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Geochemical Investigation of Late Pre-Contact Ceramic Production Patterns in Northwest Alaska

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Abstract

Study of northwest Alaskan ceramic production and distribution patterns has the potential to provide new evidence of coastal hunter-gatherer mobility and social interaction in the late pre-contact period. This research is directed at characterizing potential clay sources and linking ceramic groups to raw-material source areas through instrumental neutron activation analysis (INAA) and modeling of possible clay and temper combinations. Results of INAA of 458 ceramic, 31 clay, and 28 possible temper specimens reinforces prior identification (Anderson et al., 2011) of three broad compositional groups. Though raw materials were collected over a large area, the clay specimens demonstrate remarkable geochemical homogeneity and fall within one of the established ceramic geochemical groups, Macrogroup 2. This suggests that potters may have added little to no mineral temper to the clays and also that what we have termed Macrogroup 2 ceramics were produced in the north and central areas of northwest Alaska. Group 1 and 3 ceramics may be evidence of pottery being brought into the region from elsewhere. Results indicate that ceramics circulated widely around the region and suggest the possibility of areas of greater production perhaps due to an abundance of clay or wood fuels needed for firing. This work lays the foundation for further exploring the cultural processes that underlie these distributions and provides insight into the complexities of hunter-gatherer ceramic production and distribution.

Keywords: hunter-gatherers; mobility; exchange; ceramics; neutron activation analysis; Arctic

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1.0 Introduction

Hunter-gatherer ceramic artifacts are relatively rare (see Jordan and Zvelebil, 2009 for summary), but study of their distributions provides new insights into mobility, social interaction, and technological organization (e.g., Eerkens, 2001, 2002, 2003; Eerkens et al., 2002; Simms et al., 1997). Compositional analysis of North American Arctic ceramic technology presents an opportunity to study coastal hunter-gatherer mobility and social interaction during the late Holocene, a period of significant environmental and social change in the northwestern Arctic (Figure 1). Over at least the previous 3,000 years, coastal occupation increased and people developed specialized maritime tools and subsistence strategies. There is evidence of increasing social difference as well as complex socioeconomic structures that connected people across the region and beyond through extensive travel and trade. Compositional analysis can help archaeologists study the changing geography of these networks over time, illuminating how and why people maintained such extensive interaction networks during the Late Holocene. The goal of this paper is to characterize potential clay sources and to link ceramic groups to raw-material source areas through instrumental neutron activation analysis (INAA). The results of this work establish a foundation for studying the cultural processes involved in Arctic ceramic distribution and the social networks they represent. This work has broader implications for understanding hunter-gatherer ceramic technology, mobility, and the role of social interaction in complex hunter-gatherer groups.

2.0 Prior Work

Prior to our 2011 pilot study (Anderson et al., 2011), it was not clear if the exchange of ceramic artifacts was part of prehistoric distribution networks in northwest Alaska. While there is historic evidence of ceramic trade, the antiquity of this practice was unknown. Ceramic technology was adopted from western Beringia about 2,800 years ago (see Ackerman, 1982; Frink and Harry, 2008 for additional summary). Early ceramics are thin, relatively hard, have a globular shape, and are decorated in characteristic linear, check-stamp, or cord-marked styles. This early ceramic tradition is quite different from later, post-1500 BP Arctic ceramics. Post-1500 BP ceramic vessels are thick, softer, cylindrical or flower-pot shaped and often undecorated. Ceramics are much more abundant after 1500 BP. The rough appearance of later ceramic cooking vessels suggests expedient production and local use, but a pilot study that included INAA of 99 ceramic specimens from northwest Alaska established that hunter-gatherer ceramics were part of distribution networks over at least the last 1,000 years (Anderson et al., 2011). This work also demonstrated the potential of ceramic research for addressing questions about Arctic hunter-gatherer lifeways. Questions remained, however, about the location of production areas and the nature of interaction networks. Analysis of a larger sample of ceramics was needed. The study presented here builds on the earlier pilot project by including a larger sample which also incorporates raw clay and temper materials collected from across the region.

