The Compositional Analysis of Hunter-Gatherer Pottery from the Kuril Islands

Erik Gjesfjeld[1]

[1]UCLA Institute of Society and Genetics, University of California, Los Angeles

Abstract

Archaeological analysis of pottery remains from Northeast Asia has traditionally emphasized macroscopic traits such as decoration and vessel form. While these features are important in characterizing the cultural affiliation of pottery, compositional analysis can provide new lines of evidence that highlight social processes such as migration and exchange. Using a ceramic assemblage recovered from the Kuril Islands of Northeast Asia, this research investigates the regional exchange of pottery associated with the Epi-Jomon and Okhotsk cultural traditions. Results of this study indicate cultural differences highly influence the geographic distribution of compositional groups and patterns of regional exchange.

Keywords

archaeometry, pottery, Kuril Islands, exchange networks, maritime hunter-gatherers

Highlights

- The first compositional analysis of hunter-gatherer pottery from the Kuril Islands of Northeast Asia
- Epi-Jomon and Okhotsk occupations demonstrate compositional macrogroups with different geographic distributions
- Compositional analysis indicates limited exchange or movement of Epi-Jomon pottery between regions of the Kuril Islands

1. Introduction

Archaeological research in Northeast Asia has a long tradition of examining macroscopic traits of ceramic artifacts including decorative features and vessel forms. The widespread use of these traits is largely due to their value in constructing regional typologies and chronological sequences (Aikens and Higuchi, 1982; Deryugin, 2008; Kenrick, 1995; Kidder and Esaka, 1968; Mizoguchi, 2002; Ponkratova, 2006; Takase, 2013; Zhushchikhovskaya, 2009). While macroscopic features are likely to remain at the center of pottery analysis in this region, this research contributes to a small but growing body of literature that demonstrates the potential of compositional analysis (Anderson et al., 2011; Habu et al., 2003; Habu and Hall, 1999; Hall, 2004, 2001; Hall et al., 2002). As the first comprehensive ceramic sourcing study in this region the goals of this project are 1) to establish the reliability of compositional analysis using ceramic artifacts, 2) to examine the diversity of geochemical sources between regions of the Kuril Islands and 3) to explore the potential of geochemical data to make inferences about exchange patterns. Broadly speaking, this study aims to contribute a new line of evidence, elemental composition data, to enhance our current knowledge of pottery exchange among maritime hunter-gatherers of the North Pacific.

2. Study Area

Stretching in line for almost 1,200 km from Hokkaido to Kamchatka, the Kuril Islands are composed of 32 islands that vary in size from 5 km^2 to 3,200 km^2 (see Fig. 1). The most significant geographic features of the island chain are two major open water straits, the Bussol and Kruzenstern, which divide the archipelago into three distinct biological and geographical regions (Fitzhugh et al., 2004; Pietsch et al., 2003).

2.1 Biogeography

The pattern of biological diversity in the Kuril Islands is strongly influenced by the geographic barriers of the major straits, the large disparity in island sizes and the proximity of each island to the larger land masses of Hokkaido and Kamchatka (Pietsch et al., 2003). In general, higher biological diversity is recognized on islands located in the southern region with significantly lower resource diversity in the more remote central and northern islands. This pattern is observable in the flora of the archipelago with the southern islands maintaining a wide diversity of trees and shrubs including spruce, larch and oak as compared to the grasses of the tundra-covered northern and central islands (Anderson et al. 2008). The fauna of the archipelago also demonstrates this pattern with the southern islands containing a much higher diversity of terrestrial mammals, insects, freshwater mollusks, terrestrial mollusks and freshwater fish (Hoekstra and Fagan, 1998; Pietsch et al., 2003, 2001). The central islands, while ecologically less diverse compared to the southern and even northernmost islands, do contain high abundances of marine mammals, particularly sea lions, seals and sea otters, at least at present.

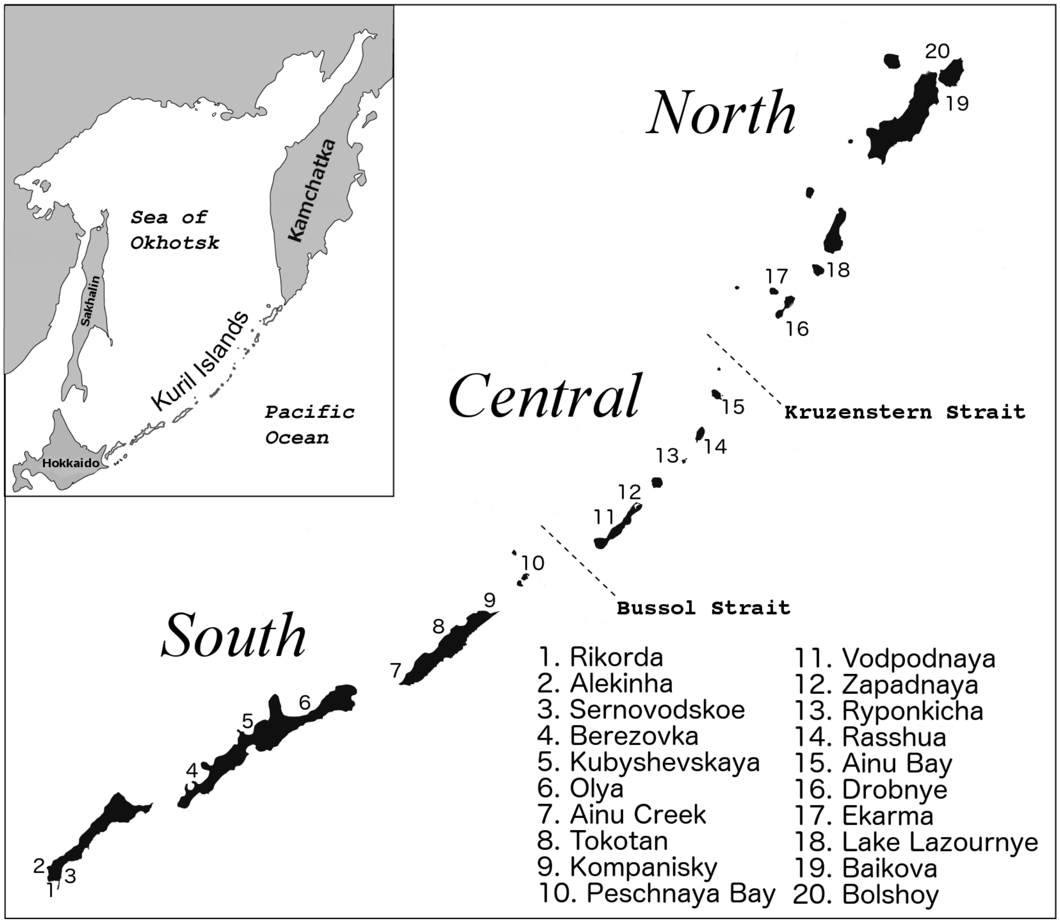

Figure 1. Map of the Kuril Islands with names of key straits, region names and sites used in this study

