%	14.3%	0.0%	50.0%	100.0%
	% within group	8.8%	0.0%	0.0%	20.0%	0.0%	38.9%	11.9%
XMK-00007	Count	2	0	0	7	0	1	10
	% within site	20.0%	0.0%	0.0%	70.0%	0.0%	10.0%	100.0%
	% within group	3.5%	0.0%	0.0%	70.0%	0.0%	5.6%	8.5%
XMK-00016	Count	2	0	3	1	6	0	12
	% within site	16.7%	0.0%	25.0%	8.3%	50.0%	0.0%	100.0%
	% within group	3.5%	0.0%	20.0%	10.0%	85.7%	0.0%	10.2%
Geological Samples								
Surface rocks, Aniakchak	Count	7	8	0	0	0	0	15
	% within site	46.7%	53.3%	0.0%	0.0%	0.0%	0.0%	100.0%
	% within group	12.3%	72.7%	0.0%	0.0%	0.0%	0.0%	12.7%
Total	Count	57	11	15	10	7	18	118

Table 5.8 shows some sites located near each other contain samples with similar element values. 90.9 percent of Group 2 samples come from the lower central peninsula: CHK sites, SUT sites, and the Aniakchak geological samples. Over 80 percent of samples from Group 3 come from the

northern interior peninsula sites: 66.7 percent of samples from DIL-00161 and 20 percent from XMK-00016. 70 percent of Group 4 samples come from XMK-00007. 94.4 percent of Group 6 is comprised of UGA-00052 samples and the two SUT sites. Group 1 is the only group that contains samples from all sites and comprises 48.3 percent of all samples. The section below tests this possibility and determines the geographic distribution of the groups found in Alaska Peninsula sites.

5.2 Establishing a Geographic Range of Statistically Similar Element Values Among Alaska Peninsula Sites

The geographic distribution of group assignments in the Alaska Peninsula is discussed in this section in order to determine likely local sources. Based on the above results, sites located relatively close were compared to determine if samples were evenly distributed into possible source groups, indicating people in those sites procured toolstone from the same general area: CHK-00005 and CHK-00011, both Norton and Koniag samples from UGA-00052, SUT-00024 and SUT-00027, and the two Katmai sites XMK-00007 and XMK-00016.

Table 5.5. Chi-Square Test for CHK-00005 and CHK-00011 Samples

	Group 1		Group 2		Group 3		Total (n)
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
CHK-00005	15	16.54	1	.49	2	.97	18
CHK-00011	19	17.46	0	.51	0	1.03	19
Total	34		2		2		37

(df= 2, test statistic=4.56, p=.1023)

The results of this test shows there is no significant difference in sample distributions of group assignments between the two sites; therefore the two CHK sites can be interpreted as containing samples with the same distribution of toolstone which reflects locally available toolstone used at the two sites. The distribution of samples among the CHK sites is reflected in the group assignment of geological samples from Aniakchak (Table 5.3); all the geological samples are found in Groups 1 and 2. The close proximity of Aniakchak and CHK sites give additional evidence that the element values of toolstone found in this area is similar.

In order to determine if residents at site UGA-00052 used the same toolstone over time, samples from Norton and Koniag components from UGA-00052 are compared. While the sample size is small, both components contain statistically similar sample distributions in groups. The two SUT sites were compared in order to find if toolstone was distributed similarly according to group assignment as well in Table 5.7. Table 5.6 shows that UGA-00052 components used toolstone with similar element values and likely sources.

Table 5.6. Chi-Square Test for UGA-00052 Components

	Group 3		Group 4		Group 6		Total (n)
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
Koniag	1	1.43	2	2	1	.57	4
Norton	4	3.57	5	5	1	1.43	10
Total	5		7		2		14

(df= 2, test statistic=1.534, p=.4644)

Table 5.7. Chi-Square Test for SUT-00024 and SUT-00027 Samples

	Group 1		Group 2		Group 5		Group 6		Total (n)
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
SUT-00024	1	1.43	1	.71	1	.71	7	7.14	10
SUT-00027	1	.57	0	.29	0	.29	3	2.86	4
Total	2		1		1		10		14

(df= 3, test statistic=5.139, p=.1619)

Table 5.6 has shown samples from both UGA components can be interpreted as containing the same distribution of similar element values for toolstone, and Table 5.7 presents the same findings for SUT-00024 and SUT-00027 samples. Based on geographic proximity, SUT samples were tested with UGA samples in order to determine if similar element values in toolstone were found within a larger geographic range.

Table 5.8. Chi-Square Test for SUT-00024, SUT-00027, and UGA-00052 Samples

	Group 1		Group 2		Group 4		Group 5		Group 6		Total (n)
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
SUT	2	3.5	1	.5	0	1	1	.5	10	8.5	14
UGA	5	3.5	0	.5	2	1	0	.5	7	8.5	14
Total	7		1		2		1		17		28

(df= 4, test statistic=8.8, p=.0663)

The above tests show that the samples from sites according to proximity contain similar values, and therefore local toolstone procurement occurred at several locales on the central Alaska Peninsula. In order to further explore a geographic boundary that contains similar distributions of toolstone element values, other sites (CHK-00005 and CHK-00011) were compared with SUT sites due to geographic proximity. The relatively short distance between CHK and SUT sites lead to the expectation that toolstone would contain similar element values in this area. Unlike the above results, CHK and SUT sites contain statistically different proportions of toolstone (Table 5.8).

Table 5.9. Chi-Square Test for CHK and SUT Samples

	Group 1		Group 2		Group 4		Group 5		Group 6		Total (n)
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
CHK	34	26.12	2	1.45	0	7.25	1	1.45	0	.73	37
SUT	2	9.88	0	.57	10	2.75	1	.55	1	.27	14
Total	36		2		10		2		1		51

(df= 4, test statistic=39.235, p<.0001)

The geographic boundary of local toolstone has been established for this part of the Alaska Peninsula, as Table 5.9 shows CHK sites are different from the relatively close UGA-00052, SUT-00024, and SUT-00027 sites. Frequent eruptions and pyroclastic flows may account for some of the variability among element values in this area; this is discussed in Section 6. Following the above results, sites located north in the Katmai quadrangle, XMK-00007 and XMK-00016, are compared in order to determine if a geographic range for toolstone with similar element values existed between the two sites.

Table 5.10. Chi-Square Test for XMK-00007 and XMK-00016 Samples

	Group 1		Group 2		Group 4		Group 5		Group 6		Total (n)
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
XMK-00007	2	1.82	0	1.36	7	3.64	1	.45	0	2.73	10
XMK-00016	2	2.18	3	1.64	1	4.36	0	.55	6	3.27	12
Total	4		3		8		1		6		22

(df= 4, test statistic=18.28, p=.0011)

XMK-00007 and XMK-00016 do not contain statistically similar distributions of samples per group. The majority of samples from XMK-00007 are found in Group 4 and half of XMK-00016 samples are assigned to Group 6. It is worth nothing that no samples are assigned to Group 3. While Table 5.10 shows a significant difference in overall sample distributions among the groups between the two sites, 80 percent of Group 4 samples from the Alaska Peninsula are found in sites XMK-00007 and XMK-00016 (Table 5.4). Only one other site (UGA-00052) contained samples from Group 4; therefore Group 4 is provisionally identified as a likely local source in the Brooks River/north-central Alaska Peninsula coastal region used by residents at XMK-00007 and XMK-00016.

This section has shown that the group assignments can be used to establish possible geographic boundaries in several locations in the central Alaska Peninsula. The areas where toolstone contained similar element values are: CHK (including Aniakchak geological samples), SUT and UGA, and possibly Group 4 in the Katmai area particularly on the Pacific coast. The following section will determine if the abundance and sizes of flakes can provide further evidence for these provisional local toolstone sources.

5.3 Geographic Distribution of Likely Sources According to Abundance and Weight of Samples

Since group assignments in section 5.3 indicate certain likely sources clustered near several geographically proximate sites, another way to examine likely proxy source groups is to compare the weights of tool types as well as determine if the abundance of certain tool types are located near likely sources. In particular, the weight of flakes can reveal different stages of reduction, with heavier flakes indicating primary or secondary reduction closer to a source (Newman 1994).

Smaller, lighter flakes are expected to be found farther away from a source which indicates some degree of lithic curation or conservation. Lithic identification of artifacts was used from previous research found in catalogs, inventories, site reports, and publications as well as identifications given by researchers including myself for samples without a previous identification. Due to several identifications of flake samples, 'flake' for Table 5.11 includes interior flakes, flake tools, and waste flakes.

In order to determine if the abundance and weight of flakes are related to the location of likely sources, Alaska Peninsula flake samples are listed according weight (g) in Table 5.11. If more than one sample is contained in a particular group per site, the number of samples (n=) and the averaged weight are listed.

5.3.1 Alaska Peninsula

Table 5.11. Weight (g) of Alaska Peninsula Flakes

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
CHK-00005	16.11 n=15	4.48	6.31 n=2			
CHK-00011	7.83 n=14					
DIL-00161	4.95 n=5	2.03	3.43 n=8			
SUT-00024	5.60	4.36			8.67	13.04 n=5
SUT-00027						5.59 n=3
UGA-00052	8.31 n=5			11.19 n=2		10.19 n=7
XMK-00007	8.70			59.79 n=4		45.31
XMK-00016	13.19 n=2		1.79 n=3	3.13	6.69 n=6	

Table 5.11 shows that according to most sites there is a trend that heavier flakes are generally found in groups containing greater numbers of flakes. CHK-00005 contains the greatest number and the heaviest averaged flakes from Group 1. Table 5.4 shows 83.3 percent of CHK-00005 samples are contained in Group 1. Eight of 14 flakes from DIL-00161 are contained Group 3,

which also contains 62.5 percent of the samples from the site. The heaviest averaged flakes from SUT-00024 are from Group 6 where 70 percent of samples are contained while all of SUT-00027 flakes are found in Group 6. The heaviest flakes from UGA-00052 are in Group 4, which contains 70 percent of the samples from the site. XMK-00016 has the greatest number of flakes from Group 5 where 50 percent of the samples from the site are found. While heavier flakes can indicate proximity to a source area, smaller flakes can be used as a factor to measure possible relative distances to source. For example Group 2 and 3 would be farther away from CHK-00005 than Group 1. While not every site contains clear differences between size and abundances per site, it would appear SUT-00024 would be closer to Group 6. The more evenly distributed abundances of flakes with small differences in weight from UGA-00052 samples reflect the distributions of samples per group (Table 5.4). The results show an overall trend that heavier flakes found in groups that contain more flakes per site. These findings also show that sites containing few samples from a particular group may indicate lithic conservation occurred as a result of these samples deriving from farther away.

5.3.2 Kodiak Island

Kodiak flakes are listed according to weight per group number and site number in order to compare differences in flake weight and overall abundances of flakes per group number within each site. Kodiak samples were assigned to groups created from the Alaska Peninsula discussed in Section 5.7. The weights of flakes were expected to be related to the numbers of samples per group number within each site. This relationship would reflect possible distances to source areas as samples deriving from farther away are expected to show evidence of lithic conservation. Like the Alaska Peninsula samples in Table 5.11, samples are listed according weight (g) and if more than one sample is contained in a particular group per site, the number of samples (n=) and the averaged weight are listed. The term ‘flakes’ in Table 5.12 includes interior flakes and utilized flakes. Due to the small number of samples, sampled cobbles were also listed in order to provide further evidence of proximity to a source area. Three samples from AFG-00015 were placed into one of the six groups (Table 5.21); these samples are adzes and adze chips (see Appendix C) therefore this site is not included in Table 5.12.

Table 5.12. Weight (g) of Selected Kodiak Samples

Site Number	Tool type	Group 1	Group 3	Group 4
KOD-00044	Flake			n=2 14.77
KOD-00145	Core			103.57
	Flake		4.51	n=6 21.22
KAR-00001	Core	97.14		
	Flake	n=4 4.96	n=4 18.31	

While the sample size is small, the group assignments of Kodiak samples show clear differences between the two KOD sites and KAR-00001. Rather than show evidence in conserving lithic material at KOD-00044 and KOD-00145, flakes from these two sites are exclusively contained in Group 4. The core from KOD-00145 is further evidence that the range of element values contained within Alaska Peninsula samples that comprise Group 4 are very similar to the flakes from these two Late Kachemak sites. In contrast to the KOD samples, the flakes from KAR-00001 are equally distributed in Groups 1 and 3. The averaged flake weight of KAR-00001 samples in Group 3 is larger than samples from Group 1, indicating possibly earlier stage reduction of tools. However the core from KAR-00001 is contained in Group 1 suggesting this group is also located relatively close to this site or was easily accessible to people living there. Using the weight of flakes as a function of distance to a source, it would appear Group 1 is located possibly the farthest away out of the three groups listed in Table 5.12, while Group 4 is located the closest to Kodiak.

5.4 Variability of Toolstone According to Site Types and Occupations

In order to explore the variability of toolstone among Alaska Peninsula sites, site occupations were compared in this section. Previous research has shown that the diversity of lithic materials in short term summer fish camp occupations should be less than long term occupations, as short/seasonal occupations are directly related to the seasonal rounds while year-round settlements or villages contain evidence for a wider range of activities including logistical mobility. Having established possible geographic boundaries of local toolstone, the number of Alaska Peninsula sites provides an opportunity to explore differences in volcanic toolstone variability. Site occupations as defined by previous researchers are listed as the following: camp sites (CHK-00005 and XMK-00007) and village sites (DIL-00161, SUT-00024, SUT-00027, UGA-00052, and XMK-00016) are compared.

Table 5.13. Chi Square Test for Samples from Selected Alaska Peninsula Villages and Camps

	Group 1		Group 2		Group 3.		Group 4		Group 5		Group 6		Total
	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	
Village	14	23.06	2	1.31	13	8.56	3	6.59	7	4.61	17	11.86	56
Camp	21	11.94	0	.68	0	4.44	7	3.41	0	2.39	1	6.14	29
Total	35		2		13		10		7		18		85

(df= 5, test statistic=56.18, p<.0001)

Long term villages and short term camps contain statistically different frequencies of samples distributed across group assignments (Table 5.13). The variability of toolstone is greater at sites associated with long term occupations. Village sites contain samples in all six groups while camp sites contain samples in three groups. This result reinforces the idea that villages have more variety of lithics due to higher rates of sedentism and greater variety of site activities. However this result may be caused by site location rather than length of occupation. In order to determine if the diversity of toolstone element values is related to site location, Section 5.5 contains statistical tests that compared samples according to site location and cultural tradition.

5.5 Variability of Toolstone According to Site Location

This section compares the distributions of samples per group assignment between interior and coastal sites according to component in order to find possible differences in lithic variability according to site location. Norton and Koniag sites were separated in order to control for time period. Alaska Peninsula sites contain both interior and coastal sites and will be compared. In order to determine this difference in site location changed over time, I compared Norton aged interior sites (DIL-00161, UGA-00052) and coastal sites (SUT-00024 and SUT-00027). CHK sites were omitted because almost 100 percent of the CHK samples were assigned to Group 1 and the clear differences in toolstone variability in these sites would have skewed the results.

Table 5.14. Chi Square Test for Samples from Coastal and Interior Norton Sites

	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total (n)
	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	
Interior	9	7.15	1	1.3	10	6.5	1	.65	0	.65	5	9.75	26
Coast	2	3.85	1	.7	0	3.5	0	3.5	1	.35	10	5.25	14
Total	11		2		10		1		1		15		40

(df= 5, test statistic=22.62, p=.0004)

Table 5.15. Chi Square Test for Coastal and Interior Alaska Peninsula Koniag Sites

	Group 1		Group 3		Group 4		Group 5		Group 6		Total (n)
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
Interior	3	15.47	3	1.93	2	5.8	6	3.87	2	1.93	29
Coast	21	8.53	0	1.07	7	3.2	0	2.13	1	1.07	16
Total	24		3		9		6		3		45

(df= 4, test statistic=44.14, p<.0001)

These results show both Norton and Koniag interior and coastal sties contain different distributions of samples (Tables 5.14 and 5.15). These sites are located in a wide geographic range however it appears toolstone variability did not significantly change between site locations over time. Due to this pattern of significant differences in toolstone variability between interior and coastal sites over time, this section of results further supports evidence that Alaska Peninsula sites maintained local subsistence economies over time. The section below compares sites by component in order to examine differences in toolstone variability over time regardless of site type or location.

5.6 Alaska Peninsula Samples Compared According to Time Period and Cultural Tradition

Section 5.3 tested for differences between Norton and Koniag/Thule samples from sites located relatively close together. In order to test for differences in group assignment over time regardless of site type or location, tests were performed. The first test compared all samples separated into Early or Late time periods. Comparing the two time periods on the Alaska Peninsula is performed rather than comparing components in order to include sites SUT-00024, SUT-00027 and XMK-00007 as discussed in Section 3.2. It is expected the two periods will contain different proportions of samples in groups because sites occupied within each period spans a large geographic range.

Table 5.16. Chi Square Test for Early and Late Time Periods among Alaska Peninsula Samples

	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total (n)
	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	
Early	26	28.18	3	1.7	12	8.45	1	5.63	1	3.94	15	10.14	58
Late	24	21.84	0	.67	3	6.55	9	4.36	6	3.06	3	7.86	45
Total	50		3		15		10		7		18		103

(df= 5, test statistic=34.1, p<.0001)

The results from Table 5.16 show statistically dissimilar distributions of samples within group assignments over time. These results echo previous results that have shown Alaska Peninsula toolstone variability remained the same over time. The only statistically similar distribution of samples among Alaska Peninsula sites have occurred within small geographic areas regardless of time period.

5.6.1 Alaska Peninsula Samples Compared by Cultural Tradition

A second test was performed in order to determine if differences occurred over time according to cultural tradition, excluding the two SUT sites. This was done in order to control for the Norton tradition samples by removing sites that were not defined as Norton by previous researchers. While SUT sites have been removed in Table 5.18, the large geographic spread of the Alaska Peninsula sites is still expected to yield statistically significant differences in sample distributions over time.

Table 5.17. Chi Square Test for Samples from Norton and Alaska Peninsula Koniag Sites

	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total (n)
	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	
Norton	24	24.26	0	1.01	3	7.58	9	5.06	6	3.03	3	4.04	45
Koniag	24	23.75	2	.99	12	7.42	1	4.93	0	2.97	5	3.95	44
Total	48		2		15		10		6		8		89

(df= 5, test statistic=23.97, p=.0002)

Table 5.17 shows statistically significant differences in sample distributions occurred over time, reinforcing previous results of the samples. Below are tests that compare samples among Norton and Koniag sites in order to determine if toolstone variability was different between contemporaneous sites.

Table 5.18. Chi Square Test among Norton Samples

	Group 1		Group 2		Group 3		Group 4		Group 6		Total (n)
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
CHK-00005	15	9.81	1	.82	2	4.91	0	.41	0	2.05	18
DIL-00161	5	8.73	1	.73	10	4.36	0	.36	0	1.82	16
UGA-00052	4	5.45	0	.45	0	2.73	1	.23	5	1.14	10
Total	24		2		12		1		5		44

(df= 8, test statistic=50.08, $p<.0001$)

Table 5.19. Chi Square Test among Alaska Peninsula Koniag Samples

	Group 1		Group 3		Group 4		Group 5		Group 6		Total (n)
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
CHK-00011	19	10.13	0	1.27	0	3.8	0	2.53	0	1.27	19
UGA-00052	1	2.13	0	.27	1	.8	0	.53	2	.27	4
XMK-00007	2	5.33	0	.67	7	2	0	1.33	1	.67	10
XMK-00016	2	6.4	3	.8	1	2.4	6	1.6	0	.8	12
Total	24		3		9		6		3		45

(df= 12, test statistic=69.41, $p=.05$)

Results from Tables 5.18 and 5.19 show a significant difference in sample distribution over time, indicating toolstone variability during each component in late prehistory. If either Norton or Koniag sites showed statistically similar sample distributions among contemporaneous sites, those results would have represented a change in toolstone variability. However, these results support previous data throughout Section 5 that geographic distance alone is the determining factor in local toolstone availability.

5.6.2 Alaska Peninsula Samples Compared by Excluding Samples from Distant Sites

A test was performed in order to determine if geographic distance determines similarities among Norton and Koniag samples in Table 5.20, with samples from sites identified as geographic outliers excluded (sites DIL-00161 and XMK-00007).