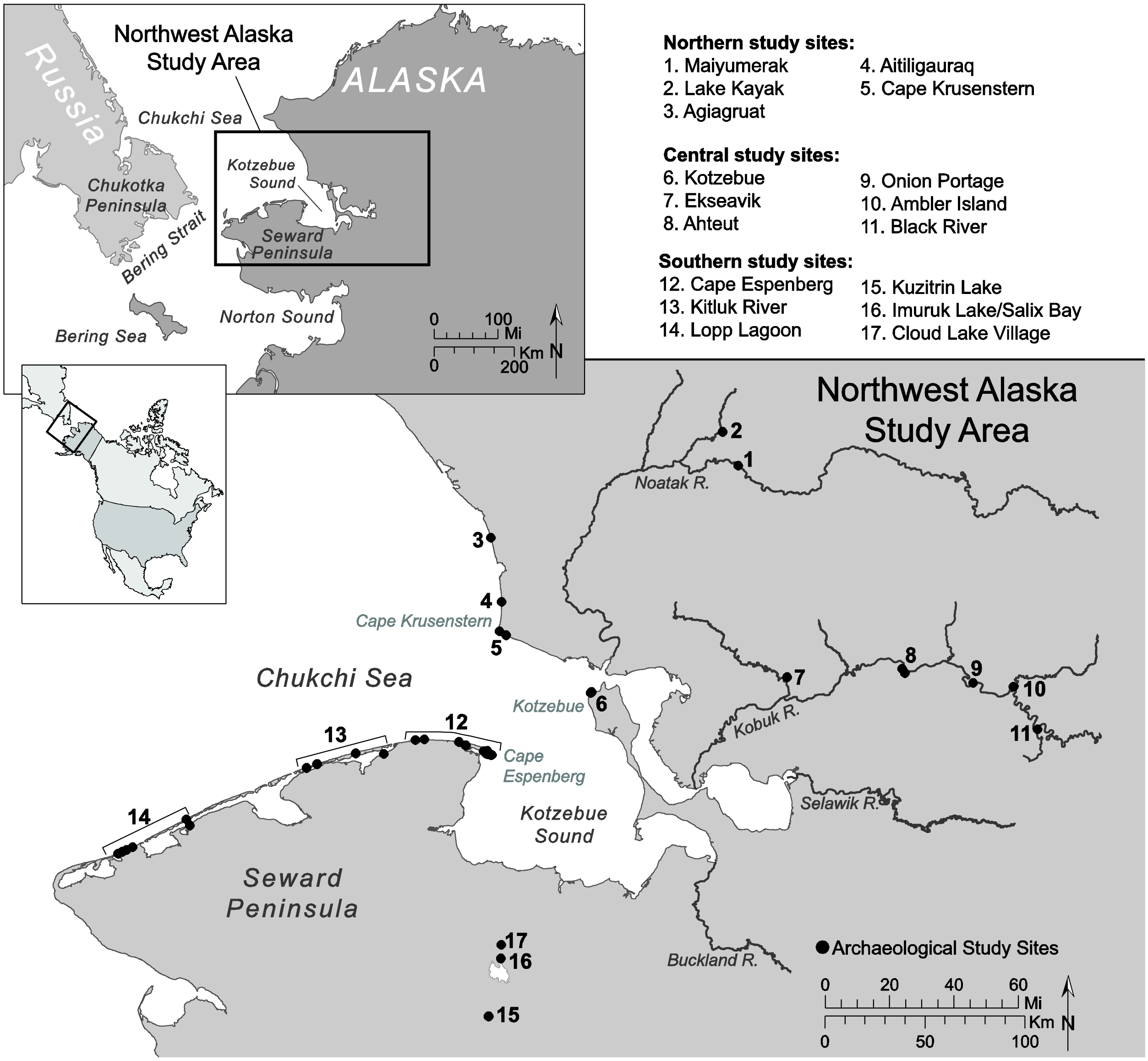

Figure 1. Map of study area with archaeological study site locations indicated.

3.0 Samples

3.1 Ceramics

This study relies on existing ceramic collections from northwest Alaska. The advantage of this approach is that it allows significant temporal and geographic expansion of the project. The disadvantages of using museum collections include variation in sample sizes from sites available for study, limited provenience and contextual information, and limited information on collection methods in some cases. Information was most limited for collections made by Giddings in the 1940s and 50s at Kotzebue and along the Kobuk River (Giddings, 1952), but the value of including these relatively large collections from otherwise unstudied areas of northwest Alaska outweighed the disadvantages. A total of 8,395 ceramic specimens from 17 sites spanning the study period (

Table 1) were classified according to various technological and decorative attributes using standard ceramic analysis methods (e.g., Rice, 1987). A subsample of specimens for INAA was selected from each site based on the nature and size of primary temper, exterior color, and exterior surface treatment (Anderson, 2011). Rim sherds were preferentially selected for analysis to limit the potential of sampling the same vessel twice. An additional 360 ceramic specimens were submitted for analysis by neutron activation as part of this study, bringing the total sample to 458 specimens[1].

3.2 Clay and Temper Samples

Although study of ceramic production and distribution patterns is possible without direct comparison to geological samples of clay from potential source areas, analyses of clays can aid in connecting ceramic geochemical groups to production locales (Eerkens, 2002; Quinn et al., 2013). Additionally, surveys directed at identifying raw materials for ceramic production can yield information about the availability and suitability of clays at both local and regional scales. A clay survey was conducted as part of this project to aid in identifying ceramic distribution patterns and to gain insight into potters' choices during the production process. Survey design was informed by ethnographic data on clay sources (Anderson, accepted), by available geologic information, and by logistical issues associated with working in remote areas of northwest Alaska. Identification and sampling of reported and possible sources near the archaeological study sites were priorities. Survey was conducted along the Kobuk River and its tributaries, along the northern coast, and in several areas of the southern coast and interior (Figure 2). A total of 40 clay specimens and 39 possible temper specimens were collected

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[1] Specimen SLA 244, though submitted for analysis, was of insufficient mass for reliable analysis by neutron activation using standard University of Missouri Research Reactor procedures.

during the survey, and two additional clay specimens were provided by colleagues. Of these, 28 temper and 31 clay specimens were submitted for geochemical analysis (Table 3).

Collection methods and an in-depth discussion of survey results are detailed elsewhere (Anderson, accepted); however, key findings of the survey that are important for interpreting these geochemical analyses are as follows. First, clays suitable for making pottery are not universally available across the study area. For example, few clay deposits appropriate for pottery making were identified in the southern part of the study area. Second, there is considerable variability in clay quality and in the nature and density of aplastic inclusions within a given geological deposit. Third, not all sources of clay were used by Native Alaskan potters, despite being located in close proximity to archaeological sites. In sum, these findings suggest that even though geological deposits of clay are widespread, access to suitable or desirable clays may have been restricted by cultural factors such as the season of site occupation, the extent of a particular group's territory, and the nature of intergroup relationships within the region.

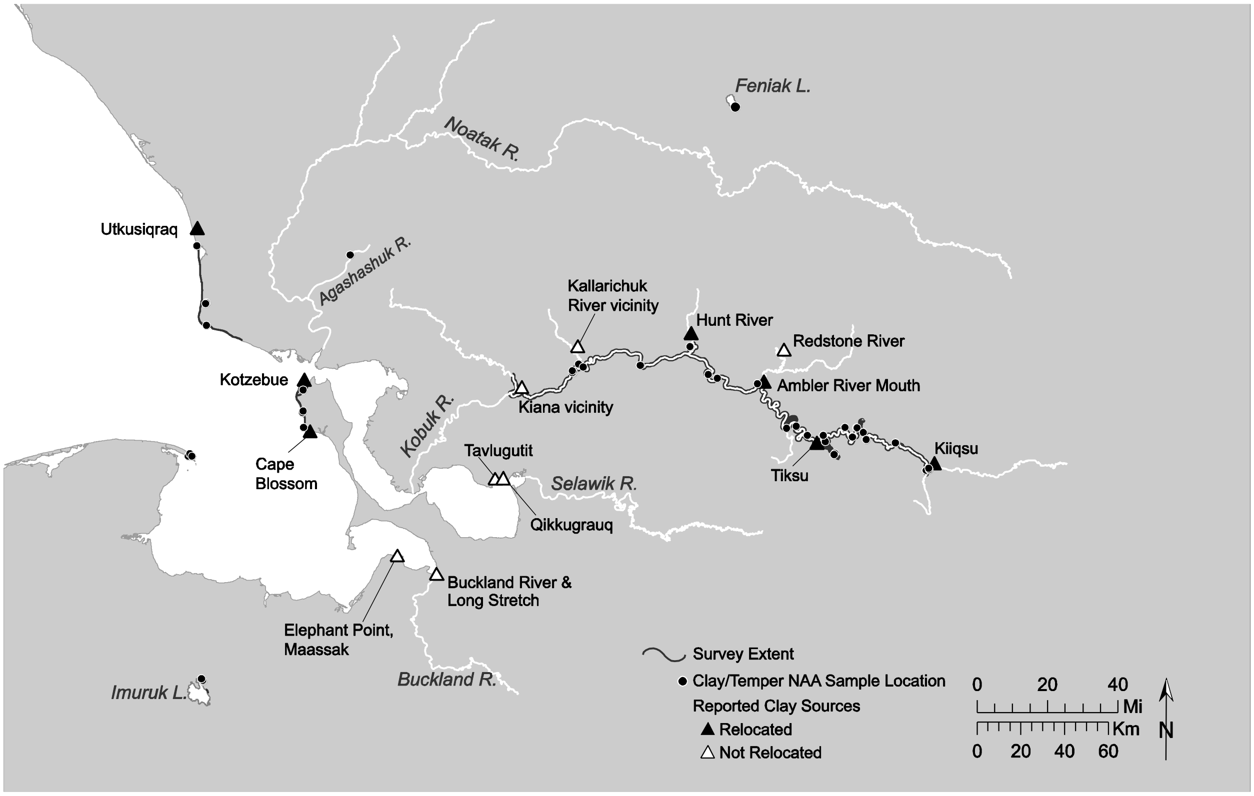

Figure 2. Reported sources and clay sampling locations.