2.2 Weather and Climate

The climatic conditions of the Kuril Islands are strongly influenced by the northwestern winds deriving from Siberia (Leonov, 1990). Winters are cold and harsh with nearly 138 snowstorm days per year and stable snow cover from November until May (Ganzei et al., 2010). Due to the interaction of the cold Oyashio current and the warm Soya current, some areas of the Kuril Islands experience nearly 215 fog days per year, making this region of one of the foggiest places on earth (Bulgakov, 1996; Razjigaeva et al., 2011; Tokinaga and Xie, 2009). Summers are wet and short with very high air humidity and unpredictable violent storms that bring heavy precipitation, strong winds and storm surges (Belousov et al., 2009).

The frequency of storms in the Kuril Islands is noted by ethnographer Carl Etter (1949: 112-113) in the recording of his journey to the Kuril Islands, "It was the middle of the summer when one might expect pleasant weather. However, the Kurile climate was the most uncertain thing I found in all my journeys in the Orient…Our boat was loaded to full capacity and freight…We went on deck and made our bed under some tarpaulins, which were wet and cold. The fog was thick enough to cut with a knife and a cold east wind blew all night, keeping us cold and unable to sleep. The Japanese crew that brought us through that fog must surely know these Kurilian waters. The sea was rolling mountains high, and our little craft seemed like an eggsell in a tempest…There are tales in which the gods provided miraculous boats for Ainu who were in distress. I would almost be willing to admit that the boat in which I returned from Etorofu was one of those miraculous boats."

While less catastrophic than violent storms, earthquakes and typhoons, long-term climate change alters the frequency of storminess and the productivity of the marine ecosystem in which hunter-gatherers rely on so heavily (Fitzhugh et al., 2016). Paleoclimate data from a variety of sources on or near the Kuril Islands point to major fluctuations in temperature and aridity through the Holocene. In general, the late Holocene was cooler and stormier than the early Holocence with intense cold and dry winds coming off the Siberian mainland (Razjigaeva et al., 2013). A detailed list of mid to late Holocene climate trends and their impact on the demography of the Kuril Islands can be found in Fitzhugh et al. (2016).

2.3 Geology

The Kuril archipelago is situated on the central portion of the Kuril-Kamchatka Island Arc formation, which also includes Eastern Hokkaido and Southern Kamchatka . The Kuril archipelago begin forming during the Late Cretaceous period (100 millions years ago) but sediment record indicate that the greater arc of Kuril Islands did not emerge above the sea surface until the Pliocene or early Pleistocene (Bulgakov, 1996). Results of K-Ar dating show that the ages of volcanic rocks shift from old in the south islands (8.36-4.2 Ma), young in the central islands (3.3-0.6 Ma) to old in the north (7.0-3.5 Ma) (Ishizuka et al., 2011). The rock composition of the Kuril Islands, especially the uppermost geologic sequences, are dominated by andesitic formations with a lower prevalence of basaltic, dacitic and rhylolitic formations (Belousov et al., 2009).

Due to a high subduction rate, the Kuril Islands are among the most active volcanic areas in the world, with the highest volcanic activity observed north of the Bussol Strait (Belousov et al., 2009). In the last three millennia, approximately eighty volcanic eruptions occurred across the island chain including two caldera-eruptions and four large Plinian eruptions. The eruptive history of the Kuril Islands in combination with their sub-arctic, marine environment creates a dynamic history of landform modification that includes sea-level change, volcanic eruptive processes, coastal aggradation and dune formation (MacInnes et al., 2014).

2.4 Culture History

The earliest evidence of human occupation in the Kuril archipelago are pottery remains with a calendar age of 7610-8160 cal BP, recovered from the archaeological sites of Yankito and Kuibyshevo located on the southern island of Iturup (Yanshina and Kuzmin, 2010). Ceramic artifacts from these sites indicate a cultural affiliation between the southern Kurils and the neighboring island of Hokkaido, as pottery from both regions demonstrate thick walls and cord-marking, which are diagnostic of the Early and Middle Jomon periods of Japan (Vasilevsky and Shubina, 2006). However, it is not until nearly 4,000 years later (3800 cal BP) that occupation in the more remote central islands is recognized (Fitzhugh et al., 2016, 2002; Niimi, 1994). Based on the styles of ceramic artifacts recovered from the central islands (Gjesfjeld, 2014) and associated radiocarbon dates (Fitzhugh et al., 2016), the first populations to colonize the central region were likely associated with the Epi-Jomon cultural tradition that existed in Hokkaido and the southern islands. Compared to the low density of archaeological sites and artifacts in the preceding Middle and Late Jomon periods, the settlement of the island chain by the Epi-Jomon can be considered extensive with dense archaeological evidence spanning all three biogeographic regions. For reasons currently unknown, Epi-Jomon populations experience a rapid decline around 2000 cal BP and are difficult to recognize archaeologically on the islands after 1500 cal BP (Fitzhugh et al., 2016).

Immediately following the Epi-Jomon period, the Okhotsk culture (1500-800 cal BP) flourished throughout East Asia despite being a period of significant social and economic change (Hudson, 2004). The development of this cultural tradition is argued to have occurred in three distinctive stages (Amano 1979 in Hudson 2004). The first stage is the initial eastern expansion from south Sakhalin Island into the Japanese archipelago including the islands of Rishiri, Rebun and northern Hokkaido. This is followed by a second stage of movement to the northeastern corner of Hokkaido and into the Kuril Islands (Hudson, 2004). Based on archaeological evidence, the Okhotsk culture is recognized throughout the entire Kuril archipelago with the highest density of settlements and artifacts occurring in the central and northern regions. During the later stages of the Okhotsk period in northeastern Hokkaido and the southern Kurils, Okhotsk populations are believed to have been assimilated by proto-Ainu populations, referred to as the Satsumon culture (Deryugin, 2008). Similar to the Epi-Jomon, Okhotsk populations in the Kuril Islands experience a rapid decline and are difficult to identify archaeologically after 700 cal BP.