Table 5.20. Selected Norton and Alaska Peninsula Koniag Samples per Group

	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6		Total (n)
	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	
Norton	19	18.22	1	.44	2	2.22	1	1.67	0	2.67	5	3.11	28
Koniag	22	22.78	0	.56	3	2.78	2	1.33	6	3.33	2	3.89	35
Total	41		1		5		3		6		7		63

(df= 5, test statistic=11.375, critical value=.0444)

Table 5.20 shows both components contain different sample distributions over time, however the test statistic value is closer to the critical value than the test statistic from Tables 5.18 and 5.19, which did not remove geographic outlier sites. Removing one more site located toward either end of the geographic range of Alaska Peninsula sites could have resulted in statistically similar sample distributions between Norton and Koniag sites. This method however would only reinforce the previous data from this section and the previous research regarding element values among volcanic sources that show element values become more similar as samples are located closer. Sections 5.2, 5.4-5.6 have shown that Alaska Peninsula samples contain similar toolstone element values within a small geographic range regardless of site type, location, or time/component. The following section contains statistical tests for Kodiak samples.

5.7 Kodiak Samples Inserted Into Alaska Peninsula Groups

After Alaska Peninsula samples created six groups that contained similar element values in section 5.2, the Kodiak samples were added to the groups using the same method of cluster analysis. The Kodiak samples that were inserted into the pre-existing groups are listed below in Table 5.21 according to site number.

Table 5.21. Group Assignments for Kodiak Samples

		Group Number				Total
		None	1	3	4	
AFG-00015	Count	12	0	3	0	15
	% within site	80.0%	0.0%	20.0%	0.0%	100.0%
	% within grp	38.7%	0.0%	33.3%	0.0%	21.4%
KAR-00001	Count	3	6	4	0	13
	% within site	23.1%	46.2%	30.8%	0.0%	100.0%
	% within grp	9.7%	100.0%	44.4%	0.0%	18.6%
KOD-00044	Count	4	0	1	11	16
	% within site	25.0%	0.0%	6.3%	68.8%	100.0%
	% within grp	12.9%	0.0%	11.1%	45.8%	22.9%
KOD-00145	Count	12	0	1	13	26
	% within site	46.2%	0.0%	3.8%	50.0%	100.0%
	% within grp	38.7%	0.0%	11.1%	54.2%	37.1%
Total	Count	31	6	9	24	70

Each Kodiak site contained samples within either Group 1, 3 or 4. Out of the 70 samples analyzed from Kodiak, 39 samples contained similar element values to the central Alaska Peninsula. 20 percent of samples from AFG-00015 contained similar toolstone element values as Alaska Peninsula samples; this was expected due to the local variations of the Koniag cultural tradition at Afognak sites. 68.8 percent of KOD-00044 samples and 50 percent of KOD-000145 samples are included in Group 4, while samples from sites XMK-00007 and XMK-00016 comprise 80 percent of Alaska Peninsula samples from Group 4 (Table 5.3). Figures 5.7-5.12 contain maps for each group, labeled with the sample percentage within each site.

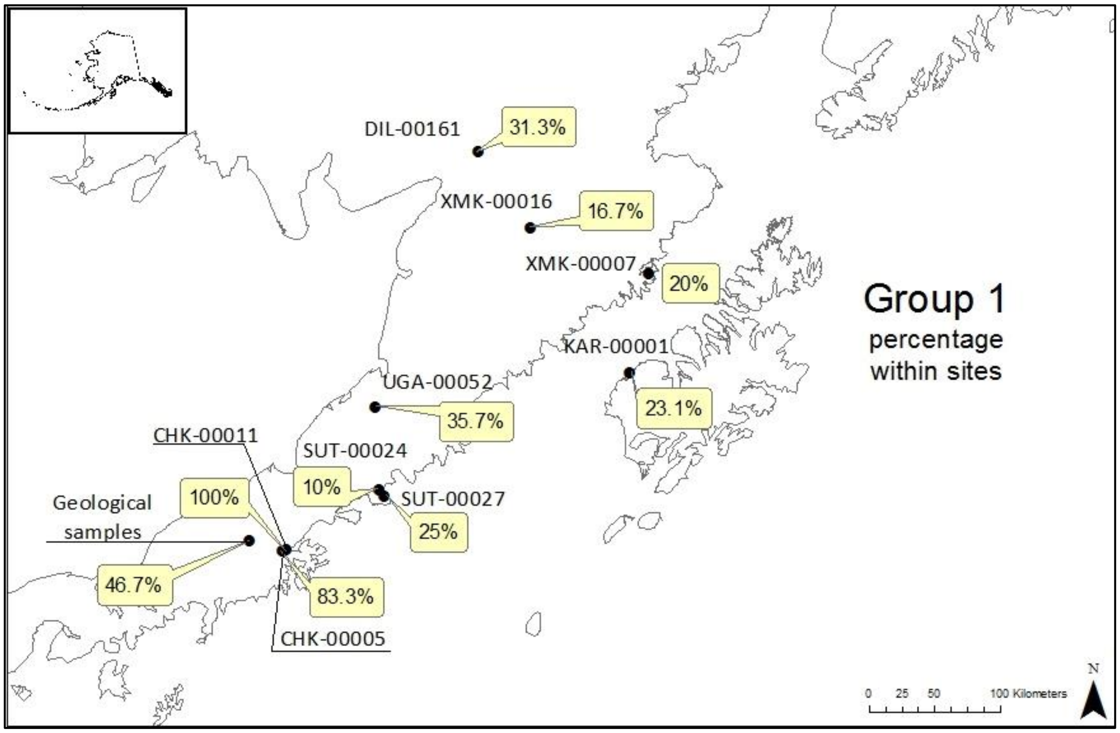

Figure 5.7. Sites containing samples in Group 1.

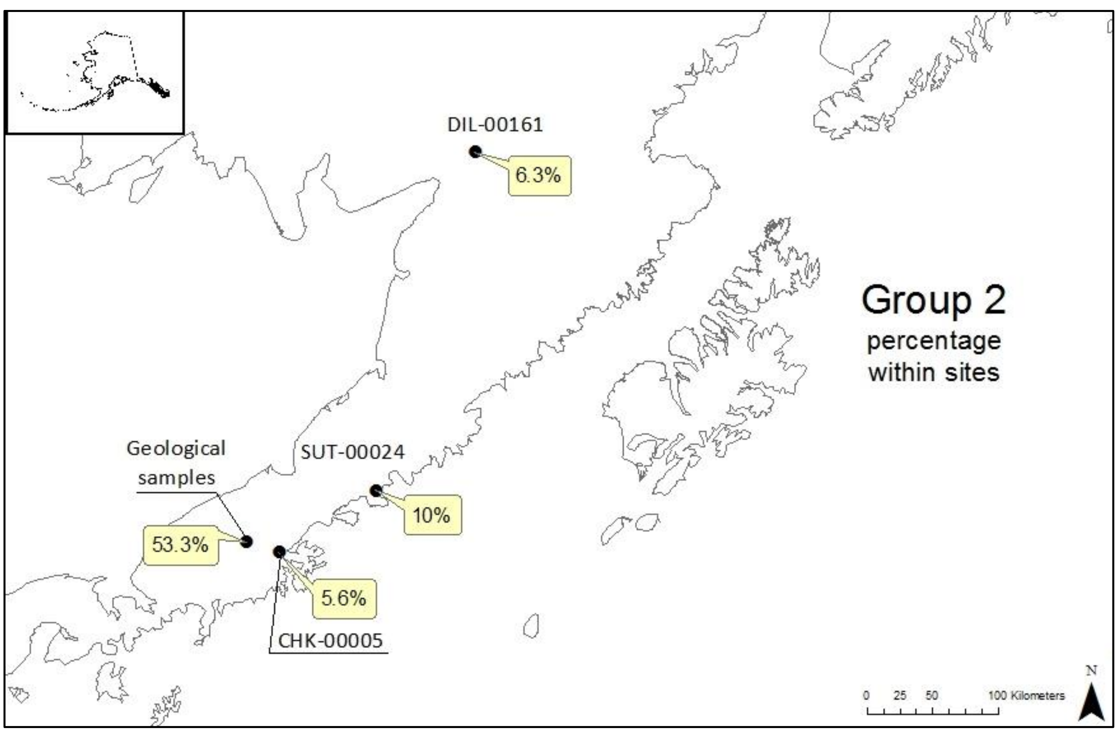

Figure 5.8. Sites containing samples in Group 2.

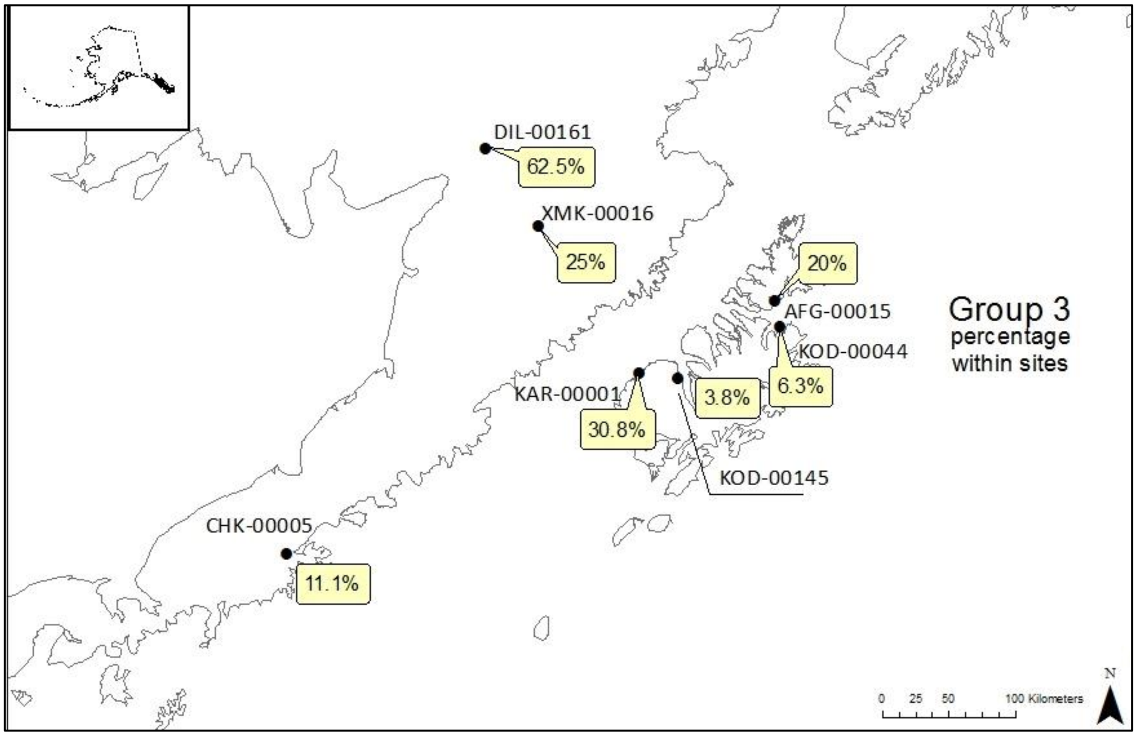

Figure 5.9. Sites containing samples in Group 3.

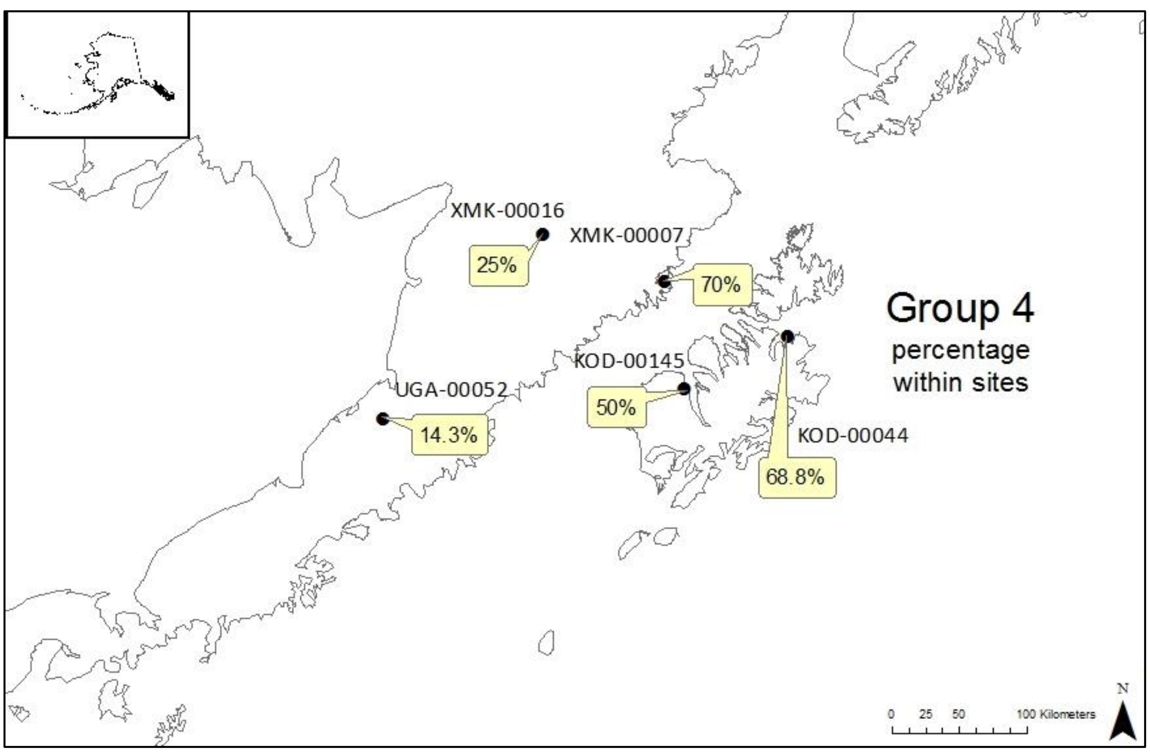

Figure 5.10. Sites containing samples in Group 4.

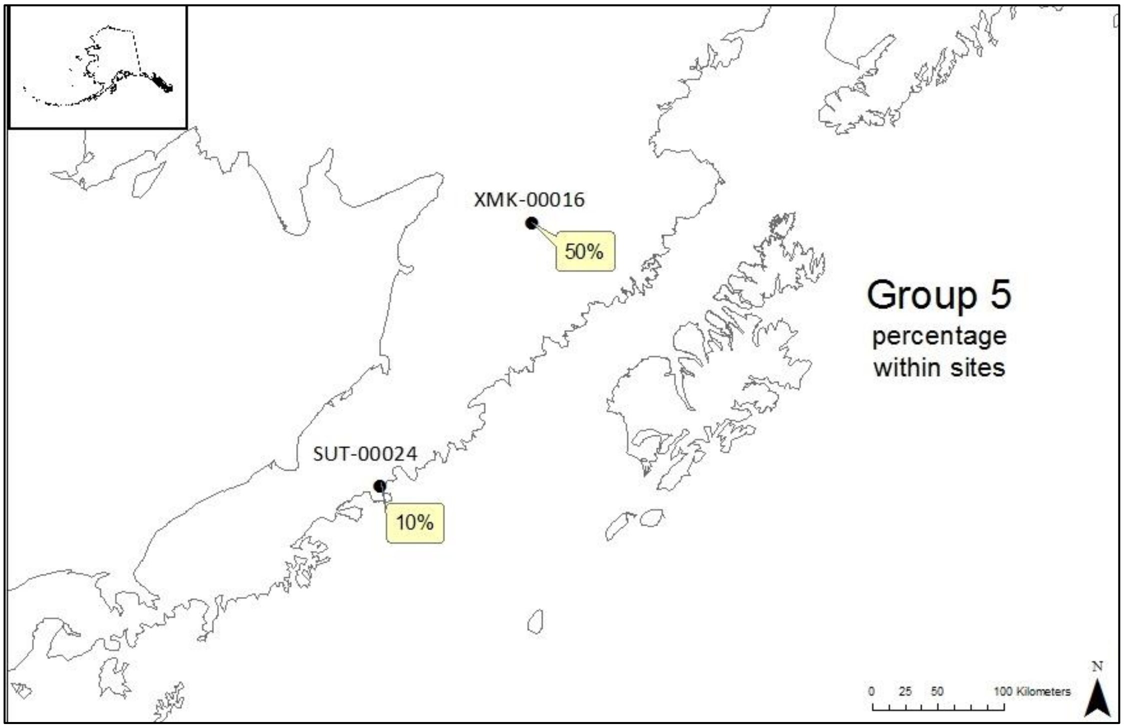

Figure 5.11. Sites containing samples in Group 5.

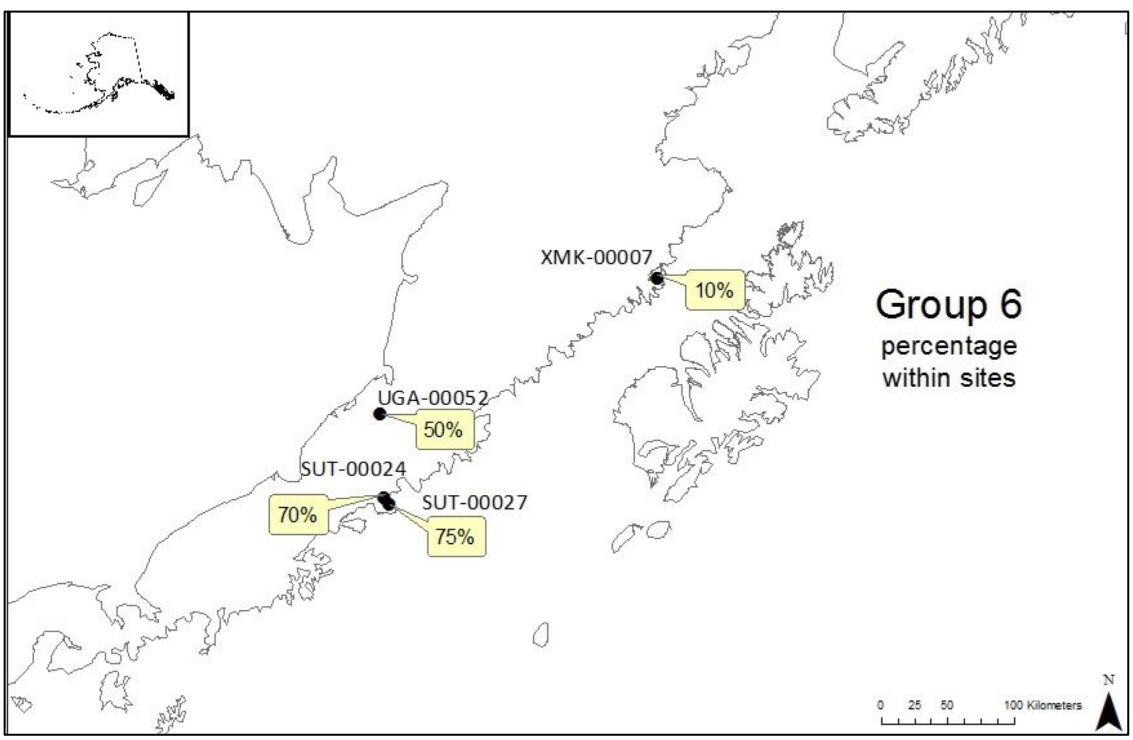

Figure 5.12. Sites containing samples in Group 6.

5.7.1 Kodiak Group Membership Over Time

Table 5.22 shows less than half (44.3 percent) of all Kodiak samples did not contain similar element values with any group formed from Alaska Peninsula samples. Kodiak populations engaged in trade and were in contact with populations located throughout the Pacific region. Evidence for many different influences contained in Kachemak and Koniag traditions can be reflected in the variety of toolstone present in Kodiak sites. In order to determine whether more or less Alaska Peninsula toolstone is present in Late Kachemak or Koniag sites, frequencies of samples according to group membership for both components were compared. If a significant difference in the abundance of Alaska Peninsula toolstone over time in the Kodiak samples, it could suggest a shift in procurement practices occurred.

Table 5.22. Kodiak Koniag and Late Kachemak Samples and Group Membership

		Group Membership		Total
		No	Yes	
Kodiak Koniag	Count	15	13	28
	% within grp	53.6%	46.4%	100.0%
	% within Kodiak Koniag	48.4%	33.3%	40.0%
Late Kachemak	Count	16	26	42
	% within grp	38.1%	61.9%	100.0%
	% within Late Kachemak	51.6%	66.7%	60.0%
Total	Count	31	39	70

Table 5.23. Chi Square Test for Group Membership Over Time in Kodiak

Method	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.631[a]	1	.202	.228	.151
Continuity Correction[b]	1.064	1	.302		
Likelihood Ratio	1.631	1	.202	.228	.151
Fisher's Exact Test				.228	.151
N of Valid Cases	70				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 12.40.

a. Computed only for a 2x2 table

Table 5.23 shows there are no significant differences in the frequency of group membership over time, indicating Kodiak populations did not obtain volcanic toolstone from the Alaska Peninsula significantly more or less over time. This result is expected given that Kodiak assemblages contain materials deriving from a variety of off-archipelago locations and evidence of trade in late prehistory as discussed in Section 1.2.4 and 2. 3.