91 Table 1. Summary of Sites and Specimens Included in the Study (See Table 2 for Chronological Details)

Site Name (Site #)	Analyzed Assemblage Size*	NAA	Chronological Units	References
Agiagruat (NOA 217)	778	26	II	Young, 2000
Ahteut (XBM 2,3)	403	52	II	Giddings, 1952; Shirar, 2011
Aitiligauraq (NOA 284)	29	9	IV	NPS, n.d.
Ambler Island (AMR 2, 6)	61	16	III	Giddings, 1952; Shirar, 2011
Black River (SHU 22)	19	5	II	Giddings, 1952
Cape Espenberg (Multiple Sites)	7	4	I	Darwent et al., 2013; Harritt, 1994; Schaaf, 1988; Unpublished Cape Espenberg Project Dates
	3899	63	II	Darwent et al., 2013; Harritt, 1994; Schaaf, 1988; Unpublished Cape Espenberg Project Dates
	507	11	III	Darwent et al., 2013; Harritt, 1994; Schaaf, 1988; Unpublished Cape Espenberg Project Dates
	409	18	III-IV	Darwent et al., 2013; Harritt, 1994; Schaaf, 1988; Unpublished Cape Espenberg Project Dates
	2	1	IV	Harritt, 1994; Schaaf, 1988
	27	2	ii-iv	Darwent et al., 2013; Harritt, 1994; Schaaf, 1988; Unpublished Cape Espenberg Project Dates
Cape Krusenstern (Multiple Sites)	5	3	I	Giddings and Anderson, 1986
	69	27	II	Giddings and Anderson, 1986
	10	4	II-III	Giddings and Anderson, 1986
	98	4	III	Giddings and Anderson, 1986
	94	12	II-IV	Giddings and Anderson, 1986
Cloud Lake Village (BEN 33)	55	10	III	Adams, 1977; Powers et al., 1975
Ekseavik (XBM 9)	179	26	II	Giddings, 1952; Shirar, 2011
Kitluk River (KTZ 145, 149)	168	22	IV	Harritt, 1994; Schaaf, 1988
Kotzebue (KTZ 31, 32)	542	63	III	Giddings, 1952
Kuzitrin (BEN 29)	25	4	III	Harritt, 1994; Powers et al., 1982; Schaaf, 1988
Lake Kayak (MIS 32)	18	3	III	Gilbert-Young, 2004; Shirar, 2011
Lopp Lagoon (TEL 104)	4	4	II	Harritt, 1994; Schaaf, 1988
	1	1	III	Harritt, 1994; Schaaf, 1988
	53	7	ii-iii	Harritt, 1994; Schaaf, 1988
	31	1	ii-iii	Harritt, 1994; Schaaf, 1988
	98	6	III	Harritt, 1994; Schaaf, 1988
Lopp Lagoon (TEL 86)	23	4	II	Harritt, 1994; Schaaf, 1988

	2	1	II	Shirar, 2007, 2011
	15	0	ii-iii	Shirar, 2007, 2011
	653	33	III	Shirar, 2007, 2011
Maiyumerak (XBM 131)	24	0	IV	Shirar, 2007, 2011
Onion Portage (AMR 1)	36	11	III	Giddings, 1952
Salix Bay (BEN 106)	41	6	III-IV	Harrit, 1994; Powers et al., 1982; Schaaf, 1988
Total	**8385**	**459**		

"ii-iii" notation indicates uncertain date range. "II-III" notation indicates transitional period.

*Sherds smaller than 10mm in all directions were excluded from study

Table 2. Chronological units

Period	Age Range (cal BP)	Associated Archaeological Cultures
I	3000-1000	Choris, Norton, Birnirk
II	1000-550	Thule, Early Late Arctic Woodland
III	550-250	Late Arctic Woodland, Kotzebue
IV	Historic (post-250)	Historic