Ethnographic work shows us that the Kuril Ainu lived throughout the island chain in relatively large pit house villages as well as smaller seasonal camps (Fitzhugh et al. 2002; Kono and Fitzhugh 1999). Kikuchi (1999) suggests that the Ainu movement from Hokkaido into the Kuril Islands would have likely taken place during the fourteenth or fifteenth centuries (AD) following abandonment by the Okhotsk culture. Ethnographic evidence from Ainu populations highlights the presence of an extensive local, regional and distant trading network of various products (Ohnuki-Tierney, 1976). This included exchange between neighboring islands as well as distant trading of surplus marine mammal products (food and oil) and small "treasures" such as beads, earrings, bird feathers and hides (Ohnuki-Tierney, 1976; Tezuka, 1998). During the early eighteenth century carrying into the nineteenth century, the Russian-American Company settled the Kurils with transplanted Alaskan and Siberian sea mammal hunters (Shubin 1994). The Japanese occupation of the island chain during the twentieth century forcefully displaced many Ainu populations and World War II saw the occupation and fortification of the region by the Russian military.

3. Hypotheses and expectations

Building from the information networks model (Fitzhugh et al., 2011), this research adopts the starting assumption that the formation and maintenance of exchange relationships is an adaptive mechanism for mitigating uncertainty through the acquisition of information and the formation of social partners in regions outside of the local area (Blong, 1982; Krajick, 2005; Minc and Smith, 1989; Minc, 1986; Rautman, 1993; Whallon, 2011, 2006; Wiessner, 1982, 1977). Expectations deriving from this model suggest that all else being equal, populations living in regions with higher uncertainty will tend to form "integrated" networks, which are characterized by exchange relationships occurring at local, regional and distant spatial scales. Alternatively, populations living in regions with lower uncertainty would tend to demonstrate more "isolated" network structures with few ties beyond the local area. These expectations are based on the assumption that in regions of higher uncertainty there is a greater need to acquire information at inter-regional scales as this information helps reduce resource shortfalls in the local area (Fitzhugh et al., 2011). Therefore, it is reasonable to expect that in regions characterized by high levels of uncertainty about local conditions, populations are more willing to pay the costs associated with establishing and maintaining regional or distant exchange partners.

In the application of this model to the Kuril Islands, it is generally assumed that the maritime foraging populations that inhabited the Kuril Islands would have easily moved between close islands and through narrower straits; however, movement across these larger straits would have been difficult (Phillips, 2011). Perhaps the biggest challenge to boat travel, which would have been a necessity for foraging and connecting with neighbors, are the violent, frequent and unpredictable storms that are characteristic of the island chain (Fitzhugh et al., 2016). As the modern explorer Jon Turk (Turk, 2005) discovered in his kayak expedition through the island chain, the larger straits are especially difficult to navigate as the ocean currents and winds are highly unpredictable. As Turk writes about his crossing of the Bussol Strait (Turk, 2005, p. 85), "without howling wind, rising storm or warning the plain ocean suddenly reared into fifteen-foot breaking waves". Similar experiences with Ainu sailors are also cited by the early explorer Krasheninnikov (1963:35), noting that: "the channels are crossed in light boats, in less than half a day, but the passage is excessively difficult, because the tide runs very rapid in all of them…In the time of the flood, the waves are rapid and white, so large that even in calm weather they rise two or three fathoms high".

It is the initial expectation of this research that populations inhabiting the central islands would have experienced greater social and environmental uncertainty that those inhabiting the southern region. This assumption is based on the lower diversity of resources that can be exploited during times of crisis (see section 2.1), longer inter-island distances coupled with the unpredictability and frequency of storms (section 2.2) and a greater frequency of unpredictable volcanic eruptions (section 2.3). Building from this assumption, it can be hypothesized that the Epi-Jomon occupation, which primarily occupied the southern region (Table 1), would demonstrate a more localized network structure and lack evidence for the exchange of pottery at inter-regional scales. In contrast, the occupation of the Kuril Islands by the Okhotsk culture was predominantly located in the central and northern regions of the island chain. It is therefore expected that the Okhotsk will demonstrate stronger tendencies towards an integrated network structure with evidence for the exchange or movement of pottery across regional boundaries.

4. Materials and Methods

Over the last few years, examining ceramic artifacts through geochemical analysis has become an increasingly common approach (Ashley et al., 2015; Castanzo, 2014; De La Fuente et al., 2015; Falabella et al., 2013; Glowacki et al., 2015; Grave et al., 2014; Minc et al., 2014; Nunes et al., 2013; Ownby et al., 2014; Peterson, 2015; Rodríguez-Alegría et al., 2013; Sharratt et al., 2015; Stoner et al., 2015, 2014). However, the increasing popularity of "sourcing" ceramic artifacts has not diminished some inherent concerns about the results, especially when compared to the more traditional analysis of obsidian (Eerkens et al., 2002; Neff, 2000). Perhaps most significant is that raw clay resources are often numerous throughout any landscape making the sampling of potential raw clay sources a tedious and expensive process that often yields poor results (Anderson et al., 2011; Eerkens et al., 2002). Raw clay sources are also typically larger than obsidian sources making the inference between a specific geographic location and a raw clay source more difficult (Neff, 2000). Finally, raw clay is formed and transported through a wide variety of geologic processes. This can include the weathering of volcanic ash or alluvial deposition, both of which can cause the blending of clay particles and obscure what would otherwise be distinct clay source groups by creating a more homogenous distribution of elements (Eerkens et al., 2002; Pollard and Heron, 2008).

Despite these issues, it is important to note that in some contexts the compositional analysis of pottery may be useful, even thought it may have lower spatial and geochemical resolution. For example, in the Kuril Islands raw obsidian sources are only found outside of island chain in Hokkaido and Kamchatka (Ono et al., 2014). Therefore, the analysis of obsidian artifacts recovered from archaeological sites in the island chain is most informative about exchange with partners outside of the archipelago (Phillips and Speakman, 2009). In addition, given the higher costs of procurement for Kuril inhabitants and the lower proportion of obsidian compared to chert and basalt (Phillips, 2011), the exchange of obsidian is more likely to reflect the exchange of "exotic" or "luxury" items. Clay, which is available in small quantities on many of islands, can be considered more of an everyday material that is more representative of seasonal movement or reciprocal exchanges relationships between individuals within the Kuril Islands.

Differentiating the movement of pottery by trade or exchange from the movement of pottery as part of seasonal migrations can be extremely difficult within archaeological contexts (Anderson et al., 2011). In this research, there is no attempt to differentiate between pottery movement due to trade or exchange and pottery movement due to seasonal migrations as both types of movement are considered adaptive responses to mitigate local uncertainty. However, based on ethnographic evidence from the Ainu (Ohnuki-Tierney, 1976; Tezuka, 1998), trade and exchange between Kuril regions was common so it is expected that at least some, if not many, of the pottery vessels in this analysis were either directly or indirectly (as a container) involved in exchange networks.