5.7.2 Comparing Kodiak Samples According to Cultural Tradition

In order to find differences in the variability of toolstone element values between Kodiak samples, samples are first compared among components and then between components. However Koniag samples will not be compared according to site since only three samples from AFG-00015 are included in a group. It is worth noting however that both Koniag sites contain samples exclusively from Group 1 or Group 3. The large proportion of samples from Late Kachemak sites KOD-00044 and KOD-00145 in Groups 3 and 4 may form statistically similar associations between samples from these two sites.

Table 5.24. Chi Square Test for Late Kachemak Samples

	Group 3		Group 4		Total
	Obs.	Exp.	Obs.	Exp.	
KOD-00044	1	.92	11	11.08	12
KOD-00145	1	1.08	13	12.92	14
Total	2		24		26

(df= 1, test statistic=0.81, p=.3681)

As expected, Late Kachemak sites contained no statistically significant differences between sample distributions. Samples from the two sites contain a similar range of element values even though the sites are located in different areas in Kodiak Island. This could indicate populations from both sites used toolstone from the same areas in the Alaska Peninsula. This result can be interpreted as Late Kachemak populations at these sites did not have differential access to the same sources, which is reflected in the relative lack of lithic conservation of the samples as discussed in Section 5.3.

A comparison between Late Kachemak and Koniag samples was performed in order to find possible temporal differences in group assignment. Data presented in Table 5.25 show a significant difference in groups over time in Kodiak. 100 percent of all samples belonging to Group 4 come from Late Kachemak samples, with 92.3 percent of all Late Kachemak samples come from Group 4. Kodiak Koniag samples are more evenly distributed with 46.2 percent of samples in Group 1 and 53.8 percent in Group 3.

Table 5.25. Chi Square Test for Late Kachemak and Koniag Samples

Cultural Affiliation	Group 1		Group 3		Group 4		Total (n)
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
Late Kachemak	0	4	2	6	24	16	26
Koniag	6	2	7	3	0	8	13
Total	6		9		24		39

(df= 2, test statistic=27.88, p<.0001)

Since Group 4 is represented the most from samples in sites KOD-00044, KOD-00145, and XMK-00007, these samples were compared in order to determine if all three sites contain similar distributions of samples in groups. Samples from the two KOD sites are grouped together for this test based on previous results (Table 5.24).

Table 5.26. Percentage of Group Assignment of KOD-00044, KOD-00145, and XMK-00007 Samples

Site Number	Group 1	Group 3	Group 4	Group 6	Total
KOD-00044	0%	8.3%	91.7%	0%	100%
KOD-00145	0%	7.1%	92.9%	0%	100%
XMK-00007	20.0%	0%	70.0%	10.0%	100%

Table 5.27. Chi Square Test for KOD-00044, KOD-00145, and XMK-00007 Samples

Site/Quad Number	Group 1		Group 3		Group 4		Group 6		Total
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
KOD	0	1.44	2	1.44	24	23.39	0	.72	26
XMK-00007	2	.56	0	.56	7	8.61	1	.28	10
Total	2		2		31		1		36

(df= 3, test statistic=8.75, p=.0328)

The results from Table 5.27 show a statistically significant difference between the KOD sites and XMK-00007. The data presented in Tables 5.24 and 5.25 shows while samples from Late Kachemak sites are almost exclusively contained in Groups 3 and 4, XMK-00007 samples are distributed more evenly among three groups. This may indicate residents at the KOD sites used one type of toolstone from particular location(s) while people occupying XMK-00007 had access to and used a wider range of available toolstone. Group 4 can be considered an important source among XMK -00007 and Late Kachemak sites, which was found in samples primarily from the Katmai area and used during the Late Kachemak in Kodiak.

5.8 Alaska Peninsula and Kodiak Samples Compared According to Cultural Tradition

This section contains tests that compare Alaska Peninsula and Kodiak components in order to determine if significant changes in group assignment occurred over time. Tests that compare the toolstone variability between Kodiak and the Alaska Peninsula are performed. Late Kachemak and Koniag samples from Kodiak are compared with Norton and Koniag samples from the Alaska Peninsula. The following tests were the last comparisons performed that added to the discussion regarding toolstone variability in this region detailed in Section 6.

Table 5.28. Chi Square Test for Late Kachemak and Norton Samples

Cultural Affiliation	Group 1		Group 3		Group 4		Group 5		Group 6		Total (n)
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
Norton	24	15.21	3	3.17	9	20.97	6	3.8	3	1.9	45
Late Kachemak	0	8.79	2	1.83	24	12.08	0	2.2	0	1.1	26
Total	24		5		33		6		3		71

(df= 4, test statistic=40.75, p<.0001)

Table 5.29. Chi Square Test for Late Kachemak and Alaska Peninsula Koniag Samples

Cultural Affiliation	Group 1		Group 3		Group 4		Group 5		Total
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
AK Koniag	24	14.82	3	3.09	9	20.38	6	3.71	42
Late Kachemak	0	9.18	2	1.91	24	12.62	0	2.28	26
Total	24		5		33		6		68

(df= 3, test statistic=36.62, p<.0001)

Table 5.30. Chi Square Test for Norton and Kodiak Koniag Samples

Cultural Affiliation	Group 1		Group 3		Group 4		Group 5		Group 6		Total (n)
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
Norton	24	23.26	3	7.76	9	6.98	6	4.66	3	2.33	45
Kodiak Koniag	6	6.73	7	2.24	0	2.02	0	1.34	0	.67	13
Total	30		10		9		6		3		58

(df= 4, test statistic=22.34, p=.0002)

Table 5.31. Chi Square Test for Koniag Samples from the Alaska Peninsula and Kodiak

Cultural Affiliation	Group 1		Group 3		Group 4		Group 5		Total
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	
AK Koniag	24	22.91	3	7.64	9	6.87	6	4.58	42
Kodiak Koniag	6	7.1	7	2.36	0	2.13	0	1.42	13
Total	30		10		0		6		55

(df= 3, test statistic=19.75, p=.0002)

Tables 5.28-5.31 show there is no relationship between any cultural traditions and group assignment between Alaska Peninsula and Kodiak samples. This section and Sections 5.5-5.7 have shown that cultural traditions/time periods do not generally reflect homogenous toolstone values. These results are discussed further in Section 6.

6.0 Discussion and Conclusion

This section summarizes the results from Section 5 and puts the findings in context with the cultural trends described in Sections 2 and 3. The hypotheses are evaluated and then general procurement patterns over time in the Alaska Peninsula and Kodiak are observed. The implications of these findings are discussed below.

6.1 Hypotheses Revisited

The results from tests performed in Section 5 will be applied to the evaluation of the hypotheses stated in Section 2.The significant differences in the sample distributions of toolstone element values between Late Kachemak and Koniag samples from Kodiak relate to the differences in the geographic distribution of the Alaska Peninsula samples. While Kodiak samples show a difference in toolstone variability occurred over time, Alaska Peninsula samples show no significant change in toolstone procurement locations in the late prehistory.

Section 5.2 contains tests performed in order to find possible geographic boundaries for likely sources and to find variability in toolstone element values in the Alaska Peninsula. The percentage of samples per group is illustrated in Figures 5.7-5.12. Out of the three groups that Kodiak samples are assigned to, Group 1 contains samples from sites located in the largest geographic range, with every Alaska Peninsula site containing samples from Group 1. In contrast, over 80 percent of samples from Group 3 come from the northern interior peninsula sites: 66.7 percent of samples from DIL-00161 and 20 percent from XMK-00016. Group 4 was comprised of 80 percent of Alaska Peninsula samples from the Brooks River area sites XMK-00007 and XMK-00016, and 20 percent from UGA-00052 (Table 5.2). From this finding, Group 4 is located primarily in the Brooks River area, with UGA-00052 as its southern geographic limit.

Hypothesis 1: Late Kachemak populations conserved Alaska Peninsula toolstone more than Koniag populations in Kodiak.

This hypothesis is not supported by the data presented in Section 5.3 that contains evidence that lithic conservation occurred more in Koniag assemblages than Late Kachemak. Koniag site

KAR-00001 contains the smallest flakes and core (Table 5.12). Lithic conservation may have occurred at AFG-00015 due to the changes in sea level at the site location: houses in AFG-00015 contain evidence of flooding which may indicate populations tended to stayed closer to Afgonak in case materials and site occupants needed to quickly be removed if flooding occurred (Saltonstall 1997:12-16). In contrast, the Late Kachemak sites have the largest bifaces, core, and flakes. The results from this study are contradicted by evidence at KAR-00001 that there was an increase of Alaska Peninsula materials present at KAR-00001 over time (Knecht 1995:5569-571). However this finding may reflect differences site activities, as KAR-00001 focused on Karluk River fishing while KOD-00044 contains a wide diversity of faunal remains (Clark 1970; Knecht 1995; Partnow 2001; Steffian 1992a; West 2009). While Alaska Peninsula materials increased over time in Kodiak sites, Knecht (1995:572-573) notes that labrets from non-local materials have non-Koniag styles which could indicate Koniag populations on Kodiak increased raiding or even increased the number of non-Kodiak residents brought back to Kodiak as captives who wore labrets. Ethnographic data states the goal of raiding was to obtain food and clothes (Black 1977:86), which would suggests that procuring common toolstone from the Alaska Peninsula was not a priority.

The overall size of the artifacts may reflect the geographic location of these groups (discussed below). Late Kachemak samples contain the largest bifaces, core, and flakes; given that most of these samples are found in Groups 4, its likely source is close to Kodiak Island. Group 4 is primarily found in XMK-00007 samples (Table 5.2). Using relative size as a factor in determining distance to a source is observed in artifact size: the small size of the AFG-00015 biface from Group 3 could be caused by the distance between the site and the Alaska Peninsula. Additionally, the small AFG-00015 samples can be compared with KAR-00001 samples, indicating residents in southwest Kodiak engaged in more frequent travel to the peninsula. This also supports ethnographic data that states Koniag residents focused on raiding adjacent off-island locations: northeast populations raided the Chugach area while southwest Kodiak populations raided the Alaska Peninsula and eastern Aleutians (Black 1977:86, 92, 2004:140-141). Additionally the abundance of Alaska Peninsula toolstone changes over time, as 92.3 percent of Late Kachemak samples are assigned to Group 4 while Koniag samples are divided into Groups 1 (46.2 percent) and 3 (53.8 percent). These results show there were changes in the direction from where toolstone was originating over time in Kodiak. The smaller sized Koniag samples from Group 1 suggest its source is located farther away and is supported by results in section 5.2 and 5.3 that shows most of Group 1 samples come from the CHK area.

Hypothesis 2: Sites with short term occupations contain less variety of volcanic toolstone than year-round occupations.

Samples from Alaska Peninsula villages and camps are unevenly distributed into groups: samples from villages are contained within all six groups while samples from short term camps are found in three groups (Section 5.4). In addition to differences in toolstone variability between site types, Section 5.5 showed the availability of toolstone materials are differentially distributed according to interior and coastal locations in the Alaska Peninsula, with no significant changes over time. There is consensus that subsistence strategies did not significantly change over time in the Alaska Peninsula. Food resource availability remained segregated by location, and sufficient toolstone was located in those locations. While terrestrial and avian faunal remains are present in both coastal and interior Norton sites , the Pacific coast sites contain sea mammal fauna while interior sites contain evidence for mostly fishing (Dumond 1998b:195-196). This further supports Bundy’s (2007:15-17) observation that Norton sites contain dissimilar assemblages which are caused by differences in resource availability. The results support the expectation that short term sites utilized locally available materials through embedded procurement (Binford 1980; Binford 1979:266) and were present in sufficient quantity across the central Alaska Peninsula throughout the late prehistory (Andrefsky 1994).

Hypothesis 3: Koniag village sites contain a greater proportion of toolstone found at a greater distance in the central Alaska Peninsula than Late Kachemak village sites.

Hypothesis 3 is supported from the data which yield statistically significant differences in sample distributions of Late Kachemak and Koniag samples. Kodiak samples fit into Groups 1, 3, and 4 (Table 5.21). The significant difference in group assignment between Late Kachemak and Koniag samples in Kodiak is related to the geographic range of Alaska Peninsula sites. If Group

4 is primarily located in the Katmai region in the Alaska Peninsula, it would follow that Late Kachemak populations were using this toolstone as well. During the Koniag tradition it appears a change occurs, obtaining toolstone from Groups 1 and 3. Koniag samples are distributed roughly in half into Groups 1 and 3, while 92.3 percent of Late Kachemak samples are contained in Group 4. The rest of Late Kachemak samples are found in Group 3. No Late Kachemak samples are found in Group 1, which has sites located in the largest geographic range. Rather, all of Late Kachemak samples appear to be concentrated in Alaska Peninsula locales closest to Kodiak. Therefore the geographic range of toolstone with similar element values is larger during the Koniag than Late Kachemak. This finding is supported by the many lines of evidence that indicate Koniag populations on Kodiak engaged in more frequent off-shore travel in order to obtain resources, as discussed in section 1.2.4. This evidence is expected given that the abundance of raw material within a site decreases the farther away it is located from a source (Mitchell and Shackley 1995). While abundant toolstone may not have been considered a prestige item, the presence of volcanic material in Koniag sites indicates it was obtained and utilized by Kodiak populations.

Hypothesis 4: Northeast Late Kachemak site KOD-00044 does not contain significantly a larger proportion of volcanic materials from the Alaska Peninsula than southwest Late Kachemak site KOD-00145.

While located in different areas of Kodiak Island, Late Kachemak sites KOD-00044 and KOD-00145 contain similar distributions of samples within groups, showing that the toolstone element values varied less during the Late Kachemak (Table 5.24). Aside from geographic proximity to the Katmai coast where XMK-00007 is located, a possible explanation could lie in the kinship network and territorial alliances that occurred during the Late Kachemak. Maintaining social relations were increasingly important during the late prehistoric period, and communities were more territorial compared to the Early Kachemak. Both Late Kachemak sites contain trade items including beads (Clark 1970:85) and coal, however coal working has been documented at KOD-00145 suggesting an intensified use or trade of coal at this site (Steffian 1992a:156). The modified and disarticulated scattered human bones found at KOD-00044 are evidence as territorial markers for a specific community or family identity (Simon and Steffian 1994). The extent of local territories or shared accessibility over traveled areas is not known, however the presence of multiple burials in crypts and disarticulated bones also found at burials in southwest and northeast Kodiak Island during the Late Kachemak shows that this was practiced over a widespread area on the island (Steffian and Simon 1994). Ethnographic data states that Kodiak populations formed alliances and traded with each other (Black 1977:97).

These results support fauna data from the two sites that indicate occupants were obtaining relatively the same proportions of food resources. Site KOD-00044 contains primarily harbor seal and fox fauna while the Uyak Bay area (where KOD-00145 is located) contains a wide diversity of fauna (Clark 1970:87; Steffian 1992a). Differences in faunal remains from Late Kachemak sites, particularly from eastern Kodiak, are considered a representation of local procurement of unequal distributions of mammals including whales (Clark 1974:30, Steffian 1992a:144). The results above may have been different if a Late Kachemak site located in east/southeast Kodiak was sampled for this study.

Hypothesis 5: KAR-00001 contains a larger proportion of volcanic toolstone from the Alaska Peninsula than AFG-00015.

While the Late Kachemak samples contain statistically significant similar element values, the Koniag samples from Kodiak show differences in group membership according to proximity to the Alaska Peninsula. This hypothesis is supported by results that show 80 percent of AFG-00015 samples did not fit into any group compared to 23.1 percent of KAR-00001 samples (Tables 5.23-5.25). AFG-00015 is located close to Late Kachemak site KOD-00145, which does not exhibit the same decline in group membership. While the small sample sizes for Afognak sites limit discussion of the results, the decline in toolstone procurement from the Alaska Peninsula in northeast Kodiak could possibly reflect the northeast/southwest Kodiak geographic separation of Koniag tradition variations and raiding efforts. Koniag sites in Kodiak exhibit local differences in material culture including ceramics on southern Kodiak and a lack of whaling evidence on northeast Kodiak (Clark 1998:179; Fitzhugh 2003:212, 379). The differences in subsistence economies during the Koniag likely reflect differences in toolstone procurement locations (Odell 2004). AFG-00015 fauna and artifacts present evidence for an emphasis on offshore fishing in deep waters while KAR-00001 fauna indicates salmon fishing was predominant (Knecht 1995, Saltonstall 1997:44). Koniag populations focused on raiding adjacent off-island locations; the northeastern Kodiak populations raided the Kenai and Chugach populations while the south and southwest Kodiak dealt with the Alaska Peninsula and Aleutian populations (Black 1977:86, 92, 2004:140-141).

Hypothesis 6: There is no significant difference in the direction from where toolstone was originating between Norton and Thule/Koniag aged central Alaska Peninsula sites.

Hypothesis 6 is supported by the strong evidence for local volcanic toolstone being used throughout the late prehistory. The creation of groups based on element values from Alaska Peninsula samples was performed using Norton and Thule/Koniag aged sites. An assumption of many researchers is locally available volcanic toolstone was plentiful and easily accessed over time. Two tests measured association with regard to time period and components was performed and yielded results that showed significant differences in group proportions for both tests (Tables 5.16 and 5.17). In order to test geographic distance as a factor in determining group assignment, a test compared components excluding geographic outlier sites was performed (Table 5.20), which showed geographic distance is an important factor for similar toolstone element values. Along with this result, Tables 5.5-5.8 provide additional support that shows the temporal differences are obscured by geographic distances; Norton and Thule/Koniag aged sites located in close proximity show no significant differences in the geographic range of toolstone procured.

Hypothesis 7: There is a significant difference in the variability of volcanic toolstone among Norton sites on the Alaska Peninsula.

This hypothesis is supported by results that find variability among all Norton sites, regardless of site function or location (Tables 5.14 and 5.18). The local variations and relative lack of extensive communication among Norton sites in the Alaska Peninsula are reflected in the dissimilar toolstone element values. All Norton samples are included within five geochemical groups, reflecting the range of elemental values across the geographic distance of the sites and the lack of an extensive trade network (Figures 5.7-5.12). Table 5.20 shows the Norton samples (from sites UGA-00052, DIL-00161, and CHK-00005) do not belong to statistically similar group assignments. UGA-00052 and DIL-00161 are village sites, which exhibit greater sedentism with year-round or semi-annual occupations, and may not have engaged in long distance travel to acquire resources. CHK-00005 is a seasonal fishing site, indicating people used locally available materials for tools (Shirar et.al. 2011:17-22, 117-128); this is reflected in the relative lack of lithic material variability (Table 5.13).

While located in relative close proximity, cultural variations among the lower central Alaska Peninsula sites can be a possible explanation for the differences among group assignments per the SUT, UGA-00052, and CHK sites during this time. The possibility of similar influences from the Aleutian and Kachemak cultural traditions for UGA-00052 and the SUT sites has been raised by researchers (Maschner 2004; Hoffman 2009:108; VanderHoek and Myron 2004). The cultural affiliation for the SUT sites may indicate that while people at the SUT sites experienced a variety of influences, tools remained locally procured or this area obtained a steady supply of toolstone from elsewhere

Hypothesis 8: There is a significant difference in the sources of volcanic toolstone among Koniag sites on the Alaska Peninsula.

Unlike the Norton samples, the differences in toolstone element values among samples from Koniag sites cannot be attributed to local variations in material culture. The large geographic range of Koniag sites can account for the variability among Koniag sites (Table 5.19). While the Koniag tradition reached across the central Alaska Peninsula, it lacked the same evidence for extensive trading that Kodiak sites contain as discussed in Sections 1.2.4. and Section 2.3. If the subsistence pattern did not change over time, Alaska Peninsula populations may not have experienced the same degree of resource consolidation that Kodiak populations engaged in during the Koniag tradition. Population density remained relatively sparse on the Alaska Peninsula throughout the late prehistory, with the largest population centers located around the Ugashik River drainage system (Dumond 1987, 1991:103, 1998b). If volcanic toolstone had been in demand or was not easily accessible for Alaska Peninsula populations, toolstone element values would have been significant different among CHK, UGA, and XMK sites over time.