Table 3. Clay and Temper Samples Subjected to INAA

Region	Sampling Location	Sample Type	Identifier	Deposit
North	Cape Krusenstern	Temper	SLA429	Beach
North	Cape Krusenstern	Temper	SLA430	Beach
North	Cape Krusenstern (North CAKR Lagoon)	Clay	SLA427	Sedimentary - Glacial
North	Cape Krusenstern (North CAKR Lagoon)	Temper	SLA428	Beach
North	Kotlik Lagoon	Clay	SLA364	Sedimentary - Glacial
North	Kotlik Lagoon	Clay	SLA365	Sedimentary - Glacial
North	Noatak River - Feniak Lake site (XHP 4)	Clay	SLA456	Unknown
Central	Aggie (tributary of Kobuk River)	Clay	SLA366	Unknown
Central	Hunt River (tributary of Kobuk River)	Temper	SLA451	Beach
Central	Kobuk River (Lower)	Clay	SLA392	Unknown
Central	Kobuk River (Lower)	Clay	SLA393	Unknown
Central	Kobuk River (Lower)	Clay	SLA454	Unknown
Central	Kobuk River (Lower) - Big site	Temper	SLA455	Beach
Central	Kobuk River (Middle) - Kallarichuk River	Temper	SLA453	Beach
Central	Kobuk River (Middle) - Ahteut site	Clay	SLA391	Sedimentary - Glacial
Central	Kobuk River (Middle) - Ahteut site	Temper	SLA452	Beach
Central	Kobuk River (Middle) - Ambler site	Clay	SLA389	Sedimentary - Glacial
Central	Kobuk River (Middle) - Onion Portage site	Clay	SLA390	Sedimentary - Glacial
Central	Kobuk River (Middle) - Onion Portage site	Temper	SLA450	Beach
Central	Kobuk River (Upper)	Clay	SLA382	Sedimentary – Fluvial
Central	Kobuk River (Upper)	Clay	SLA383	Sedimentary - Glacial
Central	Kobuk River (Upper)	Temper	SLA444	Beach
Central	Kobuk River (Upper) - Black River site	Temper	SLA449	Beach
Central	Kobuk River (Upper) - Cosmos Creek Mouth	Temper	SLA447	Beach
Central	Kobuk River (Upper) - Kobuk Village	Clay	SLA388	Sedimentary - Glacial
Central	Kobuk River (Upper) - Near Kogoluktuk River	Clay	SLA380	Sedimentary – Fluvial
Central	Kobuk River (Upper) - Near Kogoluktuk River	Clay	SLA381	Sedimentary – Fluvial
Central	Kobuk River (Upper) - Near Kogoluktuk River	Temper	SLA442	Beach
Central	Kobuk River (Upper) - Near Kogoluktuk River	Temper	SLA443	Beach
Central	Kobuk River (Upper) - Near Mauneluk River	Clay	SLA378	Sedimentary - Glacial
Central	Kobuk River (Upper) - Near Mauneluk River	Clay	SLA379	Sedimentary - Glacial
Central	Kobuk River (Upper) - Near Mauneluk River	Temper	SLA441	Beach
Central	Kobuk River (Upper) - Pah River Mouth	Clay	SLA376	Sedimentary - Glacial
Central	Kobuk River (Upper) - Pah River Mouth	Temper	SLA439	Beach
Central	Kobuk River (Upper) - Pah River Mouth	Temper	SLA440	Beach
Central	Kobuk River (Upper) - Pick River	Clay	SLA384	Sedimentary - Alluvium/Fluvial
Central	Kobuk River (Upper) - Pick River	Clay	SLA385	Sedimentary - Alluvium/Fluvial
Central	Kobuk River (Upper) - Pick River	Sand/Gravel	SLA445	Beach
Central	Kobuk River (Upper) - Shungnak	Clay	SLA386	Sedimentary - Glacial
Central	Kobuk River (Upper) - Shungnak	Clay	SLA387	Sedimentary - Glacial
Central	Kobuk River (Upper) - Shungnak	Temper	SLA446	Beach
Central	Kobuk River (Upper) - Shungnak River	Temper	SLA448	Beach
Central	Kotzebue-Cape Blossom	Clay	SLA369	Sedimentary - Glacial

Central	Kotzebue-Cape Blossom	Clay	SLA370	Sedimentary - Glacial
Central	Kotzebue-Cape Blossom	Clay	SLA371	Sedimentary - Glacial
Central	Kotzebue-Cape Blossom	Temper	SLA435	Beach
Central	Kotzebue-Cape Blossom	Temper	SLA436	Beach
South	Cape Espenberg site	Clay	SLA367	Sedimentary - nearshore or glacial deposit
South	Cape Espenberg site	Temper	SLA431	Beach
South	Cape Espenberg site	Temper	SLA432	Dune
South	Cape Espenberg site	Temper	SLA433	Beach
South	Imuruk Lake - Salix Bay site	Temper	SLA437	Beach
South	Imuruk Lake	Clay	SLA372	Residual
South	Imuruk Lake	Clay	SLA373	Residual
South	Imuruk Lake	Clay	SLA375	Residual
South	Imuruk Lake	Temper	SLA438	Beach

4.0 Methods

Analyses of the ceramic, clay, and temper specimens were performed at the University of Missouri Research Reactor (MURR) by the Archaeometry Laboratory, and protocols for sample preparation, irradiation, and gamma-ray spectroscopy followed established procedures (Glascock, 1992; Glascock and Neff, 2003; Neff, 2000). The interpretation of compositional data obtained from the analysis of archaeological materials is discussed in detail elsewhere (Baxter and Buck, 2000; Bieber et al., 1976; Bishop and Neff, 1989; Glascock, 1992; Harbottle, 1976; Neff, 2000) and is not summarized here. Statistical analyses employed for identification of ceramic and clay geochemical groups included principal component analysis and Mahalanobis distance calculations. Compositional data generated for clay and temper specimens were combined to model potential ceramic compositions following methods outlined by Neff et al. (1988).

5.0 Results

5.1 Ceramics

Analyses of the additional 360 ceramic specimens reinforce our prior identification of three broad compositional macrogroups (Anderson et al., 2011). Principal components analysis indicates that greater than 90% of the cumulative variance in the 458-specimen ceramic sample can be explained by seven components (Table 4). The first principal component (PC) is positively loaded on Cs, Ta, and Rb, and negatively loaded on transition metals such as V, Co, and Cr (Figure 3). Subgroupings developed in the pilot study were refined with this additional analysis; many of the outliers to Macrogroups 1 and 2 were successfully reassigned, and Subgroup 2e was entirely eliminated. The majority of specimens can be assigned to the remaining groups and subgroups (Table 5). Ninety-five specimens (20.7%) remain unassigned to any compositional group. In compositional studies of this size and scope, this is not an unreasonable number of unassignable specimens. They could represent ceramic products from exotic or distant sources, or they could reflect sampling issues (e.g., local sources that are insufficiently represented in the present sample).