4.1 Samples

In total, 297 sherds and 3 standards were analyzed in this study. Sherds were selected for analysis through a stratified random sampling process in which the region, island, site, excavation unit and level, vessel part and decorative features defined sampling strata. When possible, sherds with distinctive forms or decorative features were selected for analysis, as these sherds provide the easiest determination of cultural affiliation. However, only 11% of the recovered sherds from the archipleago demonstrated diagnostic design elements or vessel forms (Gjesfjeld 2014). If distinctive sherds were not available for sampling, either through the absence of diagnostic traits or restrictions on physically modifying the artifacts (sherds tagged for possible museum display were not to be sampled), samples were randomly selected within each excavation level.

Site Name	Region	Cultural Affiliations	Bedrock Composition	Landform	# of ICP-MS Samples
Rikorda[1]	South	EJ	Andesite	Coastal plain (H)	15
Alĕkinha[2]	South	EJ, OK	Andesite	Coastal dunes (H)	10
Sernovodskoe[3]	South	EJ	Andesite	Fluvial plain (H)	14
Berezovka[4]	South	EJ, OK	Andesite	Coastal dunes (H)	17
Kubyshevskaya[5]	South	EJ	Andesite-basaltic	Coastal dunes (H)	17
Olya[6]	South	EJ, OK	Siliceous-diatomite	Terrace (P)	16
Ainu Creek[7]	South	EJ, OK	Andesite	Coastal plain (H)	30
Tokotan[8]	South	OK	"Green tuff"	Coastal dunes (H)	10
Kompanisky[9]	South	EJ, OK	"Green tuff"	Coastal dunes (H)	20
Peschanaya Bay[10]	Central	EJ	N/A	Landslide (H)	13
Vodopodnaya[11]	Central	OK	N/A	Terrace (P)	25
Zapadnaya[12]	Central	EJ, OK	N/A	N/A	10
Ryponkicha[13]	Central	OK	N/A	Ignimbite (H)	8
Rasshua[14]	Central	EJ	N/A	Terrace (P)	25
Ainu Bay[15]	Central	AI	N/A	Terrace (P)	9
Drobyne[16]	North	EJ,OK	N/A	Terrace (P)	25
Ekarma[17]	North	OK	N/A	Landslide (H)	5
Lake Lazournye[18]	North	OK	N/A	N/A	10
Baikova[19]	North	OK	Siliceous-diatomite	Terrace (P)	8
Bolshoy[20]	North	OK, AI	Andesite	Dune (H/P)	10

Table 1. Archaeological sites included in this study with numbers corresponding to locations in Figure 1. Cultural affiliations at each site were determined by diagnostic pottery decorations and radiocarbon dates (EJ=Epi-Jomon, OK=Okhotsk, AI=Ainu). Bedrock compositions were drawn from Sergeev et al. (1987) (N/A=Not Available). Current landforms were taken from MacInnes et al. (2014) (H=Holocene and P=Pleistocene).

4.2 ICP-MS

While the use of ICP-MS methods for elemental characterization in the natural sciences is common, the preferred method for provenance studies among archaeologists is often

Instrumental Neutron Activation Analysis (INAA). The prevalence of INAA among archaeologists is largely due to strong historical research connections between archaeologists and INAA research facilities as well as its high sensitivity and precision across a broad spectrum of elemental masses (Kennett et al., 2002). However, INAA does have a few of drawbacks including a higher cost per sample than ICP-MS and the need for access to a nuclear reactor, which are becoming increasing limited due to high costs of maintenance. Besides the reduced cost per sample, ICP-MS methods also allow for the analysis of smaller samples (~200 mg), the detection of more elements (up to 70 elements) and generally lower detection limits (Kennett et al., 2002).

All samples used in this analysis were analyzed by ICP-MS with sample preparation carried out in the Laboratory of Geochronology and Isotopes at the Institute of the Earth's Crust, Russian Academy of Sciences-Irkutsk. Acid digestion of samples was performed in Teflon containers by heating a mixture of nitric (HNO_3) and hydroflouric (HF) acid in a microwave with the addition of hydrogen peroxide for a more complete oxidation of the sample. Once digested in acid, measurements were performed on an Agilent 7500se quadrupole mass spectrometer with the use of USGS geologic standards (DNC-1, QLO-1, RGM-1) for calibration. In total, elemental concentration values for 41 elements were produced from the ICP-MS analysis (Table 2). This data is freely available at the Digital Archaeology Repository (doi:10.6067/XCV85M66NM).

4.3 Statistical Analysis of Concentration Data

The goal of statistical analysis of elemental concentration data is to identify distinct analytical groups within the data. Using diagnostic sherd decorations as well as radiocarbon dates associated with distinct excavation levels, the 297 analyzed samples were subdivided into four categories based on their cultural affiliation. In total, 143 sherds were classified as Epi-Jomon, 123 sherds were classified as Okhotsk, nine as Ainu and 22 as unknown. Based on low sample sizes for sherds classified as Ainu, only concentration data for Epi-Jomon and Okhotsk will be presented here.

Identification of distinct analytical groups followed the MURR statistical approach (Baxter, 2001; Baxter and Buck, 2000; Glascock et al., 2004), which is commonly employed in archaeometric studies. Element compositions were logarithmically transformed prior to multivariate analysis to reduce the influence of high concentration elements (Glascock et al., 2004). Source groupings were initially identified through cluster analysis (CA) and refined through principal component analysis (PCA) and Mahalanobis distance-based (MD) probabilities. Principal component analysis also served as the basis for limiting the number of elemental variables used in the calculation of MD probabilities through the use of R-Q mode analysis (Neff 1994). R-Q mode biplots (Figures 2A and 3A) are useful in identifying elements that most highly influence the principal component analysis by representing the contribution of each element with the length of its vector (Glascock et al., 2004). The determination of group membership was determined through the use of Mahalanobis distances, which calculate the probability of a sample belonging to a group that is predefined from CA and PCA (Glascock et al., 2004).

Source groups and group membership were initially determined through the use of the MURRAP associated with GAUSS 8.0 (freely available from the Archaeometry Laboratory at the University of Missouri). Initial results of this research were then reproduced by the author using the R statistical environment (R Development Core Team, 2010). R code used in this research for cluster analysis, principal component analysis and Mahalanobis distance probabilities is available at www.github.com/erikgjes.