6.2 Discussion

This section describes and summarizes the results as it pertains to the late prehistoric procurement patterns in both the central Alaska Peninsula and Kodiak Archipelago. Results will be discussed in the following order: comparing Kodiak and Alaska Peninsula samples, comparing Alaska Peninsula samples over time, and comparing Kodiak samples over time. This section provides the foundation for the implications of these findings as discussed in Section 6.3.

6.2.1 Comparing Kodiak and Alaska Peninsula Samples

Kodiak and Alaska Peninsula samples were expected to be distributed unevenly among groups given previous archaeological data which shows central Alaska Peninsula populations in these locations were focused on local subsistence economies based on seasonally available food resources and few trade/non-local items found in Norton sites (discussed in Sections 1.2.1 and 2.4). However Group 4 is comprised of samples from these sites: 70 percent of XMK-00007 samples, 91.7 percent of KOD-00044, and 92.9 percent of KOD-00145 samples. While Group 4 consists of samples from primarily XMK sites in the Alaska Peninsula and Late Kachemak sites in Kodiak, all Koniag samples from Kodiak fit into either Group 1 or Group 3. The geographic shift of likely toolstone procurement locations in Kodiak sites coincides with the Koniag tradition. The presence of slate at CHK-00011 has been used to link CHK area populations with the Koniag tradition, where Koniag cultural material appears to spread southward down the Alaska Peninsula over time (Dumond 1992:100; Hatfield 2010). This reflects research by Raff et al. (2010) that showed different haplogroups appeared in Katmai and moved westward toward the western Aleutians after 1000 BP.

6.2.2 Geographic Proximity of Local Volcanic Toolstone Over Time in the Alaska Peninsula

Data presented in Sections 5.2 and 5.5 shows that the geographic distance of sites on the Alaska Peninsula remained the most important factor in comparing sites containing toolstone with similar element values. Establishing geographic limits of sites containing toolstone with similar element values gives further evidence to support hypotheses 6, 7, and 8. Geographic locales containing sites with toolstone containing similar element value are: in CHK sites CHK-00005 and CHK-00011, and one locale found within three sites: UGA-00052, SUT-00024 and SUT-00027. DIL-00161 and XMK-00016 contains the majority of Group 3 samples suggesting a difference in element values from samples found in lower peninsula sites. Additionally Katmai Koniag sites XMK-00007 and XMK-00016 account for 80 percent of Alaska Peninsula samples found in Group 4.

There has been research regarding possible population movement on the Alaska Peninsula during the Koniag tradition as discussed in Sections 1 and 2.2, and the results comparing Alaska Peninsula samples do not yield any new evidence for this topic. Possible re-occupation of Alaska Peninsula sites that brought the Koniag tradition to the Alaska Peninsula has been researched from sites used for this study: UGA-00052 and XMK-00016 (Bundy et al 2005; Hoffman 2009). As explained by Hoffman (2009:102-104), locally available tool materials may have been easily accessible to new people occupying older sites. At the same time, cultural influences instead of migration episodes could exhibit the same local toolstone procurement patterns. The findings of no significant changes in elemental values from samples in Alaska Peninsula sites or locales with multiple components over time gives support to the idea of an immediately available and steady supply of volcanic raw materials in which new and pre-existing populations could have readily utilized.

A possible explanation for the differences in toolstone element values may be due to the direction and magnitude of pyroclastic flows in the Alaska Peninsula. The Alagnak River (where DIL-00161 is located) and the Ugashik River (where UGA-00052 is located) flow into Bristol Bay, transporting the sediment and cobbles from the Aleutian Range. While not identified as Norton sites, the time period in which SUT-00024 and SUT-00027 were occupied are contemporaneous with the Norton tradition. Samples from UGA-00052 and from both SUT sites form one local geochemical profile (Table 6.5). Both SUT sites and UGA-00052 are considered to have been within the possible pyroclastic flow zone of the 3500 BP Aniakchak eruption (VanderHoek and Myron 2004:Figure 7-4). Unlike UGA-00052 and the two SUT sites, CHK-

00005 and CHK-00011 lie outside the possible geographic boundary of the affected area containing pyroclastic debris or flow from the Aniakchak caldera forming eruption. Instead, the two Chignik sites are located closer to the affected areas following the 3700-3500 BP eruption of Mount Veniaminof (VanderHoek and Myron 2004:Figure 7-4). While the SUT sites are located roughly equidistant to the CHK sites and UGA-00052, the similar toolstone element values contained in SUT and UGA-00052 samples could have been caused by the eruptive history on the peninsula.

6.2.3 Geographic Proximity of Non-local Volcanic Toolstone Over Time in Kodiak

The locations from which toolstone originated appear to have changed over time for Kodiak populations and not central Alaska Peninsula populations. The Late Kachemak samples show a strong relationship to samples from a Koniag site in the Katmai coast. In contrast, the Koniag sites contain toolstone from a geographic range that is primarily found in sites located in the lower central peninsula. The Late Kachemak is characterized by widening mobility and territorial claims that would have included access to toolstone from multiple locations. As resource consolidation increased and repeated raiding against the same populations occurred throughout the region, easily accessible areas may have changed over time. The reported ethnographic fighting/raids between the inhabitants from the resource-rich Alaska Peninsula with those in Kodiak can be observed in the different overall samples distributions between the Late Kachemak and Koniag samples on Kodiak, the increase in lithic conservation observed in KAR-0001 samples, and may account for the lack of toolstone diversity in the Chignik, Ugashik, and Katmai locales. Kinship ties and territorial defense increased during the Koniag which may have allowed for a steady supply of resources from particular areas.

There are multiple results that support the idea of Koniag populations engaging in travel across larger geographic areas. While both Late Kachemak and Kodiak components have samples in Group 3, 92.3 percent of Late Kachemak samples are included in Group 4, with no Kodiak Koniag samples present. During the Late Kachemak, one Alaska Peninsula site (XMK-00007) is included significantly with KOD sites in Group 4. In contrast, all Kodiak Koniag samples are included in Groups 1 and 3, both of which contain samples from at least two Alaska Peninsula components. Additionally, 53.6 percent of Kodiak Koniag samples are not included in any group; compared to 33.3 percent of Late Kachemak samples (Table 5.23). This result shows that Koniag populations from these sites exhibited a greater reliance on toolstone from elsewhere than Late Kachemak populations.

The distribution of toolstone found in Kodiak sites may be attributed to preferentially selecting toolstone. The purpose of raids was to gather food, clothes and slaves (Black 1977:85-86), therefore obtaining common toolstone may not have been a high priority for Kodiak populations. However Groups 1 and 2 come from the lower central peninsula, primarily from CHK and the Aniakchak geological samples and Group 1 is found only in Koniag sites in Kodiak; researchers have noted the presence of 'Aleutian/Aniakchak basalt' (Tennessen 2009:191, 203-204), a type of dark fine grained volcanic rock type that people in the lower Alaska Peninsula commonly used. This type of rock may have been preferentially used by peninsula populations and by Kodiak residents as well during the Koniag. They were willing to travel farther than Late Kachemak and obtained toolstone during this travel. However if Kodiak populations preferred this particular type of toolstone and if this toolstone is represented in samples from the lower Alaska Peninsula sites in this study, populations located in other areas in the Alaska Peninsula did not appear to prefer this toolstone from the samples used in this study.

6.3 Conclusion

No relationship is found between volcanic toolstone variability and site type, time period, or cultural tradition in Alaska Peninsula sites. The findings here have demonstrated that volcanic toolstone remained locally procured, and several geographic boundaries of source areas were identified. The implications of these findings are that seasonal rounds remained relatively stable, volcanic toolstone remained plentiful, and while the Koniag cultural tradition is found throughout the peninsula, populations living there did not appear to engage in resource consolidation or controlling access to food resources like contemporaneous Kodiak populations. The presence of the Koniag tradition in the Alaska Peninsula did not appear to alter toolstone procurement locations across the peninsula and suggests the ubiquity of volcanic toolstone remained static over time or was not considered a valued trade item. These findings are supported by the diversity of faunal remains in peninsula sites, unchanging local diets found in late prehistoric individuals, and no significant change in site location over time which reflect changes in food resources.

Koniag populations in Kodiak used toolstone from different likely areas than Late Kachemak populations; this supports the current data gathered from archaeological, ethnographic, and biological data shows that changes in the social landscape and subsistence patterns altered the way Kodiak populations obtained resources over time. If territorial alliances were developing during the Late Kachemak, they became more pronounced during the Koniag tradition and a change occurred in the direction from where toolstone likely originated. Whereas 92.3 percent of Late Kachemak samples are included in Group 4, KAR-00001 samples are divided into Groups 1 and 3 more evenly. Koniag sites were more diversified, with almost all of AFG-00015 samples not similar to the Alaska Peninsula samples, suggesting Koniag populations became geographically fragmented over time. While late prehistoric material culture spread throughout Kodiak, Clark (1998:180) interprets the local variants of both Late Kachemak and Koniag traditions as comprising the local histories of separate communities. These separate communities became more distinct over time with ethnographic accounts of potlatches and inter-community interaction (Black 1977). Kinship ties and territorial defense increased during the Koniag which may have allowed for a steady supply of resources from particular areas. The frequent raiding or warfare during the Koniag tradition may have allowed KAR-00001 residents to obtain toolstone from a greater variety of locations. The reported ethnographic fighting/raids between the inhabitants from the resource-rich Alaska Peninsula with those in Kodiak can be observed in the different overall samples distributions between the Late Kachemak and Koniag samples on Kodiak, the increase in lithic conservation observed in KAR-0001 samples, and may account for the lack of toolstone diversity in the Chignik, Ugashik, and Katmai locales.

Using toolstone from different areas in the Alaska Peninsula over time gives support to the idea of a “patchy resource area” on Kodiak, with localized groups that created widespread socially unequal populations where raiding for resources became common over time (Fitzhugh 2003). As resource consolidation increased and frequent raids of the same populations occurred throughout the region, easily accessible areas may have changed over time. While both Late Kachemak site KOD-00145 and Koniag site KAR-00001 were village sites located in southwest Kodiak Island, the larger KAR-00001 site is located closer to the coast and is interpreted to be a warehouse for consolidation and storage purposes for the southwest Kodiak region (Knecht 1995). The Karluk river system and Uyak Bay area (where KAR-00001 and KOD-000145) contain a variety of food resources whereas other areas of Kodiak did not contain a wide diversity. 46.2 percent of KAR-00001 samples are included in Group 1, which also contains samples from every Alaska Peninsula site and all of the geological samples. Samples from three of the four Kodiak sites (AFG-00015, KOD-00044, and KOD-00145) are not present in Group 1 (Table 6.15). This finding shows greater proportions of samples containing similar element values between KAR-00001 and the Alaska Peninsula.

A widening variety of toolstone reflects the expanding Koniag tradition across the central Alaska Peninsula and the greater North Pacific region. There are multiple results that support the idea of Koniag populations engaging in travel across larger geographic areas. While both Late Kachemak and Kodiak components have samples in Group 3, 92.3 percent of Late Kachemak samples are included in Group 4, with no Kodiak Koniag samples present. Additionally, 53.6 percent of Kodiak Koniag samples are not included in any group compared to 33.3 percent of Late Kachemak samples (Table 5.23). This result shows that Koniag populations from these sites exhibited a greater reliance on toolstone from elsewhere than Late Kachemak populations.

Additional samples from the North Pacific region can refine the patterns seen in this small scale study. Many avenues for analyzing additional samples exist. Samples from the Katmai coast and Koniag sites in the Kodiak archipelago would give a better perspective on the variability of volcanic toolstone on Kodiak. Similarly, sampling more Afognak sites and southeast Kodiak would help determine if a pattern of obtaining toolstone in geographically proximate areas can be determined. Establishing a range of elemental values among volcanic sources or sites from the eastern Aleutian archipelago, southern Alaska Peninsula, Kachemak Bay, Cook Inlet and south central Alaska would clarify the similarities observed among the central Alaska Peninsula and Kodiak samples from this study. The results of this exploratory study support previous research that shows the many differences existed between Alaska Peninsula and Kodiak late prehistoric populations, despite containing similar assemblages. This study adds to the vast literature that explores this dynamic late prehistoric record, and future research will refine the patterns observed from volcanic toolstone in this region.

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Appendix A

Feasibility Study for Southwest Alaska Volcanic Artifact Sourcing Project

This appendix describes initial testing of the PXRF to establish its suitability for use in testing volcanic artifact sourcing. While not studied as extensively as obsidian, basalt and other volcanic rocks are increasingly used for geochemical provenance studies in archaeology. Before analyzing the elemental data of samples, it is necessary to assess the precision of the PXRF machine. Are the values reflecting the most accurate representation of the sample, or are they reflecting error in the instrument or incorrect sample parameters (i.e. uneven sample surface)? Precision of a machine used for geochemical analysis is commonly calculated by measuring standards on the machine and comparing the results with known published values (Hughes 1998:108). This is the method used to determine precision of this machine for the purposes of this study. This appendix consists of three sections. Section 1 discusses the various ways to classify the igneous rock type of a sample using element values. Section 2 contains mini-experiments or experiments designed to measure the precision and accuracy of the PXRF machine and Section 3 contains a test comparing the precision and accuracy between the PXRF and XRF machines.

Methods: The Bruker Tracer III-V PXRF machine housed at the University of Alaska Museum of the North (UAMN) was used for this study. An Al-Ti filter was used for the x-ray path, with the beam set to 40keV and 15nA for a total of 300 live seconds (lsec). for each sample and each experiment. Methods used for the AXIOS XRF machine housed at the University of Alaska Fairbanks (UAF) Reichardt Natural Sciences building are described in the appropriate sections.

Spreadsheets for the standard and archaeological sample info are attached separately. Elements chosen for analysis are the following: Na, Mg, Si, K, Ca, Ba (L energy shell), Ti, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Pb (L line), Th, Rb, Sr, Y, Zr, and Nb. The values for mid-z elements (Rb, Sr, Y, Zr, and Nb) are expected to be the most useful for discerning differences among volcanic rocks, discussed in Section 1.1. Elements Co, Ni, Cu, Zn, Ga, As, Pb, and Th contain the some of the lowest values and are not usually used in archaeological studies. Williams-Thorpe et al found that these elements, among others, have such small values that it is difficult to determine their presence unless their values are greater than 100ppm (Williams-Thorpe et al 1999:235). The energy line used for the measurement is listed next to each element. ‘Na’ is ultimately listed as ‘NaKa1’ to indicate that the Na photons were obtained from the first k energy shell of a particle.

1.0 Preliminary Considerations

This section discusses topics that needed to be researched prior to conducting the study: determining what elements should be analyzed (Section 1.1) and how data from elements can be used in provenance studies using volcanic rock (Section 1.2). These two topics detail relevant information and current practices regarding volcanic rock provenance studies in anthropology. While this section does not list every aspect to conducting a provenance study, it provides information regarding key components for this specific study. The tests performed are listed in Section 2 and 3 following the discussion of these considerations.

1.1 Deciding Which Elements to Use

Trace elements, defined as comprising 0.1 wt. % or less of a material, are important when understanding the geochemical composition of a material because they reflect the formation of the local magma and the concentration of elements found in the mantle prior to eruption (Anderson 1981:83). Certain elements are ejected from the mantle more readily than other elements during melting because these elements are not easily incorporated into the crystal structure of minerals found in the mantle. Rocks produced from magmatic processes reflect these trace element concentrations, which give a unique footprint of the local magma reservoir and mantle at a particular location. One group of elements that are considered 'incompatible' with the mantle does not fit because their ionic radii are too large (LILE 'large ion lithophile elements). They are K, Rb, Sr, Cs, Ba, Li, Na, Be, Mg, Pb and Eu. The other group of elements is incompatible with the mantle because their charges are too high (HFSE 'high field strength elements'): Ce, Zr, Nb, Hf, Ta, Ti, U, and Th. "In crustal plate/magma interactions Rb, Sr, Zr and Nb are elements not readily incorporated into many solid mineral phases either because they have a large ionic radius (Rb, Sr) or because they have strong ionic charges (Zr, Nb). As a result they are preferentially concentrated into residual liquids during magmatic processes and can provide a sensitive measure of magmatic evolution" (Grave et al 2012:1676).

Overall, the most reliable measurements are reported to come from the range of elements Ti-Nb (Shackley 2011a:10). Some incompatible elements are observed as oxides in trace element data, which PXRF cannot perform without a vacuum (i.e. MgO). With these limitations in mind, while all the above elements are inclined to be expelled first from the mantle and into magma, Rb, Sr, Y, Nb and Zr are at energy that PXRF gave reliable precision in these experiments. Some results from experiments in this appendix contain element values with precise results, particularly Ga. The values do not vary between samples and therefore prove to be a poor discriminator of different artifacts observed.

In determining which elements are appropriate for a particular study, several factors are considered. While some previous studies use elements important to their regional sources (Ogburn 2004), others examine the elements according to the precision they obtained from their machine (Mills et al 2010, Weisler and Kirch 1996, Williams-Thorpe 1999:232). Researchers have different methods: In Hawaii, for example, they look at the element range from Mg to Nb (Lundblad et al 2011:67). Some researchers look at the weight (in percent) of major oxides (DiPiazza and Pearthree 2001, Weisler and Kirch 1996). In general, mid-z trace elements (Sr, Rb, Zr, Y, and Nb) show reliability in measuring basalt and other mafic rocks in archaeological provenance studies.

> The elements that are incompatible with the solid phase in high-temperature melts are most stable in glasses and are likely to be intrasource invariable (Cann 1983; Zielinkski et al. 1977). These include Rb, Se, Y, and Nb, and perhaps Ba as long as devitrification is not advanced (Cox et al. 1979). Many other elements are absorbed easily into the solid phase within the melt and can vary quite extensively within a single source. The inclusion of too many of these elements, such as Cr, Co, Ga, Ge, Ni, or some major compounds, certainly will group sources together that are quite spatially or diachronically distinct, or at least will covertly skew the classification analysis [Shackley 1988:764].

1.2 Using Elemental Data for Archaeological Sourcing of Igneous Rocks

The quickest and most general method of discerning igneous rock type in terms of elemental composition is to look at the percentage of SiO_2. Mafic rocks, which include basalt, should have a range of 45-52 percent SiO_2. Intermediate rocks (including andesite) have a range of 52-63 percent of SiO_2. Intermediate-felsic rocks (including dacite) are classified as having a range between 63-69 percent of SiO_2.Felsic rocks (including rhyolite) should have more than 69 percent SiO_2. However, looking at only one element can yield misclassification in fine-grained rock type comparisons. A key difference between PXRF and XRF machine is the ability to measure lower energy x-rays because PXRFs typically operate in air which absorbs the x-rays from elements such as Si.

Basalt consists of primarily Fe and Mg, and Si, while other igneous rocks contain the same basic composition with varying percentages. A commonly used way to define rock type by elements is by using the TAS diagram. The "total alkali versus silica" classification divides the rock types by comparing the weight percentage (weight percent) of SiO_2 and $Na_2O + K_2O$. Another way to discriminate between igneous rock types is the AFM diagram ("alkalis, Fe [iron], magnesium"), which plots samples according to the total alkalis ($Na_2O + K_2O$), MgO, and FeO in weight percent. Analyzing the amount of Fe in a sample can also discern if the type of basalt is tholeiitic or calc-alkalic igneous rocks (these two types are formed by the crystallization process of the magma used to form the rock, which can then be traced to a source). Both ways of determining rock type are performed routinely in geology, however by far the most utilized technique for defining an igneous rock type is by analyzing the mineral composition of a sample. Mineralogical analyses have been performed in archaeological studies; however the efficiency and non-destructive techniques of XRF are preferred.

After distinguishing rock types, comparing rock compositions within each classification becomes less clear. For intra-rock type comparison, there is a diagram that can be used that is identical to the TAS classification, except it substitutes MgO for SiO_2. This classification system is effective for mafic rocks because MgO is a better discriminator between differences in mafic rock element values than SiO_2. Ultimately, choosing which elements to analyze for intra-rock type comparisons between samples for provenance studies relies on the source elemental data. To complicate finding the potential source of a sample, each volcanic source can have a high degree of variability not only among sources but within each volcanic source. “Successive flows from the same magma chamber are erupted at different times in the magma chamber crystallization, and so they too will show differences in minor or trace element ratios. Geochemical matching begins with obtaining a number of different minor and trace element values for each source flow, as a baseline.” (McCall 2005:273-274). Not only are there potential problems for determining a good match for a sample within each source, but tracing a sample to a secondary igneous source can be difficult to determine (Lundblad et al 2011:66). Each volcanic event can produce unique element signatures which can be helpful if sources are located at great distances or potentially produce homogenous element values among volcanic eruptions if multiple sources are located in close proximity.