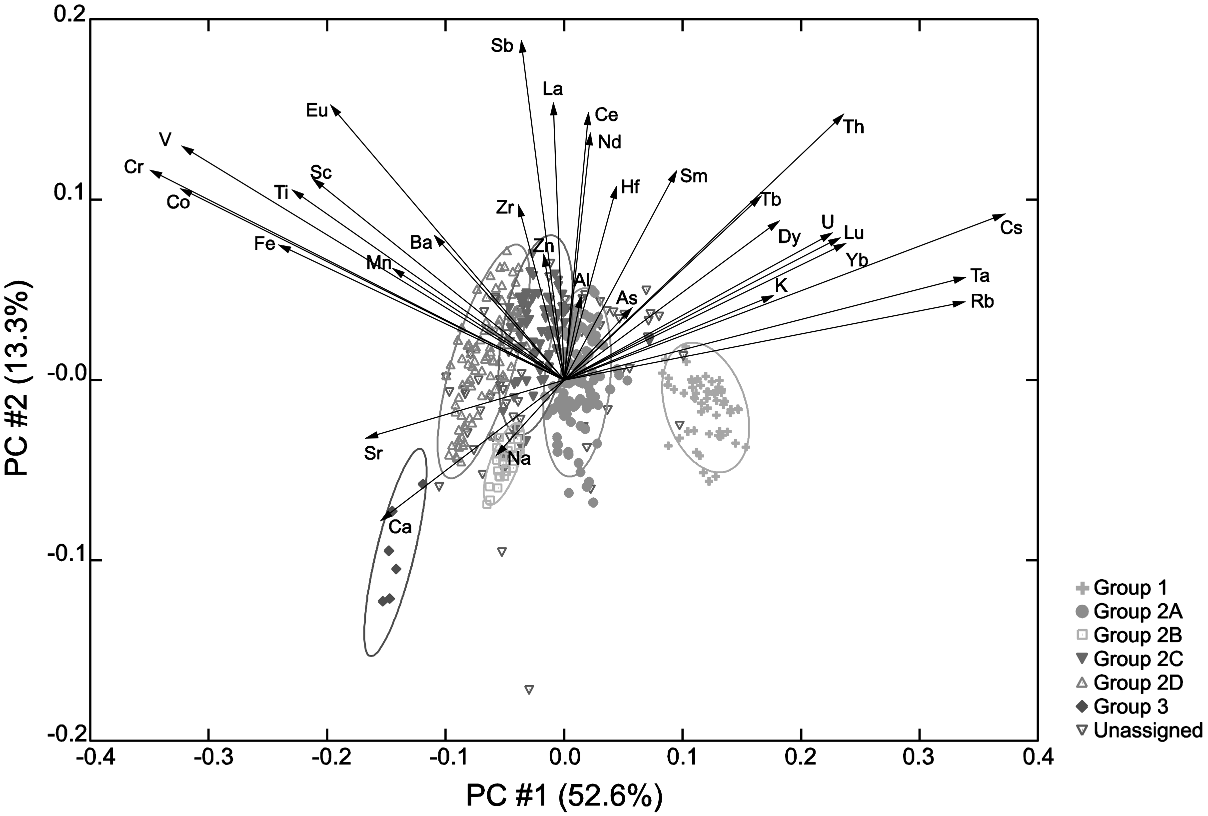

Figure 3. Principal component biplot showing compositional groups and unassigned specimens for the northwestern Alaska ceramic dataset. Elemental loading vectors are shown and labeled. Ellipses are drawn at the 90% confidence interval.

Table 4. Principal Components Analysis of the Alaskan Ceramic Sample

	PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**	**PC7**
% Variance:	52.643	13.29	10.652	5.327	4.187	2.145	1.865
% Cum. Variance:	52.643	65.933	76.585	81.911	86.098	88.244	90.109
Eigenvalues:	2.053	0.518	0.415	0.208	0.163	0.084	0.073
Cs	**0.325**	0.16	0.152	**-0.402**	-0.25	**0.153**	0.109
Ta	**0.296**	0.099	**0.321**	0.213	-0.086	-0.079	**0.208**
Rb	**0.295**	0.075	0.099	-0.144	-0.217	-0.109	0.077
Yb	0.208	0.132	0.192	0.174	0.095	-0.008	0.087
Th	0.206	0.256	**-0.269**	0.035	-0.076	-0.135	-0.062
Lu	0.204	0.137	0.175	0.178	0.08	-0.016	0.09
U	0.198	0.142	-0.034	-0.009	0.019	**-0.281**	0.07
Dy	0.159	0.154	0.117	0.182	0.089	0.004	0.045
K	0.155	0.082	-0.025	-0.116	-0.275	-0.075	-0.083
Tb	0.145	0.177	0.089	0.183	0.085	-0.019	0.036
Sm	0.083	0.202	-0.032	0.151	0.037	0	-0.015
As	0.05	0.07	**0.421**	**-0.349**	**0.206**	-0.143	**-0.422**
Hf	0.039	0.187	-0.077	0.081	-0.078	**0.15**	-0.017
Nd	0.02	0.238	**-0.177**	0.12	-0.007	0.006	-0.055
Ce	0.018	0.258	**-0.213**	0.097	-0.008	-0.042	-0.051
Al	0.013	0.082	0.022	-0.011	-0.138	**0.122**	-0.063
La	-0.008	0.267	**-0.253**	0.073	-0.04	-0.038	-0.052
Zn	-0.015	0.121	0.058	0.074	**0.16**	**-0.247**	**-0.196**
Sb	-0.032	**0.327**	0.093	**-0.214**	0.094	**0.134**	**-0.507**
Zr	-0.034	0.169	**-0.162**	0.052	-0.039	0.028	0.003
Na	-0.051	**-0.073**	0.224	0.111	**-0.485**	0.015	0.104
Ba	-0.096	0.14	**-0.288**	**-0.242**	-0.159	**-0.405**	0.095
Mn	-0.126	0.108	0.181	0.121	**0.133**	**-0.368**	0.068
Ca	-0.136	**-0.135**	0.186	**0.434**	-0.194	**-0.309**	**-0.32**
Sr	-0.146	**-0.056**	0.031	-0.063	**-0.506**	**-0.289**	**-0.185**
Eu	-0.172	0.265	-0.089	0.08	-0.079	**0.107**	-0.016
Sc	-0.185	0.194	0.159	-0.037	-0.093	**0.196**	0.023
Ti	-0.201	0.184	0.11	0.154	-0.149	**0.251**	0.052
Fe	-0.211	0.13	0.038	0.102	0.005	0.04	-0.063
V	**-0.282**	0.226	0.221	-0.016	-0.158	**0.203**	0.065
Co	**-0.283**	0.185	0.132	-0.03	0.076	-0.117	0.12
Cr	**-0.305**	0.203	0.152	**-0.272**	**0.156**	**-0.255**	**0.479**

Note: The first seven PCs are shown, accounting for more than 90% of the cumulative variance in the dataset. Strong elemental loading of individual components is shown in bold.

Table 5. Ceramic Geochemical Group Assignments

Region	Site Name	1	2a	2b	2c	2d	3	Unassigned	Chronological Unit
North	Agiagruat	0	5	1	18	1	0	1	II
	Aitiligauraq	9	0	0	0	0	0	0	IV
	Cape Krusenstern I	0	0	0	0	0	0	3	I
	Cape Krusenstern II	1	9	0	5	3	1	8	II
	Cape Krusenstern III	4	0	0	0	0	0	0	III
	Cape Krusenstern II-III	0	1	0	1	2	0	0	II-III
	Cape Krusenstern ii-iv	0	2	0	1	1	1	5	ii-iv
	Cape Krusenstern II-IV	0	0	0	1	0	0	1	II-IV
	Lake Kayak	2	0	0	0	0	0	1	IV
	Maiyumerak III	0	24	4	2	1	0	2	III
	Maiyumerak II	0	1	0	0	0	0	0	II
Central	Ahteut	0	39	0	8	1	0	4	II
	Ambler Island	3	0	1	5	1	4	2	III
	Black River	4	0	0	0	0	0	1	II
	Ekseavik	0	10	0	10	4	0	2	II
	Kotzebue	8	15	15	5	3	0	17	III
	Onion Portage	0	8	0	0	0	0	3	III
South	Cape Espenberg I	0	0	0	1	2	0	1	I
	Cape Espenberg II	1	1	1	10	27	0	23	II
	Cape Espenberg III	2	0	0	1	3	0	5	III
	Cape Espenberg III-IV	7	0	0	0	7	0	3	III-IV
	Cape Espenberg ii-iv	0	0	0	0	0	0	2	ii-iv
	Cape Espenberg IV	1	0	0	0	0	0	0	IV
	Cloud Lake Village	1	0	1	2	6	0	0	III
	Kitluk River (KTZ 145)	3	0	2	1	14	0	2	IV
	Kuzitrin	0	0	0	0	3	0	1	III
	Lopp Lagoon II	5	0	0	0	2	0	0	II