	Epi-Jomon (EJ)			**Okhotsk (OK)**		
	EJ-1 (n=60)	EJ-2 (n=38)	EJ-3 (n=5)	OK-1 (n=52)	OK-2 (n=27)	OK-3 (n=13)
Th	3.33 ± 1.03	0.96 ± 0.29	1.57 ± 0.06	1.61 ± 0.9	1.52 ± 0.78	0.77 ± 0.44
U	0.9 ± 0.24	0.4 ± 0.11	0.31 ± 0.09	0.59 ± 0.34	0.31 ± 0.09	0.27 ± 0.2
Rb	26.76 ± 5.96	11.47 ± 3.37	10.97 ± 2.44	17.77 ± 8.94	11.9 ± 3.95	9.88 ± 4.86
K	7341.52 ± 1715.12	4478.46 ± 1657.61	3978.41 ± 473.12	6861.07 ± 2940.89	5567.07 ± 2214.02	4983.17 ± 2373.46
Cs	2.56 ± 0.95	1.8 ± 0.56	1.17 ± 0.33	1.9 ± 0.78	0.81 ± 0.35	1.54 ± 0.95
Sr	198.58 ± 58.3	243.72 ± 68.59	229.73 ± 19.3	296.04 ± 150.28	310.08 ± 68.47	195.64 ± 71.26
Ba	292.84 ± 74.51	197.79 ± 51.72	191.46 ± 14.66	268.12 ± 95.98	247.98 ± 72.76	171.54 ± 41.84
Be	0.88 ± 0.13	0.61 ± 0.1	0.59 ± 0.11	0.64 ± 0.18	0.64 ± 0.06	0.51 ± 0.12
La	9.67 ± 2.51	4.98 ± 1.63	5.1 ± 0.53	6.45 ± 2.77	7.42 ± 1.15	4.37 ± 1.63
Ce	23.36 ± 4.87	12.66 ± 3.27	14.5 ± 0.98	16.7 ± 6.41	18.58 ± 2.28	11.43 ± 4.15
Pr	2.84 ± 0.61	1.7 ± 0.46	1.84 ± 0.16	2.17 ± 0.77	2.33 ± 0.28	1.62 ± 0.63
Nd	12.5 ± 2.53	8.35 ± 1.97	9.14 ± 0.79	10.21 ± 3.23	10.98 ± 1.33	7.95 ± 2.91
Sm	3.21 ± 0.64	2.41 ± 0.45	2.75 ± 0.21	2.73 ± 0.65	2.89 ± 0.37	2.21 ± 0.69
Eu	0.96 ± 0.19	0.72 ± 0.13	0.78 ± 0.04	0.76 ± 0.17	0.87 ± 0.12	0.55 ± 0.17
Gd	3.18 ± 0.69	2.54 ± 0.48	3.17 ± 0.35	2.77 ± 0.56	2.93 ± 0.48	2.09 ± 0.53
Tb	0.54 ± 0.13	0.44 ± 0.09	0.5 ± 0.03	0.44 ± 0.1	0.47 ± 0.09	0.31 ± 0.08
Dy	3.6 ± 0.88	3.04 ± 0.53	3.67 ± 0.26	3.01 ± 0.65	3.11 ± 0.63	2.15 ± 0.49
Ho	0.74 ± 0.17	0.64 ± 0.11	0.75 ± 0.04	0.63 ± 0.12	0.65 ± 0.13	0.46 ± 0.11
Er	2.18 ± 0.58	1.86 ± 0.37	2.26 ± 0.16	1.82 ± 0.4	1.85 ± 0.39	1.29 ± 0.34
Tm	0.32 ± 0.08	0.27 ± 0.05	0.32 ± 0.02	0.27 ± 0.06	0.27 ± 0.06	0.19 ± 0.05
Yb	2.18 ± 0.56	1.84 ± 0.37	2.22 ± 0.18	1.82 ± 0.42	1.78 ± 0.39	1.27 ± 0.35
Lu	0.31 ± 0.08	0.27 ± 0.05	0.3 ± 0.02	0.26 ± 0.06	0.27 ± 0.06	0.19 ± 0.05
Ga	18.37 ± 1.95	15.36 ± 0.95	18.71 ± 1.1	16.32 ± 1.81	14.44 ± 0.88	14.77 ± 1.78
Tl	0.29 ± 0.13	0.36 ± 0.22	0.06 ± 0.03	0.29 ± 0.2	0.04 ± 0.04	0.23 ± 0.16
Pb	13.25 ± 6.02	10.37 ± 3.89	8 ± 1.17	16.13 ± 22.08	6.92 ± 2.32	10.49 ± 5.25
Y	18.71 ± 5.09	16.35 ± 3.58	20.2 ± 1.45	16.32 ± 3.4	17.07 ± 3.65	11.85 ± 3.15
Zn	81.67 ± 47.41	128.73 ± 60.21	117.22 ± 24.04	134.98 ± 95.29	176.42 ± 46.89	54.52 ± 34.85
Zr	93.99 ± 16.2	66.52 ± 18.15	80.27 ± 15.43	74.46 ± 18.21	69.75 ± 15.74	55.66 ± 12.63
Nb	3.43 ± 0.83	1.65 ± 0.37	1.72 ± 0.34	1.97 ± 0.77	2.11 ± 0.52	1.38 ± 0.33
Mo	1.11 ± 0.75	0.58 ± 0.39	0.67 ± 0.07	1.14 ± 0.47	0.43 ± 0.29	1.46 ± 0.79
Sc	28.14 ± 3.5	31.03 ± 4.21	33.63 ± 2.42	29.46 ± 5.9	27.33 ± 4.01	25.3 ± 5.41
Cu	27.42 ± 11.8	47.1 ± 15.66	102.29 ± 14.95	54.17 ± 29.31	39.97 ± 15.57	49.55 ± 23.28
Hf	2.78 ± 0.5	1.96 ± 0.42	2.51 ± 0.23	2.22 ± 0.49	2.04 ± 0.35	1.75 ± 0.43
Ta	0.24 ± 0.08	0.1 ± 0.04	0.14 ± 0.05	0.14 ± 0.06	0.1 ± 0.05	0.08 ± 0.05
W	0.54 ± 0.23	0.27 ± 0.14	0.27 ± 0.05	0.35 ± 0.14	1.15 ± 1.4	0.4 ± 0.17
Ti	5539.03 ± 671.89	4473.8 ± 391.45	6037.25 ± 474.97	4846.63 ± 800.62	4707.99 ± 360	4245.77 ± 988.54
Cr	27.79 ± 13.63	26.66 ± 9.95	12.22 ± 2.55	39.38 ± 37.81	57.13 ± 44.97	6.92 ± 4.9
Co	15.82 ± 4.77	18.42 ± 3.46	25.43 ± 1.95	17.31 ± 6.56	27.37 ± 7.64	9.56 ± 6.28
Ni	13.03 ± 5.03	12.58 ± 5.1	8.57 ± 1.81	16.62 ± 11.48	37.29 ± 24.05	3.4 ± 1.74
V	191.27 ± 37.72	229.93 ± 33.21	278.56 ± 44.25	220.83 ± 51.87	205.83 ± 34.86	209.42 ± 61.83
Mn	778.43 ± 291.6	777.59 ± 319.04	1295.21 ± 257.93	805.26 ± 357.75	1134.41 ± 484.47	434.66 ± 200.67

Table 2. Summary statistics (mean ± standard deviation) in parts per million for compositional macrogroups (MG) based on cultural affiliation. Samples that were not assigned to each group (outliers) through CA, PCA and MD probabilities are not included in the totals above (Epi-Jomon had 40 samples identified as outliers and Okhotsk samples had 31).