For archaeological provenance studies, researchers have used different methods in order to ascertain which elements to use for mafic and intermediate rock. There is no consensus as to which elements are most effective in evaluating the different types of igneous rocks for provenance studies other than SiO2, K2O, FeO, and MnO. While some studies seem to use elements important to their regional sources (Ogburn 2004), others use elements for their studies according to the precision they obtained from their machine (Mills et al 2008, Weisler and Kirch 1996, Williams-Thorpe 1999:232). For trace elements, mid-z elements have been shown to be most effective in distinguishing geochemistry source signatures, regardless of weathering on samples (Lundblad et al 2011).

2.0 Multiple Experiments

This section contains various experiments performed in order to explore the accuracy and precision of the PXRF instrument. In Section 2.1, standards are measured three times, Section 2.2 contains the a mini-experiment using ten samples measured three times, Section 2.3 consists of several assays performed in several locations on a sample surface, and a comparison of element values from a phenocryst and non-phenocryst surface of samples are contained in Section 2.4.

2.1 Standards Measured Three Times

This experiment was performed in order to assess the accuracy and precision of the PXRF instrument using standards and known published values.

2.1.2. Methods

Each standard was taken from the Advanced Instrumentation Lab housed at the Reichardt Natural Sciences building at UAF, with permission from Dr. Ken Severin. The standards used for this precision test partially comprise the calibration co-efficient standards used for this thesis. The following 5 USGS standards were used for this study: BR, AGV-1, BCR-1, BE-N, and BIR-1. AGV-1, an andesite standard, was used to examine variability. After removing each standard from its plastic covering, it was placed facedown with the center of the sample lying directly over the PXRF beam. Each sample maintained a stationary position on the machine covered by the protective cap. After each 300 sec assay was completed, the trigger was released, a new assay was set up in S1PXRF, and then the trigger was activated again until the 300 sec were completed. This was repeated until three assays were performed on each sample. On the spreadsheet, the standards were given numbered suffixes for each time they were analyzed for this study. Each standard was measured 3 times in the same location on the sample. For example, BR is labeled as BR-1, BR-2, and BR-3. AGV-1 is labeled as AGV-1-1, AGV-1-2, AGV-1-3, etc. Then an average of each standard was calculated and compared to the published values. Tables A-1 – A-4 contain the results of the five standards measured three times.

For the BHQ standard, additional methods were performed: This sample was obtained from the Fairbanks DGGS building with permission by Melanie Werdon. The sample was cut and polished for a smooth flat surface before analysis. This sample was run three times under the x-ray beam using the same instrument and parameters, but in four different locations on the sample. Not all elements were published by DGGS for this standard. The values from each location on the sample were averaged and compared to the published values as shown in Tables A-5 and A-6.

A standard deviation (SD) was calculated for each element. The relative standard deviation (RSD) was calculated as a way to measure the precision as a percentage of the mean; a lower percentage means low variability. Negative values were not calculated in determining SD and RSD because negative measurements are equivalent to 0 ppm; the negative values were replaced with 0 during calculations. The percentage error {(x-y)/y} was calculated for each element and standard when comparing the average and published values. When comparing values with published values of standards, the percent error (% error) is listed in tables using the calculation: {100 x (value-published value)/published value}.

2.1.3. Results of Five USGS standards Measured Three Times

The values from four standards (AGV-1, BIR-1, BR, and BCR-1) yielded the largest standard deviations for element Si while BE-N yielded the largest MgO standard deviation, as shown in Tables A-1 – A-4. The MgO values for BE-N may be explained by the type of basalt it is. While these standard deviation values may be potentially problematic, the difference of a few thousand ppms is not great, especially considering the large ppm values for Si. The smallest standard deviation for each standard is As, an element with little value for discerning volcanic sources in archaeological provenance literature. The highest RSD values are: elements K (BR and BE-N), Mg (BCR-1), Nb (BIR-1) and Ba, Cr, and Ni (AGV-1). All highest RSD values except with standard BR contain assays containing negative measurements. Excluding measurements with negative values, the highest RSD percentages are: elements K (BR, AGV-1), Mg (BIR-1and BE-N) and Na (BCR-1). The measurements are most variable among major elements with lighter atomic weight. The elements with the lowest RSD are (excluding those with negative values): Co (BR, BCR-1, and BE-N), As (AGV-1), and Ca (BIR-1).

Andesite standard AGV-1 produced more negative values than the other standards. AGV-1 produced two negative values for each element: Ba, Cr, and Ni. These three element values deviate from the published AGV-1 values and highlight the differences that exist when creating a calibration co-efficient for a specific material. The need to create calibration coefficients using the appropriate standard material is important. However the trace element values for AGV-1 were positive with small SD values, which highlight the importance of choosing the appropriate elements to measure in a study. The main results in this section show that while there is some variation between each sample analyzed, the PXRF machine can produce reliable values.

2.1.4. Results Comparing Mean Values and Published Values

The average observed values were calculated with the published values for each standard. The lowest accuracy for BR, BIR-1, and BE-N is element K. Other elements containing the lowest accuracy are Cr (in standard BCR) and Mg (AGV-1). The elements with the highest accuracy values are: Na (in standard BR), Ca (BE-N), Co (BIR-1), Ba (BCR), and Zr (AGV-1). Table 2 presents the data.

Results of BHQ Standard: The element with the smallest RSD (%) is Zr. The element Mg yielded the lowest in precision and accuracy, while Si is the most accurate averaged measurement.

2.1.5 Conclusion

Out of all elements measured, BIR-1, BE-N, and BHQ yielded the lowest precision for Mg. Similarly, the accuracy for Mg was lowest for BHQ and AGV-1. Zr is the element with the greatest accuracy in AGV-1, while Zr yielded the greatest precision in BHQ. From this study, Mg proves to be a less reliable and accurate element to measure, while Zr has shown to yield both reliable and accurate measurements than other elements. This study established a range in precision and accuracy of the PXRF instrument for the selected elements and samples.

Table A- 1. Five USGS Standards Measured Three Times (Na-Fe)

Standard	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
BR-1	14967	73812	813616	137134	145083	1217	27647	424	2215	86704
BR-2	37872	70486	438498	26233	141273	1099	27106	383	2015	81706
BR-3	38739	104114	385673	18116	142712	1133	27145	446	1917	90409
Mean	30526	82804	545929	60494	143023	1150	27300	418	2049	86273
Std.Dev.	13482	18530	233324	66496	1924	61	302	32	152	4367
RSD (%)	44.16	22.38	42.74	109.92	1.35	5.28	1.11	7.66	7.41	5.06
AGV-1-1	37783	100146	393232	35526	49955	24	9781	0	924	24271
AGV-1-2	38799	81610	362832	11863	44812	0	9091	0	876	29911
AGV-1-3	38636	33608	459927	39512	50856	0	8372	26	935	22195
Mean	38406	71788	405330	28967	48541	8	9082	5	911	25459
Std.Dev.	546	34339	49665	14946	3261	14	705	9	31	3993

Table A-1 continued

Standard	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
RSD (%)	1.42	47.83	12.25	51.60	6.72	173.21	7.76	173.21	3.44	15.68
BIR-1-1	38100	104126	363010	4130	131157	19	10466	330	1781	86027
BIR-1-2	36133	0	494284	47747	131526	45	10160	273	1619	63891
BIR-1-3	38832	62507	400688	30440	129589	36	10533	270	1606	79168
Mean	37688	55544	419328	27439	130758	33	10387	291	1669	76362
Std.Dev.	1396	52411	67593	21963	1029	13	199	34	97	11332
RSD (%)	3.70	94.36	16.12	80.04	0.79	39.61	1.91	11.62	5.84	14.84
BCR-1-1	29390	39274	604602	5811	74073	717	22537	142	1741	86924
BCR-1-2	5729	0	1194732	10780	71785	640	21484	46	1605	94119
BCR-1-3	6452	0	741829	12904	70179	671	22163	140	1641	80901
Mean	13857	13091	847054	9832	72012	676	22061	110	1662	87315
Std.Dev.	13457	22675	308816	3641	1957	39	534	55	70	6617

Table A-1 continued

Standard	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
RSD (%)	97.11	173.21	36.46	37.03	2.72	5.73	2.42	50.17	4.24	7.58
BE-N-1	35530	103960	447931	66760	141070	1045	26380	398	2032	87112
BE-N-2	35446	100626	366234	0	138091	969	25672	328	1989	90517
BE-N-3	38757	25587	387465	3041	139465	1019	25887	373	1930	94027
Mean	36577	76724	400543	23267	139542	1011	25980	367	1984	90552
Std.Dev.	1888	44318	42390	37697	1491	39	363	35	51	3458
RSD (%)	5.16	57.76	10.58	162.02	1.07	3.82	1.40	9.68	2.58	3.82

Table A-2. Five USGS Standards Measured Three Times (Co-Nb)

Standard	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
BR-1	50	292	121	165	15	1	8	11	55	1380	44	254	109
BR-2	51	256	97	152	15	1	9	11	55	1356	41	256	102
BR-3	51	270	119	150	14	1	5	10	52	1351	44	260	104
Mean	51	272	112	156	15	1	7	11	54	1362	43	257	105
Std.Dev.	0	18	13	8	1	0	2	0	2	16	2	3	4
RSD (%)	1.14	6.66	11.85	5.23	3.94	0	28.39	5.41	3.21	1.14	4.03	1.19	3.43
AGV-1-1	15	23	112	92	15	1	36	11	70	706	37	228	17
AGV-1-2	17	0	110	87	14	1	40	11	68	690	36	227	15
AGV-1-3	15	0	114	83	15	1	34	9	68	696	36	227	15
Mean	15	8	112	87	15	1	37	10	69	697	36	227	16
Std.Dev.	1	13	2	5	1	0	3	1	1	8	1	1	1

Table A-2 continued

Standard	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
RSD (%)	7.37	173.21	1.79	5.16	3.94	0	8.33	11.17	1.68	1.16	1.59	0.25	7.37
BIR-1-1	51	164	181	80	16	1	4	0	1	121	14	11	1
BIR-1-2	50	131	173	71	16	1	4	0	1	119	15	9	0
BIR-1-3	51	184	163	80	16	1	5	0	0	122	16	6	0
Mean	51	160	172	77	16	1	4	0	1	121	15	9	0
Std.Dev.	1	27	9	5	0	0	1	0	1	2	1	3	1
RSD (%)	1.14	16.76	5.23	7	0	0	13.32	0.00	86.60	1.27	6.67	29.04	173.21
BCR-1-1	51	36	76	95	16	1	7	6	41	304	42	187	10
BCR-1-2	51	29	42	112	16	1	6	5	41	302	37	187	11
BCR-1-3	51	28	54	101	15	1	5	5	38	306	38	185	11
Mean	51	31	57	103	16	1	6	5	40	304	39	186	11

Table A-2 continued

Standard	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
Std.Dev.	0	4	17	9	1	0	1	1	2	2	3	1	1
RSD (%)	.00	14.06	30.08	8.40	3.69	.00	16.67	10.83	4.33	.66	6.78	.62	5.41
BE-N-1	51	254	116	137	16	1	7	10	48	1355	40	259	103
BE-N-2	51	240	117	127	15	1	5	11	50	1325	44	261	102
BE-N-3	51	285	107	126	14	1	5	7	50	1338	42	264	102
Mean	51	260	113	130	15	1	6	9	49	1339	42	261	102
Std.Dev.	.00	23	6	6	1	0	1	2	1	15	2	3	1
RSD (%)	0	8.87	4.86	4.68	6.67	.00	20.38	22.30	2.34	1.12	4.76	.96	.56

Table A-3. Comparison of Mean Values and Published Values (Na-Fe)

Standard Name	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
BR	30526	82804	545929	60494	143023	1150	27299	417	2049	86273
Published BR	30500	132800	382000	14000	138000	1050	26000	380	2000	65700
Mean	30513	107802	463965	37247	140512	1100	26650	399	2025	75987
Std.Dev.	18.38	35353	115915	32876	3552	71	919	26	35	14547
% error: 100 x (value-published value)/ published value	.09	37.65	42.91	332.10	3.64	9.52	5.00	9.84	2.45	31.31
BIR-1	37688	48646	419328	27439	130758	33	10387	291	1669	76362
published BIR-1	17500	96800	477700	270	132400	8	9600	382	1710	83800
Mean	27594	72723	448514	13855	131579	20	9994	337	1690	80081

Table A-3 continued

Standard Name	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
Std.Dev.	14275	34050	41275	19211	1161	18	556.49	64	29	5259
% error: (value-published value)/ published value	115.36	49.75	12.22	10062.59	1.24	328.57	8.20	24	2.40	8.88
BCR	13857	0	847054	9832	72012	676	22061	110	1662	87315
published BCR	32700	34800	540600	16900	69500	681	22400	16	1770	88800
Mean	23279	17400	693827	13366	70756	679	22231	63	1716	88058
Std.Dev.	13324	24607	216696	4998	1776	4	240	66	76	1050
% error: 100 x (value-published value)/ published value	57.62	100.00	56.69	41.82	3.61	.73	1.51	587.50	6.10	1.67
BE-N	36577	76724	400543	229965	139542	1011	25980	367	1984	90552

Table A-3 continued

Standard Name	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
published BE-N	31800	131500	382000	13900	138700	1025	26100	360	2000	67400
Mean	34189	104112	391272	121933	139121	1018	26040	363	1992	78976
Std.Dev.	3378	38732	13112	152781	595	10	85	5	11	16371
% error: 100 x (value-published value)/ published value	15.02	41.65	4.85	1554.42	.61	1.37	.46	1.85	.80	34.35
AGV-1	38406	71788	405330	28967	48541	0	9081	0	911	25459
published AGV-1	42600	15300	587900	29100	49400	1226	10500	10	920	20600
Mean	40503	43544	496615	29034	48970	600	9791	3	916	23030
Std.Dev.	2966	39943	129096	94	608	885	1003	10	6	3436
% error	9.85	369.20	31.05	.46	1.74	100.00	13.51	100.00	.98	23.59

Table A-4. Comparison of Mean Values and Published Values (Co-Nb)

Standard Name	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
BR	51	272	112	156	15	1	7	11	54	1362	43	257	105
Published BR	52	260	72	160	19	3	8	11	47	1320	50	250	98
Mean	52	266	92	158	17	2	8	11	50	1341	47	254	101
Std.Dev.	1	9	28	3	3	1	1	0	5	30	5	5	5
% error: 100 x (value-published value)/ published value	1.92	4.80	55.56	2.64	22.68	64.80	12.50	3.55	14.11	3.18	14.00	2.80	6.94
BIR-1	51	160	172	77	16	1	4	0	0	121	15	9	0
published BIR-1	51	166	126	71	16	0	3	1	1	108	16	22	2
Mean	51	163	149	74	16	1	4	0	1	115	16	16	1
Std.Dev.	0	5	33	4	0	0	1	1	0	9	1	9	1

Table A-4 continued

Standard Name	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
% error: 100 x (value-published value)/ published value	.78	3.90	36.51	7.99	2.06	125.00	25.00	100.00	69.00	12.04	6.25	59.09	85.50
BCR	51	31	57	103	16	1	6	5	40	304	39	186	11
published BCR	37	13	19	130	22	1	14	6	47	330	38	190	14
Mean	44	22	38	116	19	1	10	6	44	317	39	188	12
Std.Dev.	10	13	27	19	4	0	5	1	5	18	1	3	2
% error: 100 x (value-published value)/ published value	37.84	137.08	202.05	20.45	28.18	35.38	55.88	13.38	15.40	7.88	2.63	2.11	24.64
BE-N	51	259	113	130	15	1	6	9	49	1339	42	261	102
published BE-N	61	267	72	120	17	2	4	11	47	1370	30	265	100
Mean	56	263	93	125	16	1	5	10	48	1355	36	263	101
Std.Dev.	7	5	29	7	2	1	1	1	2	22	8	3	2

Table A-4 continued

Standard Name	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
% error: 100 x (value-published value)/ published value	16.39	2.88	56.94	8.30	13.24	47.65	50.00	15.91	4.94	2.26	40.00	1.51	2.35
AGV-1	16	0	112	87	14	1	37	10	69	697	36	227	16
published AGV-1	15	16	60	88	20	1	36	7	67	662	20	227	15
Mean	16	5	86	88	17	1	37	8	68	680	28	227	15
Std.Dev.	0	16	37	1	4	0	1	3	1	25	11	0	0
% error: 100 x (value-published value)/ published value	4.58	100.00	86.67	.90	27.80	6.82	2.78	55.85	2.04	5.29	80.00	.00	3.93

Table A-5. DGGS BHQ Standard (Na-Fe)

Sample Location	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
Center	36106	99885	653379	20738	95439	633	21353	253	1696	57204
Lower left	36965	96480	410475	0	94344	467	18716	243	2018	75279
Right	26494	97582	506212	13554	96292	565	20500	234	1801	69363
Upper left	38483	84417	371191	14257	93449	527	19861	209	1940	54575
Mean of 4 BHQ Assays	34512	94591	485314	12137	94881	548	20108	235	1864	64105
Std.Dev. of 4 BHQ Assays	5435	6929	125575	8714	1244	70	1111	19	144	9848
RSD (%) of 4 BHQ Assays	15.75	7.33	25.88	71.79	1.31	12.69	5.52	8.11	7.69	15.36
Published BHQ Values	28300	57500	496000	12500	88000	707	20800	200	1700	-
% Error of Avg and Published Values: 100 x (value-published value)/ published value	21.95	64.51	2.15	5.29	7.82	22.49	3.33	17.48	9.63	-

Table A-6. DGGS BHQ Standard (Co-Nb)

Sample Location	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
Center	49	90	24	109	15	11	6	4	33	376	48	226	16
Lower left	51	115	40	83	15	1	4	6	33	366	46	223	17
Right	50	97	35	106	16	1	5	5	34	375	46	226	17
Upper left	50	99	28	103	15	1	5	3	38	378	47	226	17
Mean of 4 BHQ Assays	50	100	32	100	15	4	5	5	35	374	47	225	17
Std.Dev. of 4 BHQ Assays	1	11	7	12	1	5	-	1	2	5	1	2	1
RSD (%) of 4 BHQ Assays	1.63	10.54	22.47	11.73	3.28	-	142.86	28.69	6.90	1.42	2	.67	2.99
Published BHQ Values	-	-	-	-	-	-	-	-	45	404	39	248	15
% Error of Avg and Published Values: 100 x (value-published value)/published value	-	-	-	-	-	-	-	-	22.22	7.43	20.52	9.27	13.33

2.2 Ten Samples Measured Three Times

This set of analyses was performed to compare the precision of the established calibration co-efficient setup and the precision of the PXRF instrument by using archaeological samples.

2.2.1 Methods

Each sample was obtained from AHRS site XMK-00109. The appearance of each sample was macroscopically similar to basalt or weathered basalt. The following samples were used for this study: BD-00240, BD-00241, BD-00242, BD-00243, BD-00244, BD-00463a, BD-00464, BD-00465, BD-00466, and BD-00468. The samples were given label suffixes each time they were analyzed. For example, BD-00243 can be found as BD-00243-1, BD-00243-2, and BD-00243-3. Each sample maintained a stationary position on the machine covered by the protective cap. After each 300 sec assay was completed, the trigger was released, a new assay was set up in S1PXRF, and then the trigger was activated again until the 300 sec were completed. This was repeated until three assays were performed on each sample. A standard deviation (SD) was subsequently calculated for each element. The relative standard deviation (RSD) was calculated as a way to measure the precision as a percentage of the mean; a lower percentage means low variability. Negative values were not calculated in determining SD and RSD because negative measurements are equivalent to 0 ppm; the negative values were replaced with 0 during calculations.

2.2.2 Results

The findings are presented in Tables A-7 and A-8. The elements with the highest precision (RSD %) per sample are: Sr (from samples BD-00240, BD-00241, BD-00465, BD-00466), Zr (BD-00242, BD-00464, BD-00468), Co (BD-00243), and As (BD-00244, BD-00463a). The elements with the lowest precision are: Na (BD-00466), Mg (BD-00240, BD-00465, BD-00468), Ba (BD-00241, BD-00243), Co (BD-00463a, BD-00464), and Ni (BD-00242, BD-00244). These results show elements Sr, Zr, and As are the most precise elements measured, while Mg, Ba, and Ni are the least precise. While all elements show generally a high degree of precision, the mid-z trace element ppm values for both the USGS standards and archaeological samples have among the most precise results. The trace elements here vary less than the precision tests for the standard.