Lopp Lagoon III	4	0	0	0	1	0	2	III
Lopp Lagoon ii-iii	3	0	0	0	3	0	3	ii-iii
Salix Bay	0	0	0	0	3	0	3	III
	58	***115***	***25***	***71***	***88***	***6***	***95***	**458**

"ii-iii" notation indicates uncertain date range versus II-III, which indicates transitional dates

Eight specimens (Table 6) in the dataset are characterized by a significantly lower concentration of Al relative to all other specimens (μ = 1.62 ± 0.77%). Of these, six specimens (SLA024, 025, 67, 135, 139, 284) are enriched in transition metals Cr and Co, as well as being characterized by significant Al depletion. The concentrations of Cr (μ = 2160.4 ± 347.7 ppm) and Co (μ = 76.7 ± 3.9 ppm) are the highest in the entire dataset. When combined with significant depletion in the rare earth elements (REEs) and alkali metals (Na, K, Rb, and Cs), these chemical characteristics are highly distinctive (Figure 4). Only two archaeological sites are represented by these six specimens: Ambler Island (n = 4) and Cape Krusenstern (n = 2). Three of the four specimens from Ambler Island are from the same house feature. Considering that the lowest observed Al concentration in the sampled clays is 5.38% (SLA366, collected from a tributary of the Kobuk River), it is reasonable to conclude that none of the sampled clay sources were used in the production of these sherds. Of the eight low Al specimens, two (SLA 356 and SLA 511) may eventually form the basis for a new compositional group. These two specimens are also depleted in Al, but their REE abundances and concentrations of transition metals are similar to the majority of other ceramic specimens analyzed here.

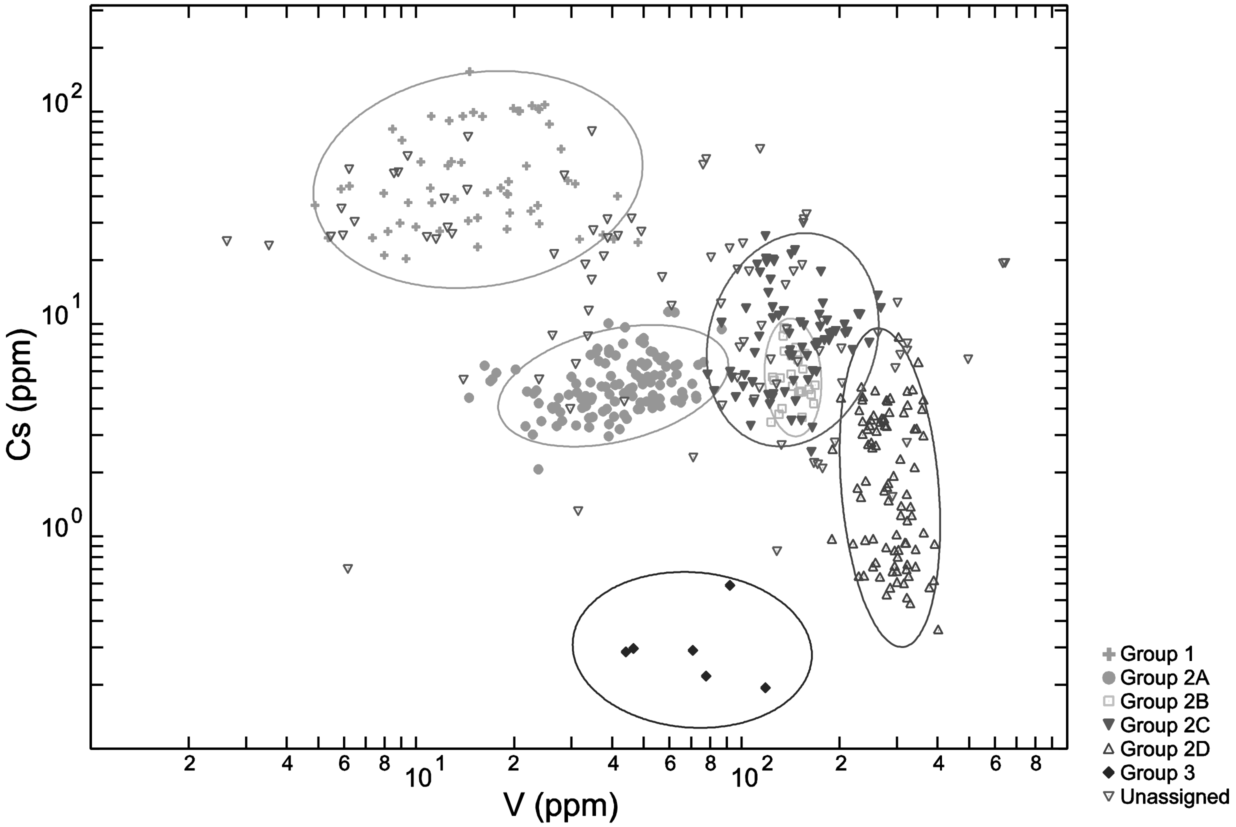

Figure 4. Bivariate plot of Cs versus V concentrations in the northwestern Alaska ceramic dataset. Ellipses are drawn at the 90% confidence interval.

Table 6. Eight Specimens Comprising the Low-Al Compositional Group

ANID	**Context**
SLA024	Ambler Island, House 7
SLA025	Ambler Island, House 7
SLA067	Cape Krusenstern, House 1B
SLA135	Ambler Island, House 7
SLA139	Ambler Island, House 10
SLA284	Cape Krusenstern, Surface Scatter 1B
SLA356	Agiagruat, Feature 6
SLA511	Cape Espenberg, 7N 8E

Note that specimens SLA356 and SLA511 have significantly lower transition-metal abundances, and therefore likely represent a different provenance or ceramic recipe.