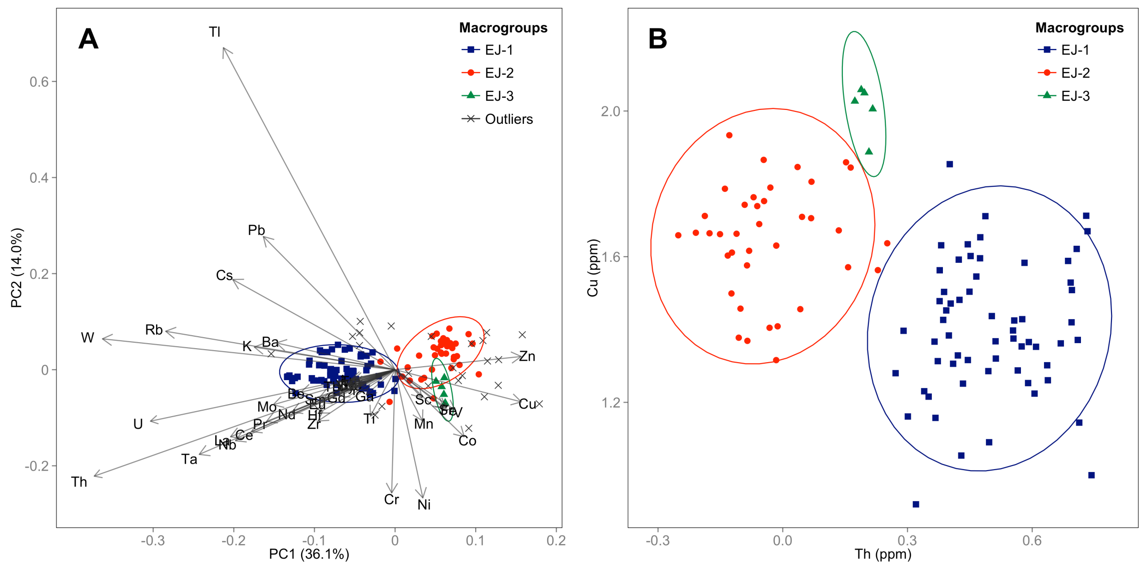

Figure 2. Biplot of Epi-Jomon samples showing principal component scores with elemental vectors (A) where the contribution of the element to the PCA is indicated by its length. Panel B key shows analytical groups for samples based on Thorium (Th) and Copper (Cu).

5. Results

5.1 Macrogroups

Using elemental composition results, this research examined the diversity of geochemical sources used in pottery production by identifying distinct analytical groups in the data. In both the Epi-Jomon and Okhotsk datasets, three compositional macrogroups were distinguished based on their elemental concentrations (Figures 2 and 3). Elememtal summary statistics for these six macrogroups can be found in table 2.

In samples associated with the Epi-Jomon cultural tradition (Fig. 2), two distinct compositional groups (EJ-1 and EJ-2) can be recognized in the biplots of both principal components and key elements (Th and Cu). Macrogroup EJ-3 was analytically defined as a distinct group in cluster analysis; however, its overlap with EJ-2 when plotting with principal components suggests uncertainty about its distinctness. Macrogroup EJ-1 is distinguished by the relative enrichment of rare earth elements, heavier transition metals (Zr, Nb, Mo, Hf, W) and alkali metals (K, Rb and Cs). Compositional group EJ-2 tends to have more depleted concentrations of rare earth elements but higher enrichment of lighter, period four transition metals, particularly zinc (Zn) and copper (Cu).

Samples belonging to the Okhotsk cultural tradition also demonstrate three main compositional groups. Similar to EJ-1, macrogroup OK-1 exhibits the relative enrichment of Lanthanide rare earth elements and alkali metals. However, it is unlikely that the EJ-1 and OK-1 compositional groups derive from the same raw clay source as the sample means for 38 of the 41 (93%) analyzed elements are significantly different ($p<0.05$) based on results from a t-test for sample means. Composition macrogroup OK-3 also demonstrates partial enrichment of lighter transition metals, similar to EJ-2, but t-test results indicate significant differences from EJ-2 in 26 of the 41 (63%) elements analyzed.

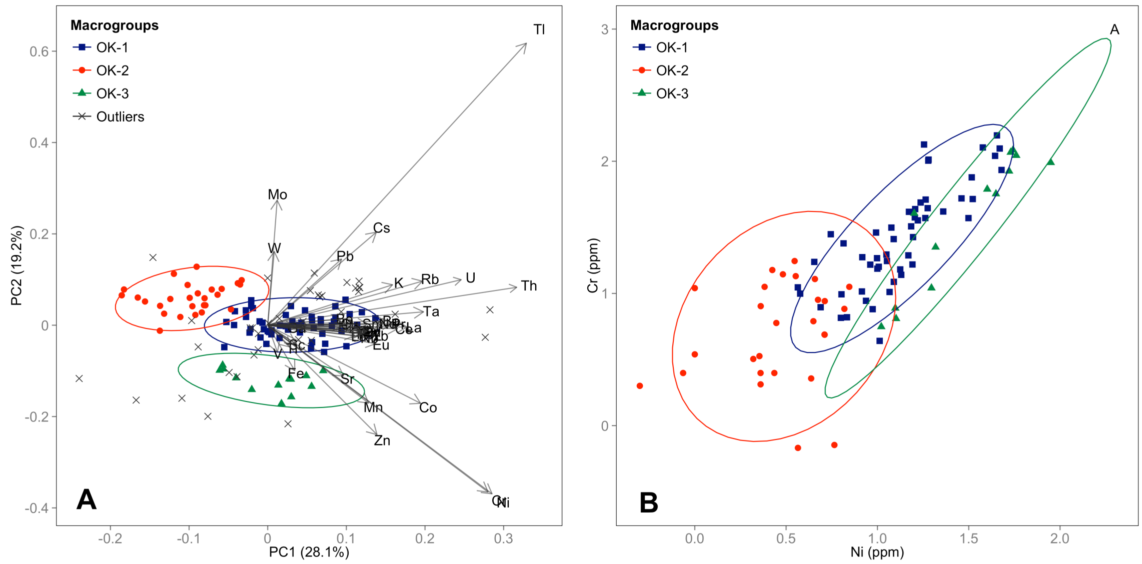

Figure 3. Biplots of Okhotsk samples showing principal component scores with elemental vectors (A) where the contribution of the element to the PCA is indicated by its length. Panel B key shows analytical groups for samples based on Nickel (Ni) and Chromium (Cr).