Table A-7. Ten Samples Analyzed Three Times (Na-Fe)

Catalog Number and Assay Number	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
XMK-00109.FS100.001 (1)	31013	0	1024198	32331	5371	513	19105	7	505	27140
XMK-00109.FS100.001 (2)	22525	0	550475	76026	8284	495	18978	0	542	39720
XMK-00109.FS100.001 (3)	32421	40135	814795	67231	9598	613	20570	11	583	30788
Mean of XMK-00109.FS100.001 assays	28653	13378	796489	58529	7751	540	19551	6	543	32549
Std.Dev. of XMK-00109.FS100.001 assays	5353	23172	237391	23111	2163	64	885	6	39	6472
RSD (%) of XMK-00109.FS100.001 assays	18.68	173.21	29.80	39.49	27.91	11.77	4.53	92.80	7.18	19.88
XMK-00109.FS103.001 (1)	38715	67628	380445	88090	22729	140	12095	117	892	35620
XMK-00109.FS103.001 (2)	37714	83195	383204	53843	24153	159	12435	116	961	36440
XMK-00109.FS103.001 (3)	35272	60159	405007	71578	22987	84	11345	131	918	30036
Mean of XMK-00109.FS103.001 assays	37234	70327	389552	71170	23290	128	11958	121	924	34032
Std.Dev. of XMK-00109.FS103.001 assays	1771	11753	13455	17127	759	39	558	9	35	3485
RSD (%) of XMK-00109.FS103.001 assays	4.76	16.71	3.45	24.06	3.26	30.54	4.66	6.91	3.77	10.24
XMK-00109.FS102.001 (1)	38110	101604	383132	142870	24596	163	12648	160	733	35949

Table A-7 continued

Catalog Number and Assay Number	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
XMK-00109.FS102.001 (2)	36746	69430	610400	138777	27118	160	12438	112	752	22643
XMK-00109.FS102.001 (3)	38590	74367	364804	82800	23296	161	12574	160	698	35013
Mean of XMK-00109.FS102.001 assays	37815	81801	452779	121482	25003	161	12553	144	728	31201
Std.Dev. of XMK-00109.FS102.001 assays	957	17327	136811	33563	1943	1	106	28	27	7427
RSD (%) of XMK-00109.FS102.001 assays	2.53	21.18	30.22	27.63	7.77	.68	.85	19.23	3.77	23.80
XMK-00109.FS101.001 (1)	36381	84889	380045	126940	23025	168	12293	146	564	26538
XMK-00109.FS101.001 (2)	31160	26024	376849	127368	21717	83	11780	139	562	27124
XMK-00109.FS101.001 (3)	34568	83057	503379	128821	22313	28	10515	106	545	29889
Mean of XMK-00109.FS101.001 assays	34036	64656	420091	127710	22352	93	11529	130	557	27850
Std.Dev. of XMK-00109.FS101.001 assays	2651	33469	72147	986	655	70	915	21	10	1790
RSD (%) of XMK-00109.FS101.001 assays	7.79	51.76	17.17	.77	2.93	75.32	7.94	16.20	1.85	6.43
XMK-00109.FS101.002 (1)	37243	98755	469288	76843	26186	89	10965	137	604	32942
XMK-00109.FS101.002 (2)	38664	103099	369091	45113	22972	47	10539	139	559	25171
XMK-00109.FS101.002 (3)	38560	103885	483771	21695	20461	23	10143	64	589	32458

Table A-7 continued

Catalog Number and Assay Number	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
Mean of XMK-00109.FS101.002 assays	38156	101913	440717	47883	23207	53	10549	113	584	30190
Std.Dev. of XMK-00109.FS101.002 assays	792	2763	62451	27679	2870	33	411	43	23	4353
RSD (%) of XMK-00109.FS101.002 assays	2.08	2.71	14.17	57.80	12.37	62.69	3.90	37.62	3.93	14.42
XMK-00109. FS102.002 (1)	34509	47620	402587	49684	25509	228	14346	42	409	12988
XMK-00109. FS102.002 (2)	28765	70802	413232	44765	24425	223	13989	93	465	22027
XMK-00109. FS102.002 (3)	36704	104459	406087	54340	19081	154	12624	97	445	15686
Mean of XMK-00109. FS102.002 assays	33326	74294	407302	49596	23005	202	13653	77	439	16900
Std.Dev. of XMK-00109. FS102.002 assays	4099.74	28580.05	5425.34	4788.32	3440.97	41.51	908.68	30.95	28.51	4640.32
RSD (%) of XMK-00109. FS102.002 assays	12.30	38.47	1.33	9.65	14.96	20.60	6.66	39.96	6.49	27.46
XMK-00109.FS102.003 (1)	34395	66253	611662	108026	25899	186	13601	81	458	17954
XMK-00109.FS102.003 (2)	34958	41636	376810	60597	22184	215	13731	31	419	19850
XMK-00109.FS102.003 (3)	33761	0	368474	83474	22703	154	12793	112	414	20349
Mean of XMK-00109.FS102.003 assays	34371	25723	452316	84032	23595	185	13375	745	430	19384
Std.Dev. of XMK-00109.FS102.003 assays	599	50408	138061	23719	2012	30	508	41	24	1264

Table A-7 continued

Catalog Number and Assay Number	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
RSD (%)of XMK-00109.FS102.003 assays	1.74	195.97	30.52	28.23	8.53	16.38	3.80	55.06	5.52	6.52
XMK-00109.FS102.004 (1)	35069	26030	362870	72260	17116	0	8148	32	492	17485
XMK-00109.FS102.004 (2)	22393	490	441113	10313	18733	0	7970	93	414	15261
XMK-00109.FS102.004 (3)	23649	0	383200	53055	18167	0	8008	50	485	19150
Mean of XMK-00109.FS102.004 assays	27037	8840	395728	45209	18005	0	8042	58	464	17298
Std.Dev. of XMK-00109.FS102.004 assays	6984	14889	40598	31710	821	0	94	32	43	1951
RSD (%) of XMK-00109.FS102.004 assays	25.83	168.43	10.26	70.14	4.56	.00	1.17	53.73	9.31	11.28
XMK-00109.FS101.003 (1)	19296	0	1545307	0	23640	196	13574	26	387	24001
XMK-00109.FS101.003 (2)	0	0	1505612	0	20888	171	13131	22	339	9110
XMK-00109.FS101.003 (3)	0	0	1710018	11023	19193	156	13090	34	381	11658
Mean of XMK-00109.FS101.003 assays	6432	0	1586979	3674	21240	174	13265	27	369	14923
Std.Dev. of XMK-00109.FS101.003 assays	11141	0	108388	6364	2245	20	268	6	26	7964
RSD (%) of XMK-00109.FS101.003 assays	173.21	0.00	6.83	173.21	10.57	11.59	2.02	22.35	7.09	53.37
XMK-00109.FS101.005 (1)	29191	65403	499688	80409	13380	604	21242	134	1038	107855

Table A-7 continued

Catalog Number and Assay Number	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
XMK-00109.FS101.005 (2)	13653	0	1234318	19411	13343	584	20562	132	1005	107273
XMK-00109.FS101.005 (3)	35559	53155	403134	10286	14644	663	21854	171	944	105202
Mean of XMK-00109.FS101.005 assays	26134	39519	712380	36702	13789	617	21219	146	996	106777
Std.Dev. of XMK-00109.FS101.005 assays	11268	34768	454582	38125	741	41	646	22	48	1394
RSD (%) of XMK-00109.FS101.005 assays	43.12	87.98	63.81	103.88	5.37	6.66	3.05	15.08	4.79	1.31

Table A-8. Ten Samples Analyzed Three Times (Co-Nb)

Catalog Number	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
XMK-00109.FS100.001 (1)	13	0	46	68	11	1	14	6	11	113	75	209	22
XMK-00109.FS100.001 (2)	17	0	66	66	12	1	18	6	12	113	77	211	21
XMK-00109.FS100.001 (3)	13	0	59	75	11	1	21	6	11	113	78	210	21
Mean of XMK-00109.FS100.001 assays	14	0	57	70	11	1	18	6	11	113	77	210	21
Std.Dev. of XMK-00109.FS100.001 assays	2	0	10	5	1	0	4	0	1	0	2	1	1
RSD (%)of XMK-00109.FS100.001 assays	16.11	.00	17.81	6.78	5.09	.00	19.88	0	5.09	.00	1.99	.48	2.71
XMK-00109.FS103.001 (1)	24	10	43	136	15	1	41	9	105	193	50	191	15
XMK-00109.FS103.001 (2)	24	15	34	146	15	1	44	8	100	193	48	190	15
XMK-00109.FS103.001 (3)	23	30	33	156	15	1	42	11	103	191	52	193	13

Table A-8 continued

Catalog Number	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
Mean of XMK-00109.FS103.001 assays	24	18	37	146	15	1	42	9	103	192	50	191	14
Std.Dev. of XMK-00109.FS103.001 assays	1	10	6	10	0	0	2	2	3	1	2	2	1
RSD (%)of XMK-00109.FS103.001 assays	2.44	56.77	15.02	6.85	.00	.00	3.61	16.37	2.45	.52	4.00	.80	8.06
XMK-00109.FS102.001 (1)	22	14	35	144	16	1	63	9	104	213	51	189	16
XMK-00109.FS102.001 (2)	17	12	33	154	15	1	52	9	102	203	52	190	14
XMK-00109.FS102.001 (3)	21	0	35	146	16	1	64	10	102	211	50	189	15
Mean of XMK-00109.FS102.001 assays	20	9	34	148	16	1	60	9	103	209	51	189	15
Std.Dev. of XMK-00109.FS102.001 assays	3	8	1	5	1	0	7	1	1	5	1	1	1
RSD (%)of XMK-00109.FS102.001 assays	13.23	87.37	3.36	3.58	3.69	.00	11.16	6.19	1.12	2.53	1.96	.30	6.67
XMK-00109.FS101.001 (1)	21	9	26	169	15	1	41	8	110	195	54	191	16

Table A-8 continued

Catalog Number	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
XMK-00109.FS101.001 (2)	21	25	23	177	14	1	23	9	114	190	54	191	15
XMK-00109.FS101.001 (3)	21	7	20	170	16	1	29	12	111	194	53	188	15
Mean of XMK-00109.FS101.001 assays	21	14	23	172	15	1	31	10	112	193	54	190	15
Std.Dev. of XMK-00109.FS101.001 assays	0	10	3	4	1	0	9	2	2	3	1	2	1
RSD (%)of XMK-00109.FS101.001 assays	.00	72.19	13.04	2.53	6.67	.00	29.57	21.53	1.86	1.37	1.08	.91	3.77
XMK-00109.FS101.002 (1)	20	6	72	117	15	1	30	9	99	197	44	184	15
XMK-00109.FS101.002 (2)	18	1	58	126	15	1	30	8	89	193	47	187	15
XMK-00109.FS101.002 (3)	20	23	67	125	16	1	27	9	93	205	44	185	13
Mean of XMK-00109.FS101.002 assays	19	10	66	123	15	1	29	9	94	198	45	185	14
Std.Dev. of XMK-00109.FS101.002 assays	1	12	7	5	1	0	2	1	5	6	2	2	1
RSD (%)of XMK-00109.FS101.002 assays	5.97	115.33	10.80	4.02	3.77	.00	5.97	6.66	5.37	3.08	3.85	.82	8.06

Table A-8 continued

Catalog Number	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
XMK-00109. FS102.002 (1)	4	0	45	166	16	1	10	3	67	265	36	176	12
XMK-00109. FS102.002 (2)	6	0	51	160	16	1	15	4	61	261	36	173	10
XMK-00109. FS102.002 (3)	2	0	37	166	15	1	13	4	63	249	37	171	10
Mean of XMK-00109. FS102.002 assays	4	0	44	164	16	1	13	4	64	258	36	173	11
Std.Dev.of XMK-00109. FS102.002 assays	2	0	7	3	1	0	3	1	3	8	1	3	1
RSD (%) of XMK-00109. FS102.002 assays	50.00	.00	15.84	2.11	3.69	.00	19.87	15.75	4.80	3.22	1.59	1.45	10.83
XMK-00109.FS102.003 (1)	0	0	35	132	16	1	12	4	68	249	35	163	8
XMK-00109.FS102.003 (2)	0	0	40	130	16	1	8	4	66	247	33	162	9
XMK-00109.FS102.003 (3)	0	0	49	134	16	1	9	3	66	243	31	162	10
Mean of XMK-00109.FS102.003 assays	0	0	41	132	16	1	10	4	67	246	33	162	9
Std.Dev.of XMK-00109.FS102.003 assays	0	0	7	2	0	0	2	1	1	3	2	1	1

Table A-8 continued

Catalog Number	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
RSD (%) of XMK-00109.FS102.003 assays	.00	.00	17.16	1.52	.00	.00	21.53	15.75	1.73	1.24	6.06	.36	11.11
XMK-00109.FS102.004 (1)	3	0	73	47	15	1	172	5	103	185	52	188	14
XMK-00109.FS102.004 (2)	1	0	74	43	15	1	174	7	101	187	50	183	14
XMK-00109.FS102.004 (3)	3	0	90	54	15	1	195	7	104	185	49	186	14
Mean of XMK-00109.FS102.004 assays	2	0	79	48	15	1	180	6	103	186	50	186	14
Std.Dev. of XMK-00109.FS102.004 assays	1	0	10	6	0	0	13	1	2	1	2	3	0
RSD (%) of XMK-00109.FS102.004 assays	49.49	.00	12.08	11.60	.00	.00	7.07	18.23	1.49	.62	3.03	1.36	.00
XMK-00109.FS101.003 (1)	8	0	25	146	16	1	14	5	77	243	37	174	8
XMK-00109.FS101.003 (2)	3	0	3	144	16	1	8	6	71	243	38	109	11
XMK-00109.FS101.003 (3)	4	0	24	146	16	1	10	4	73	242	36	171	11
Mean of 00109.FS101.003 assays	5	0	17	145	16	1	11	5	74	243	37	151	10

Table A-8 continued

Catalog Number	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
Std.Dev. of 00109.FS101.003 assays	3	0	12	1	0	0	3	1	3	1	1	37	2
RSD (%) of 00109.FS101.003 assays	52.92	.00	71.67	.79	.00	.00	28.64	20.00	4.15	.24	2.70	24.25	17.32
XMK-00109.FS101.005 (1)	47	95	47	118	12	1	58	13	10	152	70	206	26
XMK-00109.FS101.005 (2)	47	40	45	109	13	1	72	13	10	153	72	207	28
XMK-00109.FS101.005 (3)	46	77	46	134	12	1	55	13	10	156	73	204	27
Mean of XMK-00109.FS101.005 assays	47	71	46	120	12	1	62	13	10	154	72	206	27
Std.Dev. of XMK-00109.FS101.005 assays	1	28	1	13	1	0	9	0	0	2	2	2	1
RSD (%) of XMK-00109.FS101.005 assays	1.24	39.68	2.17	10.52	4.68	.00	14.71	.00	.00	1.35	2.13	.74	3.70

2.3 Multiple Locations Measured on One Sample

This experiment was performed in order to find out if there are differences in precision between different locations on a surface of a sample using PXRF.

2.3.1. Methods

BD-00522 underwent six rounds of x-ray bombardment on its surface area: three on the ventral side and three on the distal side using the same instrument setup as the above exercises. Each assay was labeled according to its side and sequential order. For example 'Side 1: 1' is the first assay performed on the first side, 'Side 1:2' is the second assay on the first side, and so on. As for the different locations on the sample surface, '1' was an assay performed on the widest part of the surface, '2' was performed on the middle of the surface, and '3' was performed on the most narrow part of the surface. A standard deviation (SD) was subsequently calculated for each element. The relative standard deviation (RSD) was calculated as a way to measure the precision as a percentage of the mean; a lower percentage means low variability. Negative values were not calculated in determining SD and RSD because negative measurements are equivalent to 0 ppm; the negative values were replaced with 0 during calculations.

2.3.2. Results

As shown in Tables A-9 and A-10, the precision for Side 1 and Side 2 is highest for element As. For Side 1, the precision is lowest for Cr, while the lowest precision for Side 2 is Mg. The results of precision are similar to those in the above exercises. The highest precision for the mean of both sides is element Zr while the lowest precision is Cr. For 18 out of the 23 elements measured, the precision for the mean of both sides is higher than the precision for either side. More variation exists between the three assays for each side than between the combined averages for each side. This could be understood by the effects of possible weathering. While this analyses show that variation does occur between different locations on a sample, it is also worth noting that fine-grained volcanic rocks are relatively homogenous in composition. The following exercise will examine differences with phenocrysts in a sample surface. These results show that performing multiple assays per sample and performing assays in different locations on sample increases accuracy.

Table A-9. Multiple Locations on One Sample (Na-Fe)

Location Of Assay and assay number	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
Side 1 (1)	38496	103533	496557	15419	48754	92	11112	61	1596	15281
Side 1 (2)	36857	104372	582738	48475	53171	135	11925	69	1746	31811
Side 1 (3)	38804	94041	363112	12323	52342	145	12334	0	1703	27484
Mean	38052	100649	480802	25406	51422	124	11790	43	1682	24859
Std.Dev.	1047	5738	110657	20039	2348	28	622	38	77	8572
RSD (%)	2.75	5.70	23.02	78.87	4.57	22.71	5.28	87.09	4.59	34.48
Side 2 (1)	35157	103773	717618	14392	47309	52	10773	7	1485	12214
Side 2 (2)	38551	72628	372517	39268	52187	185	13399	60	1740	22221
Side 2 (3)	37320	97262	672370	23763	53643	113	11565	0	1609	19061
Mean	37009	91221	587502	25808	51046	117	11912	22	1611	17832
Std.Dev.	1718	16428	187551	12564	3317	67	1347	33	128	5115
RSD (%)	4.64	18.01	31.92	48.68	6.50	57.06	11.31	146.90	7.91	28.69
Mean of Side 1	38052	100649	480802	25406	51423	124	11790	40	1682	24858

Table A-9 continued

Location Of Assay and assay number	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
Mean of Side 2	37009	91221	587502	25808	51046	117	11912	20	1611	17832
Mean of both sides	37531	95935	534152	25607	51235	120	11851	30	1646.	21345
Std.Dev.	737	6667	75448	284	266	5	86	14	50	4968

Table A-10. Multiple Locations on One Sample (Co-Nb)

Location	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
Side 1 (1)	18	0	24	101	16	1	6	5	42	367	58	226	14
Side 1 (2)	25	0	21	101	15	1	7	5	47	376	58	227	15
Side 1 (3)	24	0	13	112	15	1	5	5	43	380	59	229	17
Mean	22	0	19	105	15	1	6	5	44	374	58	227	15
Std.Dev.	4	0	6	6	1	0	1	0	3	7	1	2	2
RSD (%)	16.95	.00	29.41	6.07	3.77	.00	16.67	.00	6.01	1.78	.99	.67	9.96
Side 2 (1)	14	0	28	88	16	1	8	4	42	353	55	224	14
Side 2 (2)	26	0	23	103	14	1	8	5	50	390	63	228	15
Side 2 (3)	20	0	19	103	16	1	8	5	45	374	57	229	17
Mean	20	0	23	98	15	1	8	5	46	372	58	227	15
Std.Dev.	6	0	5	9	1	0	0	1	4	19	4	3	2
RSD (%)	30.00	.00	19.33	8.84	7.53	.00	.00	12.37	8.85	4.98	7.14	1.17	9.96
Mean of Side 1	22	0	19	105	15	1	6	5.	44	374	58	227	15

Table A-10 continued

Location	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
Mean of Side 2	20	0	23	98	15	1	8	4.	46	372	58	227	15
Mean of both sides	21	0	21	102	15	1	7	5	45	373	58	227	15
Std.Dev.	1	.00	13	5	0	0	1	1	1	1	0	0	0

2.4 Presence of Phenocrysts in Samples

This exercise was performed to compare element values for a sample surface that contains phenocrysts and a sample surface without phenocrysts.

2.4.1. Methods

BD-00511 and BD-00518 were chosen as samples because both samples contain large phenocrysts. The largest phenocryst for both samples was placed directly in the middle of the beam path. After each 300 sec assay was completed, the trigger was released, a new assay was set up in S1PXRF, and then the trigger was activated again until the 300 sec were completed. This was repeated until five assays were performed. The five values per sample were averaged into one value. This mean value was compared to a value taken from the sample surface without phenocrysts. The combined values per sample were averaged and a standard deviation (SD) and relative standard deviation (RSD %) was calculated.