5.2 Clays

All of the clay specimens analyzed here are geochemically most similar to Group 2c, with the exception of SLA393 (collected in the lower Kobuk River region), which is most similar to Group 2a (Figure 5). We used the geochemical data generated for clay and temper specimens in a mixture model to generate compositional profiles that represent ceramic products produced using each raw material. The goal of the modeling process was to explore how people may have used the raw materials we collected during the raw-material survey. Potential tempering materials (mineral grit and sand) were combined with clays from that same locality in 10% increments from zero (pure clay) to 50% (half temper and half clay, by mass). Modeled ceramic compositions were then projected against the various compositional groups proposed by Anderson et al. (2011). Group-membership probabilities based on Mahalanobis distance using 33 elemental abundances were calculated for each modeled ceramic composition (Supplementary Information 1).

Results of this modeling process suggest that all of the clays and clay/temper mixtures are most similar, in general, to our compositional Macrogroup 2, and specifically to Groups 2a and 2c. None of the modeled ceramics produced compositions similar to Group 1 or to Group 3, suggesting that these two compositional groups comprise pottery produced with resources that were not sampled during the survey. Given the coverage of the survey, it is possible that both of these compositional groups represent non-local ceramic artifacts.

Several of the raw clays as well as the modeled ceramic compositions have very low probabilities of belonging to any of the compositional groups we defined. Clays (and modeled ceramics) from Ahteut and the lower Kobuk Valley are not strong statistical matches for any of our groups, suggesting that these raw materials were likely not used for ceramic production. Clays collected from Cape Espenberg have group-membership probabilities of effectively zero, similarly indicating that they may not have been used prehistorically.

The ceramic-modeling results allow us to draw some preliminary conclusions regarding the significance of our various compositional groups. Figure 6 shows the 11 different clay sources projected against compositional groups, as well as the effects of adding 50% temper to each of the clays (see also Table 7). In each instance, adding temper to raw clay results in compositions more similar to those of ceramics placed within the Group 2 macrogroup, suggesting that some of the chemical variation within the Group 2 subgroups is likely related to the kinds and amounts of temper added to each product. Again, we note the dissimilarity of Group 1 and Group 3 to any of the raw clays and to any of the modeled ceramics, suggesting that they were produced using raw materials with fundamentally different chemical characteristics.

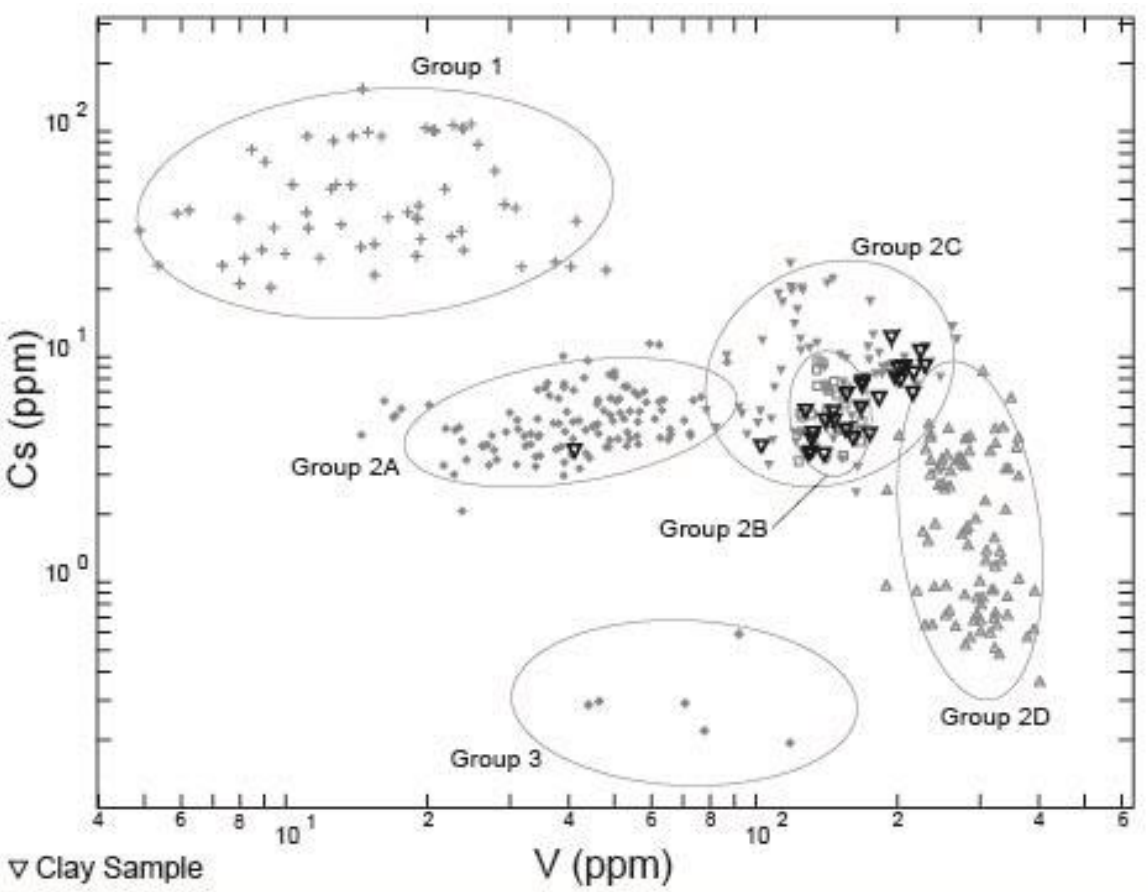

Figure 5. Bivariate plot of Cs versus V concentrations in the northwestern Alaska ceramic dataset showing geological clay specimens (labeled) grouped within Group 2c. Ellipses are drawn at the 90% confidence interval.

Table 7. Locations and Analytical IDs for Clay and Temper Materials (letters correspond to Figure 6)

		Location	Clay	Temper
Coast				
	A	Cape Espenberg	SLA367	SLA431–433
	B	Kotzebue Sound	SLA368–371	SLA435–436
	C	Cape Krusenstern	SLA427	SLA428-430
Lower Kobuk River				
	D	Lower Kobuk	SLA392–393	SLA453–455
Middle Kobuk River				
	E	Ahteut	SLA391	SLA452
	F	Onion Portage	SLA390	SLA450
Upper Kobuk				
	G	Kobuk Village	SLA380–383, SLA388	SLA442–444
	H	Mauneluk	SLA378–379	SLA441, SLA448
	I	Pah River	SLA376–377	SLA439–440
	J	Shungnak	SLA384, 386, 387	SLA445–446
Interior				
	K	Imuruk Lake	SLA372–375	SLA437–438