5.2 Geographic Association of Compositional Groups

Due to a lack of raw clay samples available for analysis, the association of compositional groups with geographic regions relies on the "criterion of abundance" (Bishop et al., 1982). This concept suggests that if a majority of samples in a single compositional grouping come from the same geographic area (*i.e.* site, valley or region) it is assumed that the raw clay source and the location of pottery production is likely found within this same geographic area.

Building from this assumption, results from the elemental analysis of pottery demonstrate that strong geographic patterns exist within some but not all compositional groups. As highlighted in Figure 4, each of the three macrogroups associated with the Epi-Jomon tradition show strong tendencies towards a single geographic region. Macrogroup EJ-1 is characterized by a significant majority (81%) of samples from the south region, EJ-2 a significant majority (92%) of samples from the central region and EJ-3 a significant majority (83%) of samples from the north region. In contrast, compositional groups associated with the Okhotsk cultural tradition do not demonstrate strong geographic associations. Macrogroup OK-1, which is the most well represented macrogroup, comprises 47% of samples from the north region, 61% of samples from the central region and 63% of samples from the south region. Given this even geographical distribution it is difficult to associate this macrogroup with a specific area. Macrogroup OK-2 is primarily found in the north (53%) and central (26%) regions and can be considered as characteristic of islands north of the Bussol strait. Macrogroup OK-3 is only found in samples archaeologically recovered from the central and southern region so it can be assigned to sources south of the Kruzernstern strait.

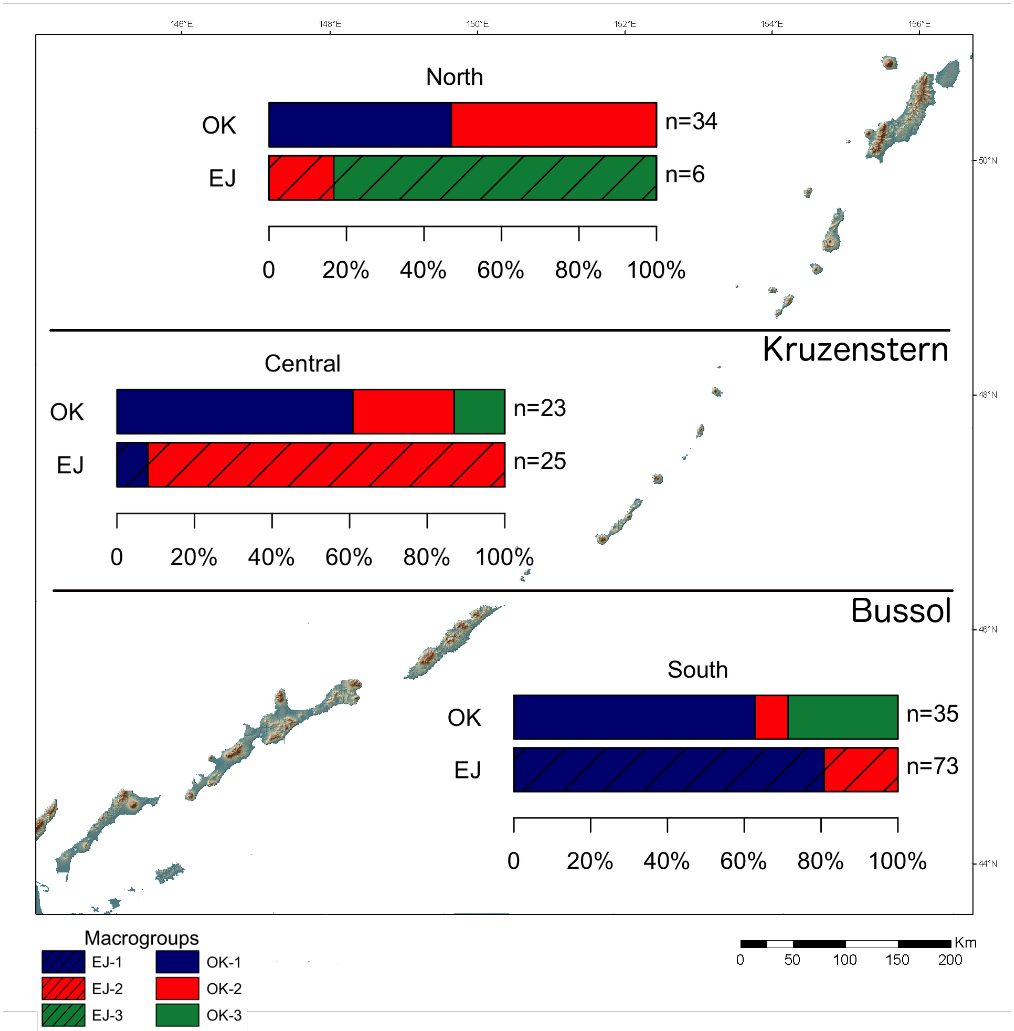

Figure 4. Geographic distribution of Epi-Jomon (EJ) and Okhotsk (OK) compositional macrogroups by region (Basemap by A. Freeburg).

6. Discussion

Results from the compositional analysis of pottery from the Kuril Islands highlight two points worthy of discussion. First, pottery samples associated with the Epi-Jomon cultural tradition demonstrate a strong geographic pattern with clear south to north differences in macrogroup distribution (see Figure 4). This suggests that clays and tempers from the Kuril Islands adhere to the provenance postulate and that differences in the elemental composition of raw materials between regions can be used to explore questions concerning the exchange or movement of pottery. Second, the strong geographic pattern recognized within Epi-Jomon compositional groups is not consistent with pottery affiliated with the Okhotsk culture. Explanations for the geographic discrepancy between Epi-Jomon and Okhtosk macrogroup distributions are explored here by examining the influence of elemental variability and the movement / exchange of pottery.