2.4.2 Results

Out of 23 elements measured, 14 element values from sample BD-00511 and 15 element values in BD-00518 displayed a large (RSD > 10) difference between the non-phenocryst sample and averaged phenocryst value as shown in Tables A-11 and A-12. The results show a phenocryst on a sample surface is not representative of the entire sample and surface appearance should be considered when using PXRF.

The differences in values among phenocryst and non-phenocryst surfaces between the two archaeological samples are apparent for the lighter elements. BD-00511 contains RSD greater than 100 percent for elements Na, Mg, and Ba while BD-00518 has the highest RSD for element Ba (88 percent). The phenocryst of BD-00518 appears larger than the phenocryst on BD-00511, however BD-00518 displayed less variation between the phenocryst and non-phenocryst surface area. Sample BD-00518 presents the smaller RSD for elements except for Fe and a few trace elements. This result can support the idea that any anomaly on a sample surface can produce large variations in elemental values regardless of size. Anomalies in archaeological contexts include contaminants such as ochre or dirt on a sample surface, which would also create inaccurate results using PXRF. A common way to avoid these concerns is by using the destructive method of creating a pressed powder pellet for each sample.

Table A-11. Phenocryst Comparison (Na-Fe)

Sample and Assay Number	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
BD-00511 (1)	0	0	1278426	32182	48099	57	10964	77	1455	28384
BD-00511 (2)	0	27865	958910	0	44448	15	10081	0	1379	30717
BD-00511 (3)	0	51140	636108	0	40106	40	10582	75	1260	38855
BD-00511 (4)	0	0	598247	5098	45597	9	9706	38	1404	35108
BD-00511 (5)	0	28964	1031309	2888	47897	0	9554	87	1382	36049
Mean	0	21594	900600	8034	45229	24	10177	55	1376	33823
BD-00511- no phenocryst	28924	97600	687816	21099	53870	183	13664	184	1773	32946
Mean of avg. phenocryst and no phenocryst values	14462	59597	794208	14567	49550	104	11921	120	1575	33385
Std.Dev. of avg. phenocryst and no phenocryst values	20452	53744	150461	9238	6110	112	2465	91	281	620
RSD (%)	141.42	90.18	18.94	63.42	12.33	108.63	20.68	76.33	17.83	1.86
BD-00518 (1)	7735	93261	556315	26465	56015	88	11452	13	1379	17494
BD-00518 (2)	17532	60423	1019717	29415	51028	71	10620	20	1353	10173
BD-00518 (3)	33738	85972	771626	8833	47258	28	9960	87	1403	11867

Table A-11 continued

Sample and Assay Number	Na	Mg	Si	K	Ca	Ba	Ti	Cr	Mn	Fe
BD-00518 (4)	37168	103982	527759	0	50531	0	8978	58	1302	8242
BD-00518 (5)	33595	102898	419591	0	48120	7	9329	54	1332	12388
Mean	25954	89307	659002	12943	50590	39	10068	46	1354	12033
BD-00518- no phenocryst	31848	99232	769594	22154	52230	127	12080	68	1753	32001
Mean of avg. phenocryst and no phenocryst values	28901	94270	714298	17549	51410	83	11074	57	1554	22017
Std.Dev. of avg. phenocryst and no phenocryst values	4168	7018	78200	6513	1160	62	1423	15.56	282	14120
RSD (%)	14.42	7.44	10.95	37.12	2.26	74.97	12.85	26	18.16	64.13

Table A-12. Phenocryst Comparison (Co-Nb)

Sample and Assay Number	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
BD-00511 (1)	24	0	55	103	14	1	7	4	37	315	52	219	14
BD-00511 (2)	22	0	53	94	16	1	7	3	33	303	53	219	14
BD-00511 (3)	24	0	47	108	15	1	6	2	37	299	49	219	14
BD-00511 (4)	24	0	53	95	15	1	10	4	36	298	49	220	14
BD-00511 (5)	23	0	53	105	15	1	6	2	33	299	50	222	16
Mean	23	0	52	101	15	1	7	3	35	303	51	220	14
BD-00511- no phenocryst	36	19	41	108	15	1	6	4	44	346	63	227	14
Mean of avg. phenocryst and no phenocryst values	30	10	47	105	15	1	7	4	40	325	57	224	14
Std.Dev. of avg. phenocryst and no phenocryst values	9	13	8	5	0	0	1	1	6	30	9	5	0
RSD (%)	31.16	141.42	16.73	4.74	.00	.00	10.88	20.20	16.11	9.37	14.89	2.21	.00
BD-00518 (1)	9	0	42	91	15	1	4	4	36	385	51	220	14
BD-00518 (2)	7	0	42	95	15	1	8	3	38	383	49	221	14
BD-00518 (3)	7	0	38	88	16	1	7	3	39	387	48	221	14
BD-00518 (4)	5	0	46	83	16	1	5	3	34	369	48	219	14
BD-00518 (5)	8	0	39	80	16	1	7	3	36	381	48	220	15

Table A-12 continued

Sample and Assay Number	Co	Ni	Cu	Zn	Ga	As	Pb	Th	Rb	Sr	Y	Zr	Nb
Mean	7	0	41	87	16	1	6	3	37	381	49	220	14
BD-00518- no phenocryst	27	0	31	104	15	1	7	4	47	392	60	227	15
Mean of avg. phenocryst and no phenocryst values	17	0	36	96	16	1	7	4	42	387	55	224	15
Std.Dev. of avg. phenocryst and no phenocryst values	14	10	7	12	1	0	1	1	7	8	8	5	1
RSD (%)	83.19	.00	19.64	12.59	4.56	.00	10.88	20.20	16.84	2.01	14.27	2.21	4.88

3.0 PXRF and XRF Comparison

This experiment was performed in order to compare the precision and accuracy of element values between the stationary AXIOS XRF machine housed at UAF Reichardt building and the PXRF machine owned by UAMN. There is debate regarding the benefits of nondestructive techniques vs. variable precision/accuracy in PXRF techniques in archaeological contexts.

3.1 Methods

5 archaeological samples, 3 BHQ basalt samples (cut into three sections for the experiment from Section 2: BH_right, BH_center, BH_right) and five USGS standards were used for this experiment. For the AXIOS machine, all samples were run as routines after the calibration was set up within the SuperQ software program in the XRF lab in the geology department. The standards used to create the calibration co-efficient for the AXIOS XRF were the same ones used for the PXRF. Elements Rb, Sr, Y, Zr and Nb were analyzed because the trace element values are the most common elements used in archaeological provenance studies/source identification. A standard deviation was calculated for each sample in Tables A-13 and A-14.

3.2 Results using Archaeological Samples

The greatest standard deviation values for 6 out of the 8 total samples (five archaeological and all three BH samples) are found in element Zr as shown in Table A-13. This finding is not supported by the experiments in Section 2 which yielded results for the greatest precision for Zr using PXRF. The smallest standard deviations are found in elements Rb (in 4 samples), Nb (3 samples) and Zr.

3.3 Results using USGS Standards and Published Values

The PXRF machine was more accurate in measuring 3 of the 5 elements for standards: AGV-1 (elements Rb, Zr, and Nb) BE-N (Rb, Sr, and Nb) and BIR-1 (Rb, Y, and Nb). PXRF was also more accurate in 4 elements for standard BCR-1: Rb, Sr, Y, and Zr. The AXIOS XRF machine is more accurate for standard BR in elements Rb, Sr, and Nb. Four elements (Rb, Y, Zr, and Nb) were measured more accurately in PXRF.

3.4 Conclusion

Both XRF and PXRF machines displayed the highest precision with elements Rb and Nb, while Zr yielded the lowest precision. A possible reason for the results for Zr is that an overlapping peak of SrKb interferes with the ZrKa peak. Differences in the ways the two calibrations were calculated means this interference may not be accounted for and should be considered when analyzing Zr in the future using these calibrations. In regards to accuracy, the PXRF machine yielded overall more accurate measurements than the XRF machine.

Table A-13. PXRF and XRF Comparison

Sample Number	Method	RbKa1	SrKa1	Y Ka1	ZrKa1	NbKa1
BD-00141	PXRF	52	380	70	225	17
	XRF	47	313	43	287	11
	Std Dev	4	47	19	44	4
BD-00148	PXRF	53	367	67	222	17
	XRF	50	306	64	295	15
	Std Dev	2	43	2	52	1.41
BD-00150	PXRF	51	363	61	226	17
	XRF	45	334	42	291	14
	Std Dev	4	21	13	46	2
BD-00153	PXRF	50	370	67	226	18
	XRF	46	326	57	284	13
	Std Dev	3	31	7	41	4
BD-00161	PXRF	13	102	43	212	15
	XRF	13	98	33	377	16
	Std Dev	0	3	7	117	1
BH_right	PXRF	34	375	46	226	17
	XRF	35	368	48	244	17
	Std Dev	1	5	2	13	0
BH_center	PXRF	33	376	48	226	16
	XRF	37	369	40	243	15
	Std Dev	3	5	6	12	1
BH_left (avg of upper and lower)	PXRF	35	372	47	225	17
	XRF	43	366	39	226	14
	Std Dev	6	4	6	1	2

Table A-14. PXRF and XRF Values Compared to Published Values (ppm)

Standard Name	Method	RbKa1	SrKa1	Y Ka1	ZrKa1	NbKa1
AGV-1	PXRF	69	697	36	227	16
	XRF	60	650	23	235	12
	Published	67	662	20	227	15
BE-N	PXRF	49	1339	42	261	102
	XRF	54	1318	27	265	104
	Published	47	1370	30	265	100
BR	PXRF	54	1362	43	257	105
	XRF	37	1298	42	264	100
	Published	47	1320	50	250	98
BCR-1	PXRF	40	304	39	186	11
	XRF	39	279	33	146	11
	Published	47	330	38	190	14
BIR-1	PXRF	0	121	15	9	0
	XRF	0	108	6	24	0
	Published	1	108	16	22	2

4.0 Conclusion

This study examined the many ways PXRF techniques can alter the precision or accuracy of a sample. In Section 2, the precision of PXRF was shown to be highest among the trace elements, particularly Zr. As described above, trace elements are most often examined in archaeological contexts. Levels of precision vary, but the averaged measurements in experiments were reliable. The elements and materials being analyzed become important when establishing a calibration setup and coefficient, as the results yielded regarding precision from the andesite standard AGV-1 in Section 1. In Section 1, the results showed some variation occurs when analyzing a sample multiple times, either by repeating assays on the same location on a sample surface or comparing different surface areas on a sample. While the variation does not seem significant for every element and every exercise performed in this section, the results show it is problematic to produce accurate and precise values without considering the material and which elements being measured.

Precision can be a relative quality depending on what material type and element is being measured, a difference of a few thousand ppm should not matter. In the case of fine-grained volcanic rocks, however, the classification system used is very precise. A one point percentage difference (10,000ppm) could result in a rock being mislabeled. It is important to note when converting the ppm for the major elements into weight percentages, the differences in values could mean that each sample alone could merit different interpretations. For example, the first assay of sample BR (BR-1) in Section 2 contains a wt. % of 81 for element Si and a combined Na_2O and K_2O weight percent of 20. According to the TAS classification system to identify volcanic rock types, this sample would fall beyond the parameters for an igneous rock. Sample BR-2 however, has a Si weight percent of 43 and $Na_2O + K_2O=7$ which would be given a label of a basanite or tephrite. Sample BR-3 has Si=39 percent and $Na_2O + K_2O=6$ percent that would be given a designation of foidite. The average of the three runs for standard BR show that Si=54 percent, and $Na_2O + K_2O=9$ percent show the sample is a basaltic trachyandesite. Although the differences in ppm are not significant, the conversion of a value to a weight percent in this example shows the importance of taking multiple runs from the instrument to arrive at the most accurate value. However performing this method contradicts the quick and efficient results

PXRF offers and depending on the goal of the study, it may not be worthwhile to define the exact rock type. This is also problematic without examining the minerals within the sample.

In addition to understanding the precision of the PXRF instrument and technology, this feasibility study showed that PXRF can produce more accurate results than a stationary XRF machine. The findings from this study show that the PXRF machine and calibration setup can produce precise and accurate measurements. The utility of PXRF in archaeological studies is beneficial not only in its efficient and nondestructive methods but in its ability to produce statistically reliable results.

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Appendix B

Comparison of Compton Energy Ranges for Calibration Co-efficient

In order to set as accurate as possible parameters within the XRF software, several factors were considered. Five standards were chosen and their values entered into the software. Using the setup described in Section 4, each standard underwent an assay. The resulting values were calibrated to match the standardized values by fitting a regression line of counts measured on the machine and known concentration values.

An option in the software program S1XRF is to find the Compton energy range, which is performed in order to normalize the data. The S1CalProcess software used a Compton range of 18.4-19.4keV for the data, however Dr. Bruce Kaiser later used a range of 19.5-22keV for the data. Both ranges were normalized to Rh. In order to find which range produced more accurate values for a true concentration, they were compared to USGS standards. Although these were the standards used to create the calibrations, the goal of this exercise was to slide the Compton ranges around and therefore using these standards for this experiment is valid. In other words, the fact these standards were used to create the co-efficient had no bearing on the Compton range numbers themselves.

The results are listed in Tables B-1 and B-2. After making accuracy percentages between the two calibrations and the published values, major elements (Na, Mg, Si, K, Ca, Ti, Mn, and Fe) and some trace elements that can be useful when looking at igneous rocks (Ni, Cu, Zn, Pb, La, Rb, Sr, Y, Nb, Zr) were compared in order to find the calibration which produced the greatest number of more accurate values. The number of more accurate elements was counted for both calibrations; any element with identical ppm values for both calibrations in a standard was not counted. The results from Tables 1 and 2 show 3 of the 5 standards (AGV-1, BCR, and BIR-1) show that the 19.5-22 calibration produced more accurate values, this is the calibration chosen for this study. BE-N values produced the most accurate measurements between Compton ranges equally: elements Sr, Zr, and Nb were more accurate using 19.5-22keV range while elements Fe, Rb, and Y yielded more accurate values in the 18.4-19.4 range.

Table B-1. 19.5-22keV Compton Range Values

USGS Standard	Fe	Rb	Sr	Y	Zr	Nb
BR	86273	54	1362	43	257	105
Published BR	65700	47	1320	50	250	98
Std.Dev.	14547	5	30	5	5	5
Accuracy (%)	76.15	87.04	96.92	86*	97.28*	93.33
BIR-1	76362	0	121	15	9	0
Published BIR-1	83800	1	108	16	22	2
Std.Dev.	5259	-	9	1	9	-
Accuracy (%)	91.24*	-	89.26	93.75*	40.1	-
BCR	87315	40	304	39	186	11
Published BCR	88800	47	330	38	190	14
Std.Dev.	1050	5	18	1	3	2
Accuracy (%)	98.33*	85.11*	92.12*	97.44*	97.89*	78.57*
BE-N	90552	49	1339	42	261	102
Published BE-N	67400	47	1370	30	265	100
Std.Dev.	16371	2	22	8	3	2
Accuracy (%)	74.43	95.92	97.74*	71.43	98.49*	98.04*
AGV-1	25459	69	697	36	227	16
Published AGV-1	20600	67	662	20	227	15
SD	3436	1	25	11	0	0
Accuracy (%)	80.91*	97.1	94.98*	55.55	100*	93.75*

* indicates higher accuracy between the two Compton range values.

Table B-2. 18.4-19.4 Compton Range Values

USGS Standard	Fe	Rb	Sr	Y	Zr	Nb
BR	79643	52	1354	39	282	102
Published BR	65700	47	1320	50	250	98
Std.Dev.	9859.14	3.41	23.88	7.68	22.53	2.64
Accuracy (%)	82.49*	90.38*	97.49*	78	88.65	96.07*
BIR-1	73150	1	105	12	41	1
Published BIR-1	83800	1	108	16	22	2
Std.Dev.	7530.63	-	1.84	2.97	13.32	-
Accuracy (%)	87.29	-	97.22*	75.00	53.66*	-
BCR	76390	38	286	34	132	9
Published BCR	88800	47	330	38	190	14
Std.Dev.	8774.93	6.35	31.27	2.54	40.72	3.31
Accuracy (%)	86.03	80.85	86.67	89.47	69.47	64.29
BE-N	75598	48	1313	36	260	96
Published BE-N	67400	47	1370	30	265	100
Std.Dev.	5796.77	1.01	40.35	4.27	3.54	2.84
Accuracy (%)	89.16*	97.92*	95.84	83.34*	98.11	96
AGV-1	29506	67	717	32	216	17
Published AGV-1	20600	67	662	20	227	15
Std.Dev.	6297.68	0.08	38.81	8.22	7.71	1.62
Accuracy (%)	69.82	100*	92.33	62.5*	95.15	88.24

* indicates higher accuracy between the two Compton range values.

Appendix C

Thesis Dataset

Database Number	Catalog Number	AHRS Number	Lithic Classification	Max dimension (mm)	Weight (gm)	Rb Ka1	Sr Ka1	Y Ka1	Zr Ka1	Nb Ka1
BD-00001	AM33-3084	AFG-00015	6	68.80	31.19	30	309	33	156	8
BD-00002	AM33-2320	AFG-00015	11	42.68	6.62	20	314	24	137	9
BD-00003	AM33-640	AFG-00015	11	47.29	9.92	29	260	31	139	9
BD-00004	AM33-2353	AFG-00015	11	43.16	12	37	275	30	141	8
BD-00005	AM33-2189	AFG-00015	11	57.05	14	30	300	27	135	8
BD-00006	AM33-2554	AFG-00015	14	74.90	11	22	302	31	148	9
BD-00008	AM33-96-909	AFG-00015	15	51.53	7	17	343	34	162	11
BD-00009	AM33-96-1767	AFG-00015	11	50.79	7	25	299	32	150	9
BD-00010	AM33-654	AFG-00015	4	17.65	18	42	343	30	153	8
BD-00011	AM33-96-1867	AFG-00015	2	29.48	5	56	271	39	146	9
BD-00013	AM33-96-1831	AFG-00015	11	27.13	5	35	31	29	148	8
BD-00015	AM33-1706	AFG-00015	11	31.41	5	41	321	33	146	7
BD-00018	AM33-2385	AFG-00015	5	21.55	2	29	310	31	147	9
BD-00052	UA88-78-2936	KOD-00145	4	70.44	176	6	116	56	199	22
BD-00053	UA88-78-780	KOD-00145	4	72.29	104	84	309	40	169	12
BD-00054	UA88-78-967	KOD-00145	16	56.21	9	67	198	41	200	12
BD-00055	UA88-964	KOD-00145	16	55.10	7	108	133	49	165	14
BD-00057	UA88-78-4186	KOD-00145	5	96.17	97.21	12	99	40	212	22
BD-00060	UA88-78-2560	KOD-00145	5	80.02	16.69	12	163	55	204	22
BD-00061	UA88-78-3226	KOD-00145	11	64.96	24.94	10	110	60	192	26
BD-00062	UA88-78-912	KOD-00145	11	66.83	19.24	8	130	79	215	22
BD-00064	UA88-78-2123	KOD-00145	18	34.48	4.52	67	316	44	198	8
BD-00065	UA88-78-389	KOD-00145	11	74.55	38.78	42	281	65	221	16
BD-00066	UA88-78-1466	KOD-00145	11	68.18	24.34	66	285	46	228	17
BD-00069	UA88-78-3872	KOD-00145	5	82.51	67.99	92	222	68	215	23
BD-00071	UA88-78-851	KOD-00145	5	54.13	19.06	102	129	53	194	16
BD-00073	UA88-78-248	KOD-00145	5	83.43	52	125	113	47	187	15
BD-00074	UA88-78-1423	KOD-00145	11	86.88	52	6	166	90	187	25
BD-00075	UA88-78-3167	KOD-00145	11	68.88	57.77	76	182	38	167	13
BD-00076	UA88-78-3978	KOD-00145	8	124.83	161.39	91	303	44	184	13
BD-00077	UA88-78-1035	KOD-00145	11	63.24	8.49	44	238	35	142	8

Database Number	Catalog Number	AHRS Number	Lithic Classification	Max dimension (mm)	Weight (gm)	Rb Ka1	Sr Ka1	Y Ka1	Zr Ka1	Nb Ka1
BD-00078	UA88-78-3566	KOD-00145	11	45.71	28.07	141	336	56	182	15
BD-00079	UA88-78-1309	KOD-00145	11	36.83	6.74	93	265	36	213	19
BD-00080	UA88-78-3673	KOD-00145	11	51.97	12.40	92	301	44	187	15
BD-00081	UA88-78-1904	KOD-00145	11	66.14	20.55	87	258	34	211	17
BD-00082	UA88-78-2568	KOD-00145	11	54.48	27.12	13	121	49	141	21
BD-00083	UA88-78-119	KOD-00145	11	67.80	23.57	15	93	61	168	25
BD-00084	UA88-78-957	KOD-00145	11	65.51	31.78	98	244	45	187	15
BD-00086	UA88-78-4116	KOD-00145	5	61.14	18.40	94	249	44	177	13
BD-00089	AM193.87.9561	KAR-00001	11	65.56	15.38	40	229	28	127	8
BD-00092	UA85.193.4287	KAR-00001	16	56.22	7.68	49	384	66	227	19
BD-00129	AM33.96.360	AFG-00015	1	88.67	73.86	45	375	35	140	10
BD-00130	AM33-3204	AFG-00015	1	73.87	177.72	55	301	36	140	8
BD-00150	CHK-005, TU-02.002	CHK-00005	11	36.13	3.54	51	363	61	226	17
BD-00153	CHK-005, TU-02.005	CHK-00005	11	42.06	7.80	50	370	67	226	18
BD-00156	CHK-005, TU-02.008	CHK-00005	11	40.17	10.56	75	358	30	154	6
BD-00159	CHK-005, TU-01.003	CHK-00005	11	29.41	2.06	62	313	33	134	7
BD-00172	UA85-209/06158	KAR-00001	11	30.10	4.70	50	363	63	229	19
BD-00173	UA85-209/5239	KAR-00001	11	44.21	7.86	26	296	33	148	12
BD-00174	UA85-209/5103	KAR-00001	11	42.10	9.63	53	377	67	225	18
BD-00176	AM193.94: 4809	KAR-00001	11	17.11	1.21	52	322	39	148	10
BD-00178	AM193.94:4993	KAR-00001	11	21.49	.63	63	321	42	159	10
BD-00179	AM193.94: 2669	KAR-00001	11	40.62	6.92	56	398	73	222	18
BD-00180	AM193.94: 4803	KAR-00001	11	38.58	14.22	54	331	42	149	9
BD-00181	AM193.95: 877	KAR-00001	4	67.77	97.14	47	417	56	228	16
BD-00208	AM193.94: 3486	KAR-00001	11	42.12	2.94	52	375	63	228	20
BD-00209	AM193. 94: 4129	KAR-00001	11	35.91	2.58	46	338	58	228	16
BD-00210	AM193.94: 2679	KAR-00001	11	28.51	2.25	51	309	34	143	9
BD-00265	UGA-052.2003.0441	UGA-00052	11	45.00	8.95	125	126	62	210	17
BD-00269	UGA.052.2003.0350.01	UGA-00052	11	30.80	5.56	70	321	70	232	21
BD-00270	UGA.052.2003.0350.02	UGA-00052	11	33.40	6.00	71	320	73	233	23
BD-00271	UGA.052.2003.0350.03	UGA-00052	11	3.74	26.40	52	367	63	228	18
BD-00272	UGA.052.2003.0690.01	UGA-00052	11	30.10	3.68	50	370	65	226	17
BD-00273	UGA.052.2003.0741.001	UGA-00052	11	50.00	13.42	97	172	52	201	14
BD-00274	UGA.052.2003.0741.002	UGA-00052	11	26.20	4.70	55	384	57	224	17

Database Number	Catalog Number	AHRS Number	Lithic Classification	Max dimension (mm)	Weight (gm)	Rb Ka1	Sr Ka1	Y Ka1	Zr Ka1	Nb Ka1
BD-00275	UGA.052.2003.0782.01	UGA-00052	11	43.00	3.62	51	376	56	226	18
BD-00279	UGA.052.2003.0790.02	UGA-00052	11	27.50	3.40	63	325	64	232	21
BD-00283	UGA.052.2004.0010.02	UGA-00052	11	25.20	3.16	55	382	56	223	17
BD-00284	UGA.052.2004.0010.03	UGA-00052	11	29.90	1.95	68	321	66	234	24
BD-00285	UGA.052.2004.0015.01	UGA-00052	19	51.30	10.42	68	342	65	232	21
BD-00286	UGA.052.2004.0054.01	UGA-00052	19	53.00	16.74	61	311	59	233	22
BD-00288	UGA.052.2004.0067.01	UGA-00052	19	19.40	1.19	71	339	71	231	21
BD-00291	ALAG 105	DIL-00161	5	37.10	6.11	63	422	41	181	8
BD-00292	ALAG 118	DIL-00161	11	31.20	4.67	40	403	60	214	17
BD-00294	ALAG 310	DIL-00161	11	28.90	3.22	42	416	63	217	17
BD-00296	ALAG 373	DIL-00161	11	27.10	4.51	56	437	39	179	9
BD-00297	ALAG 384	DIL-00161	11	30.00	3.57	74	417	41	195	10
BD-00300	ALAG 394.01	DIL-00161	11	29.50	2.28	70	402	41	188	10
BD-00301	ALAG 403.01	DIL-00161	11	37.30	4.36	73	427	44	197	11
BD-00302	ALAG 420	DIL-00161	3	51.50	63.05	69	406	38	184	10
BD-00304	ALAG 428	DIL-00161	11	33.90	2.03	51	394	62	222	10
BD-00305	ALAG 442.01	DIL-00161	11	34.00	3.75	43	412	62	218	20
BD-00310	ALAG 529.01	DIL-00161	11	26.40	1.62	62	440	42	186	9
BD-00311	ALAG 531.01	DIL-00161	11	22.00	2.36	61	457	41	188	10
BD-00312	ALAG 533.01	DIL-00161	11	25.00	2.39	43	417	63	218	18
BD-00313	ALAG 551	DIL-00161	11	42.00	10.72	41	402	63	216	18
BD-00314	ALAG 597.01	DIL-00161	11	31.80	2.63	64	402	41	185	8
BD-00317	ALAG 797.01	DIL-00161	11	38.30	6.13	68	395	39	184	10
BD-00319	ANIA 98. SUT 027. 1219.01	SUT-00027	11	34.90	2.15	63	308	66	230	19
BD-00320	ANIA 98. SUT 027. 1215.01	SUT-00027	11	55.10	8.92	69	325	71	233	22
BD-00321	ANIA 98. SUT 027. 1218.01	SUT-00027	11	37.00	7.81	51	374	66	224	18
BD-00322	ANIA 98. SUT 027. 1206.01	SUT-00027	11	20.50	5.71	63	345	61	230	19
BD-00323	ANIA 98. SUT 024. 1193.01	SUT-00024	11	71.00	19.93	72	325	71	233	23
BD-00324	ANIA 98. SUT 024. 1196. 01	SUT-00024	11	72.50	28.50	69	330	66	232	22
BD-00325	ANIA 98. SUT 024. 1176.01	SUT-00024	11	45.10	5.76	76	327	75	231	23
BD-00326	ANIA 98. SUT 024. 1074.01	SUT-00024	11	43.80	8.67	87	280	79	205	30
BD-00327	ANIA 98. SUT 024. 1092.01	SUT-00024	11	43.50	5.60	53	367	68	227	18
BD-00328	ANIA 98. SUT 024. 1090.01	SUT-00024	11	39.50	4.36	33	458	44	198	10
BD-00329	ANIA 98. SUT 024. 1073.01	SUT-00024	11	50.20	7.77	63	349	68	232	21

Database Number	Catalog Number	AHRS Number	Lithic Classification	Max dimension (mm)	Weight (gm)	Rb Ka1	Sr Ka1	Y Ka1	Zr Ka1	Nb Ka1
BD-00330	ANIA 98. SUT 024.1042	SUT-00024	5	52.10	31.56	63	328	61	231	22
BD-00331	ANIA 98. SUT 024. 1061	SUT-00024	5	49.90	10.90	57	328	59	229	20
BD-00332	ANIA 98. SUT 024. 1091.01	SUT-00024	11	34.50	3.23	72	333	70	232	21
BD-00340	KATM 311. XMK-016. 40857.01	XMK-00016	11	27.80	2.33	102	160	83	232	26
BD-00341	KATM 311, XMK-016. 40736	XMK-00016	11	33.50	4.19	101	156	80	227	25
BD-00344	KATM 074. XMK-016. 4305	XMK-00016	11	21.10	1.41	66	399	40	182	9
BD-00348	KATM 074. XMK-016. 3692	XMK-00016	11	28.10	7.08	44	349	55	230	21
BD-00349	KATM 074. XMK-016. 3734	XMK-00016	11	34.20	2.64	52	433	36	166	7
BD-00350	KATM 076. XMK-016. 1783	XMK-00016	11	41.00	11.32	97	218	63	214	30
BD-00351	KATM 074. XMK-016. 1951	XMK-00016	11	35.90	11.88	71	181	54	226	25
BD-00353	KATM 074. XMK-016. 1930	XMK-00016	11	46.10	6.88	81	188	76	231	26
BD-00357	KATM 074. XMK-016. 3739.01	XMK-00016	11	44.20	19.30	34	355	48	232	22
BD-00359	KATM 074. XMK 016. 3913	XMK-00016	11	24.50	3.13	88	203	42	175	12
BD-00360	KATM 074. XMK-016. 4179	XMK-00016	11	22.00	1.31	57	449	40	176	9
BD-00361	KATM 074. XMK-016. 3862	XMK-00016	11	28.90	3.51	87	212	80	231	24
BD-00511	1	Geological sample	9	68.97	100.00	44	346	63	227	14
BD-00512	2	Geological sample	9	85.70	47.13	46	397	60	229	17
BD-00513	3	Geological sample	9	55.26	51.63	35	363	53	221	12
BD-00514	4	Geological sample	9	62.63	67.18	45	361	62	226	15
BD-00515	5	Geological sample	9	57.54	100.00	37	356	55	223	13
BD-00516	6	Geological sample	9	48.75	77.46	39	378	59	227	16
BD-00517	7	Geological sample	9	62.51	17.51	45	357	66	230	19
BD-00518	8	Geological sample	9	46.95	28.25	47	392	60	227	15
BD-00519	9	Geological sample	9	69.10	24.37	33	393	50	218	13
BD-00520	10	Geological sample	9	62.32	100.00	40	348	51	220	12
BD-00521	11	Geological sample	9	41.24	19.28	34	424	49	212	11
BD-00522	12	Geological sample	9	36.14	8.66	48	382	63.	228	16
BD-00523	13	Geological sample	9	45.28	18.01	38	404	51	210	12
BD-00524	14	Geological sample	9	45.79	31.43	38	369	54	224	14
BD-00526	16	Geological sample	9	75.44	100.00	46	385	63	228	16
BD-01000	1-1954-0072	XMK-00007	12	89.50	61.73	118	300	50	193	12
BD-01001	1-1954-0073	XMK-00007	5	65.30	39.56	45	361	63	229	20
BD-01002	1-1954-0074	XMK-00007	17	78.80	66.08	115	280	47	185	16
BD-01005	1-1954-0059	XMK-00007	17	66.10	29.81	87	149	39	198	15

Database Number	Catalog Number	AHRS Number	Lithic Classification	Max dimension (mm)	Weight (gm)	Rb Ka1	Sr Ka1	Y Ka1	Zr Ka1	Nb Ka1
BD-01007	1-1954-0252	XMK-00007	11	101.40	59.31	99	311	42	164	13
BD-01008	1-1954-0252	XMK-00007	11	73.90	98.56	94	179	51	219	11
BD-01010	1-1954-0252	XMK-00007	11	62.80	45.31	113	327	92	226	17
BD-01011	1-1954-0252	XMK-00007	11	41.70	8.70	36	684	65	178	24
BD-01014	1-1954-0252	XMK-00007	7	35.60	4.02	94	176	44	183	13
BD-01015	1-1954-0252	XMK-00007	13	67.20	38.71	108	217	39	165	14
BD-01029	UA80-297-0001	CHK-00011	13	50.50	16.70	46	381	66	226	18
BD-01030	UA80-297-0004	CHK-00011	13	40.30	2.61	43	364	62	226	18
BD-01031	UA80-297-0005	CHK-00011	13	30.30	2.29	50	377	64	228	19
BD-01032	UA80-297-0005	CHK-00011	13	21.90	1.24	51	371	63	226	19
BD-01033	UA80-297-0005	CHK-00011	13	29.90	3.00	49	374	63	225	16
BD-01034	UA80-297-0005	CHK-00011	13	40.90	5.47	49	380	66	225	17
BD-01035	UA80-297-0013	CHK-00011	5	103.30	42.27	46	362	63	226	16
BD-01036	UA80-297-0014	CHK-00011	13	60.70	17.89	47	340	63	229	17
BD-01037	UA80-297-0014	CHK-00011	13	46.10	5.14	49	367	71	227	18
BD-01038	UA80-297-0014	CHK-00011	13	32.30	3.25	54	358	58	227	18
BD-01039	UA80-297-0014	CHK-00011	11	43.70	4.30	47	329	61	232	21
BD-01042	UA80-297-0014	CHK-00011	13	20.40	1.17	56	385	71	227	19
BD-01043	UA80-297-0014	CHK-00011	13	31.90	3.51	56	371	71	226	17
BD-01044	UA80-297-0014	CHK-00011	13	32.30	2.83	49	366	66	228	18
BD-01045	UA80-297-0015	CHK-00011	7	76.50	43.01	51	367	65	227	21
BD-01046	UA80-297-0016	CHK-00011	7	52.40	21.48	52	376	66	228	17
BD-01047	UA80-297-0017	CHK-00011	17	43.10	9.92	50	374	68	228	20
BD-01048	UA80-297-0018	CHK-00011	12	63.10	16.52	48	378	64	227	18
BD-01049	UA80-297-0019	CHK-00011	7	23.90	1.97	50	358	67	230	20
BD-01051	UA86-202-0147	KOD-00044	5	143.70	50.92	77	203	42	178	13
BD-01052	UA86-202-0175	KOD-00044	10	165.90	79.38	114	195	47	167	12
BD-01053	UA86-202-0254	KOD-00044	5	56.10	8.96	81	213	42	180	16
BD-01054	UA86-202-0270	KOD-00044	10	109.20	38.54	114	114	49	190	15
BD-01055	UA86-202-0328	KOD-00044	5	139.00	126.60	97	87	50	190	16
BD-01056	UA86-202-0331	KOD-00044	16	57.70	11.28	48	300	71	221	19
BD-01058	UA86-202-0666	KOD-00044	10	80.20	31.48	71	115	39	173	11
BD-01059	UA86-202-0683	KOD-00044	10	73.40	16.14	93	150	45	173	16
BD-01061	UA86-202-0826	KOD-00044	13	55.40	16.46	86	343	45	188	11

Database Number	Catalog Number	AHRS Number	Lithic Classification	Max dimension (mm)	Weight (gm)	Rb Ka1	Sr Ka1	Y Ka1	Zr Ka1	Nb Ka1
BD-01065	UA86-202-1696	KOD-00044	10	96.70	36.63	52	191	32	151	9
BD-01067	UA86-202-1812	KOD-00044	16	70.20	8.04	89	143	41	176	16
BD-01068	UA86-202-1817	KOD-00044	16	48.20	6.25	33	380	41	210	9
BD-01069	UA86-202-1873	KOD-00044	5	103.90	100.30	69	314	50	202	6
BD-01070	UA86-202-1049	KOD-00044	13	55.20	13.07	99	151	45	171	13
BD-01071	UA86-202-1140	KOD-00044	5	99.70	38.81	113	174	64	232	20
BD-01072	UA86-202-1146	KOD-00044	10	140.40	60.12	76	220	49	193	14
BD-01074	1	CHK-00005	11	43.50	12.56	48	349	64	230	19.
BD-01075	1	CHK-00005	13	26.00	1.96	48	369	67	227	16
BD-01076	1	CHK-00005	11	45.60	6.64	47	363	65	226	16
BD-01077	1	CHK-00005	13	23.00	1.55	50	354	68	226	17
BD-01078	1	CHK-00005	13	24.10	1.62	49	363	70	225	14
BD-01079	2	CHK-00005	13	44.60	5.91	49	364	62	226	16
BD-01080	2	CHK-00005	13	42.80	4.48	32	464	44	198	9
BD-01081	2	CHK-00005	13	54.30	8.79	48	355	67	231	22
BD-01082	2	CHK-00005	13	51.90	6.68	54	391	65	225	18
BD-01083	2	CHK-00005	13	45.70	6.69	42	374	68	226	17
BD-01084	3	CHK-00005	13	51.60	10.21	46	364	66	225	19
BD-01085	3	CHK-00005	11	36.20	6.70	51	362	64	227	18
BD-01086	3	CHK-00005	13	47.90	12.35	51	353	70	228	19
BD-01087	3	CHK-00005	11	37.20	9.18	48	372	61	229	20

*Lithic Classification: 1=adze, 2=adze chip, 3=cobble, 4=core, 5=biface, 6=biface blank, 7=biface fragment, 8=biface preform, 9=geological sample, 10=ground tool, 11=flake, 12=flake tool, 13=interior flake, 14=secondary flake, 15=thinning flake, 16=projectile point, 17=uniface, 18=utilized flake, 19=waste flake.

Appendix D

Group Assignment using SPSS and Manually Created Groups of Alaska Peninsula Samples

Sample Number	SPSS Dendrogram Results with Groups Defined at Smallest Distance (>5 samples per group)	Manual Creation of Groups Based on Visual Observation of Element Values
BD-00150	1	6
BD-00153	1	6
BD-00156	3	3
BD-00159	3	3
BD-00265	4	4
BD-00269	6	6
BD-00270	6	6
BD-00271	1	6
BD-00272	1	6
BD-00273	4	4
BD-00274	1	6
BD-00275	1	6
BD-00279	6	6
BD-00283	1	6
BD-00284	6	6
BD-00285	6	6
BD-00286	6	6
BD-00288	6	6
BD-00291	3	3
BD-00292	1	1
BD-00294	1	1
BD-00296	3	3
BD-00297	3	3
BD-00300	3	3
BD-00301	3	3
BD-00302	3	3
BD-00304	2	3
BD-00305	1	1
BD-00310	3	3
BD-00311	3	3
BD-00312	1	1
BD-00313	1	1
BD-00314	3	3
BD-00317	3	3
BD-00319	6	6
BD-00320	6	6
BD-00321	1	6
BD-00322	6	6
BD-00323	6	6
BD-00324	6	6

Sample Number	SPSS Dendrogram Results with Groups Defined at Smallest Distance (>5 samples per group)	Manual Creation of Groups Based on Visual Observation of Element Values
BD-00325	6	6
BD-00326	5	5
BD-00327	1	6
BD-00328	2	2
BD-00329	6	6
BD-00330	6	6
BD-00331	6	6
BD-00332	6	6
BD-00340	5	5
BD-00341	5	5
BD-00344	3	3
BD-00348	1	1
BD-00349	3	3
BD-00350	5	5
BD-00351	5	5
BD-00353	5	5
BD-00357	1	1
BD-00359	4	4
BD-00360	3	3
BD-00361	5	5
BD-00511	1	1
BD-00512	1	1
BD-00513	2	2
BD-00514	1	1
BD-00515	2	2
BD-00516	2	2
BD-00517	1	1
BD-00518	1	1
BD-00519	2	2
BD-00520	2	2
BD-00521	2	2
BD-00522	1	1
BD-00523	2	2
BD-00524	2	1
BD-00526	1	1
BD-01000	4	4
BD-01001	1	1
BD-01002	4	4
BD-01005	4	4
BD-01007	4	4
BD-01008	4	4
BD-01010	6	4
BD-01011	1	1
BD-01014	4	4

Sample Number	SPSS Dendrogram Results with Groups Defined at Smallest Distance (>5 samples per group)	Manual Creation of Groups Based on Visual Observation of Element Values
BD-01015	4	4
BD-01029	1	1
BD-01030	1	1
BD-01031	1	6
BD-01032	1	6
BD-01033	1	1
BD-01034	1	1
BD-01035	1	1
BD-01036	1	1
BD-01037	1	1
BD-01038	1	6
BD-01039	1	1
BD-01042	1	6
BD-01043	1	6
BD-01044	1	1
BD-01045	1	6
BD-01046	1	6
BD-01047	1	1
BD-01048	1	1
BD-01049	1	1
BD-01074	1	1
BD-01075	1	1
BD-01076	1	1
BD-01077	1	6
BD-01078	1	1
BD-01079	1	1
BD-01080	2	2
BD-01081	1	1
BD-01082	1	6
BD-01083	1	1
BD-01084	1	1
BD-01085	1	6
BD-01086	1	6
BD-01087	1	1