6.1 Elemental Variability

From a compositional perspective, the even geographic distribution of macrogroup OK-1 may exist due to Okhotsk potters using more heterogeneous clay sources. This is because as elemental variability within the compositional dataset increases, analytical groups tend to be more difficult to clearly discriminate, as distinct clusters are difficult to recognize due to larger and overlapping confidence ellipses. Therefore, any single macrogroup that demonstrates high elemental variability is more likely to be characterized by samples from multiple (if not many) different raw clay sources, including sources from potentially different geographic regions.

Based on archaeological evidence, Okhotsk populations are known to have inhabited the smaller and steeper islands of the central and northern regions. This is important as the formation of clay on islands that do not maintain low energy transport mechanisms (due to the steepness of slopes), is more likely to occur as part of the *in situ* chemical decomposition of aluminum and iron-rich materials (volcanic tephra) by organic-rich soils (Lindbo and Kozlowski, 2006; Mizota and Van Reeuwijk, 1989).

Field research performed by the Kuril Biocomplexity Project demonstrates positive evidence for the *in situ* formation of clay, as many of the organic-rich peat bogs in the central islands were underlain by mixed clay deposits (Razzhigaeva et al., 2009). It can be further argued that this clay formation process is likely to create more heterogeneous clay deposits as the primary aluminum and iron-rich parent material in the central islands comes from Aeolian deposited volcanic ash. As identified in archaeological and geological excavations, volcanic ash deposits found on many of the central and northern islands derived from eruptions that originated in every region of the Kuril Islands as well as Hokkaido and Kamchatka (Nakagawa et al., 2009). Therefore, it is reasonable to expect that the process of clay formation in these islands promote greater compositional variability than in the larger southern islands, which were more commonly inhabited by the Epi-Jomon populations. Analysis of the total elemental variation for each macrogroup (Aitchison, 1990), supports this possibility as Okhotsk compositional groups do tend to have higher elemental variation than Epi-Jomon compositional groups.

Compositional Group	Total Elemental Variation
EJ-1	3.073
EJ-2	4.404
EJ-3	1.244
OK-1	5.939
OK-2	8.486
OK-3	9.347

Table 3. Total elemental variation (TEV) for compositional groups used in this study. TEV values were calculated in the MURR application for GAUSS 8.0 based on Aitchison (1990).

6.2 Movement and/or Exchange

As initially hypothesized from the information networks model, Okhotsk populations living in the central islands are expected to engage in a social networking strategy that promotes the acquisition and exchange of information at local and inter-regional scales. Epi-Jomon populations living in the less vulnerable southern islands were expected to show little evidence for inter-regional movement or exchange of pottery. Macrogroups EJ-1, EJ-2 and EJ-3 all demonstrate strong geographical affiliations implying that few ceramic artifacts were exchanged or moved at regional scales or that pottery was not part of exchange relationships. Results from the analysis of Okhotsk samples are largely inconclusive. Macrogroup OK-1 demonstrates a widespread geographic distribution that could be a product of increased inter-regional movement / exchange of pottery or could just as easily be explained by a higher degree of elemental variability.

If focus is temporarily placed on the movement / exchange of pottery as the primary explanation for the broader distribution of the OK-1 source group, it is possible to speculate as to what cultural factors might increase the movement or exchange of pottery. As highlighted through this paper, one explanation could be the increased need for social connections outside of the central islands to help mitigate the risks and uncertainty of this area. An alternative explanation can also be suggested based on differences in the thickness of walls and bases between Epi-Jomon and Okhotsk pottery (see Gjesfjeld, in revision for additional details). Epi-Jomon pottery has mean thicknesses of 7.8 cm (wall) and 7.4 (base) whereas Okhotsk pottery demonstrates thicknesses of 9.4 cm (wall) and 11.1 cm (base). The statistically significant differences in wall and base thickness is potentially indicative of differences in cooking strategies between the cultural groups. The thicker fabric of Okhtosk pottery suggests that vessels might have been used in conjunction with hot-stone boiling methods which require over-thickened bases and walls to absorb the energy of hot stones (Reid, 1989). As discussed in Gjesfjeld (in revision), hot stone boiling techniques can be associated with low-heat cooking strategies such as the rendering of marine oil, which was known to be a prized commodity among many groups in the North Pacific (Fitzhugh, 2003) and would have been a valuable trade item for Okhotsk populations. Given the current data, it is difficult to identify the most plausible explanation for the broad source distribution of Okhotsk pottery. Future research that analyzes additional samples and utilizes more detailed mineralogical analyses will greatly enhance our understanding of Okhotsk pottery.

6. Conclusions

Given the fragmented and often incomplete archaeological record of small-scale and mobile hunter-gatherers in Northeast Asia, interpretations of exchange relationships have often relied on similarities in pottery decoration / form or the compositional analysis of lithic material. The merit of this research is an explicit and quantitative approach to reconstructing and examining the exchange or movement of ceramic artifacts.

Results of the compositional analysis of pottery from the Kuril Islands identified three compositional macrogroups in samples associated with two different cultural occupations, the Epi-Jomon and the Okhotsk. Based on the information network model, it was expected that differences should be present in the geographic distribution of macrogroups between the Epi-Jomon and Okhotsk, particularly in their degree of inter-regional exchange. Compositional groups broadly agree with model expectations for Epi-Jomon samples by demonstrating strong geographic associations. Okhotsk macrogroups do not provide conclusive evidence to support modal expectations. Possible explanations for these differences may include the increased exchange or movement of pottery due to risk-buffering mechanisms, the trade of marine oil or higher elemental variability. While some limitations still exist in the compositional analysis of archaeological pottery from hunter-gatherer contexts, this research demonstrates its utility in exploring questions of exchange and movement that can only enhance traditional methods of pottery analysis.

Acknowledgements

Erik Gjesfjeld would like to thank Ian Scharlotta, Kristin Safi and Lindsay Friedman for organizing this special volume on Archaeometric Approaches to the Archaeology of Northern Hunter-Gatherers. I would also like to thank the anonymous reviewers of this paper for their insightful comments. This research was funded by a Doctoral Dissertation Improvement Grant from the National Science Foundation Division of Polar Programs-Arctic Social Sciences (Award #1202879). Additional support was provided by the Univeristy of Washington, Seattle, WA and the Hokkaido University Museum, Hokkaido, Japan. I would like to especially thank Olga Shubina, Tatiana Roon and the staff of the Sakhalin Regional Museum for their invaluable assistance in helping me identify and prepare samples for analysis. Dr. Sergey Rasskazov and his staff at the Institute of the Earth's Crust at the Russian Academy of Sciences Irkutsk excelled in the analysis of samples. I am also deeply indebted to all the members of the Kuril Biocomplexity Project who committed so much time and effort to research the unique landscape of the Kuril Islands.

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