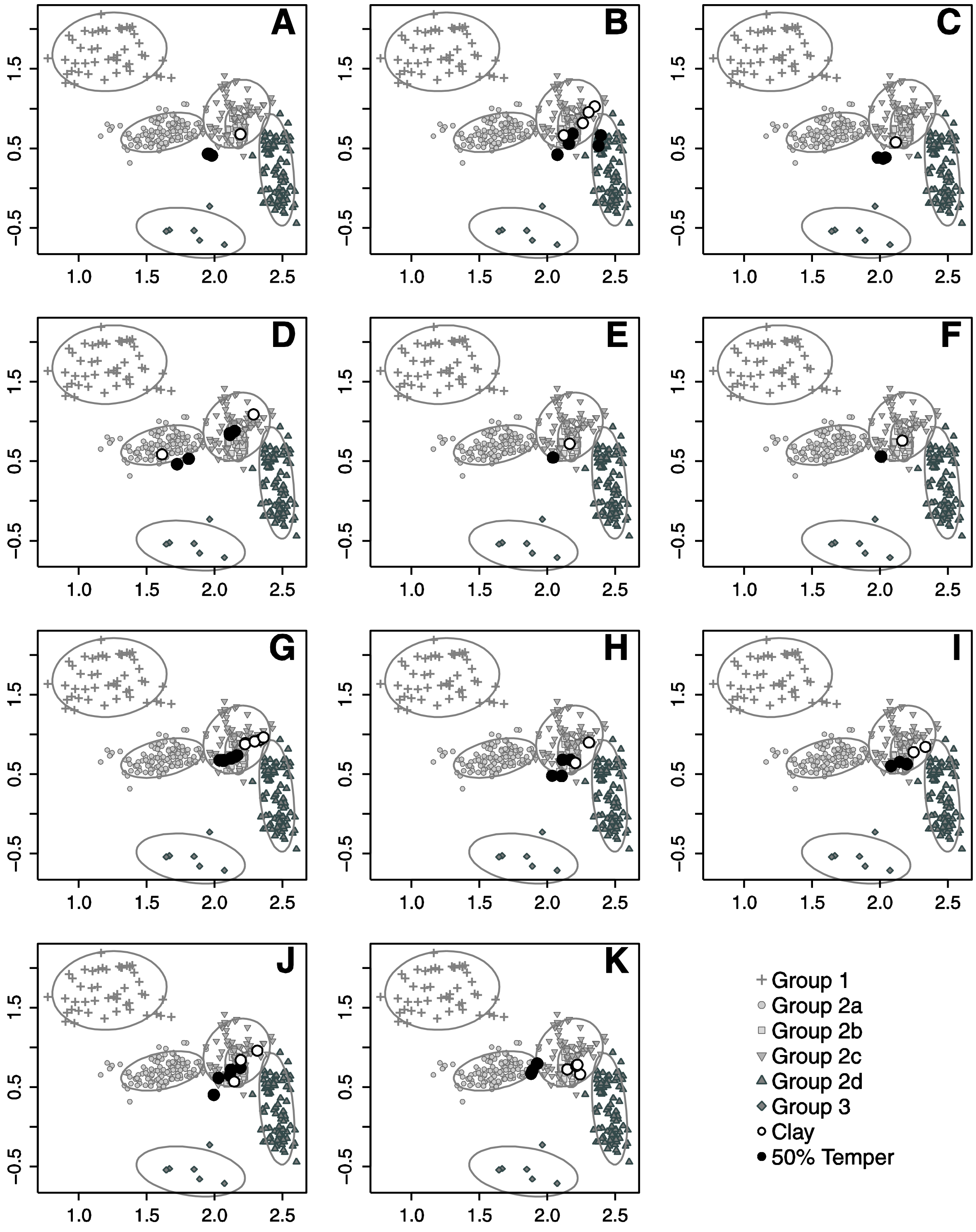

Figure 6. Log-log plot of Cs and V showing ceramic compositional groups, raw clays (white circles), and modeled ceramic compositions with 50% temper (black circles). A: Cape Espenberg; B: Kotzebue Sound; C: Cape Krusenstern; D: Lower Kobuk; E: Ahteut; F: Onion Portage; G: Kobuk

Village; H: Mauneluk; I: Pah River; J: Shungnak; K: Imuruk Lake. Confidence ellipses are drawn at the 90% confidence interval. Note that only two dimensions are shown here. Multivariate probabilities for each raw clay and for modeled ceramic compositions are provided in the Supplementary Material.

6.0 Discussion

6.1 Clay Character

The results of clay geochemical analysis indicate that clays across the region, more than 25,600,000 acres in size, are remarkably homogenous. This is surprising, given that samples were collected from a variety of depositional contexts (e.g., glacial, lacustrine, colluvial). In addition, processes of ceramic production (e.g., treatment of clay, addition of temper) and postdepositional processes (e.g., weathering, leaching/enrichment of elements and minerals) can alter the chemical composition of pottery so that the analytically determined compositions of ceramic artifacts may not necessarily appear to be statistically strong matches to geological clays. Analyses of clays and clay-rich sediments from the region suggest greater heterogeneity in clays than indicated by the bulk geochemical analyses reported here. For example, analyses of sediments associated with thermoluminescence-dated ceramics yielded variable measurements for ^{238}U, ^{233}Th, and K (Feathers 2011). X-ray diffraction (XRD) of four clay specimens (SLA 364, 369, 372, 389) from across the region indicates some variation in mineralogical composition (Table 8) though additional analysis is needed (Perkins 2012). Illite, chlorite, and albite tend to be enriched in Al, whereas dolomite and calcite are Ca-enriched. All of the clay specimens subjected to XRD contain some amount of Al-rich feldspar (albite) and Al-bearing phyllosilicate (illite), although the amount is undetermined at this time. INAA indicates that all the sampled clays have approximately the same concentrations of Al, and XRD analysis indicates that all the clays contain Al-bearing minerals. Thus, the XRD and INAA are in congruence to some degree, although XRD analysis indicates greater heterogeneity in clay composition than the INAA. XRD analysis of SLA 372 from the southern study area indicates that clays in this region are somewhat enriched in Al. While Groups 1 and 2 ceramics show some enrichment in Al, Group 3 ceramics are significantly depleted in Al; the results of XRD analysis further indicate that the Group 3 ceramics may be nonlocal in origin. Additional mineralogical analysis is necessary to test this hypothesis.

Table 8. XRD results for Four Clay Samples

Clay Sample	Minerals identified	Study Region Sample Collected
SLA 364	Illite, plagioclase albite, chlorite	North
SLA 369	Illite, chlorite, plagioclase albite, calcite, dolomite	Central
SLA 389	Illite, chlorite, calcite, dolomite, plagioclase albite	Central
SLA 372	Sanidine, chlorite, plagioclase albite, illite	South

Ultimately, the analysis of clays proved to be of limited usefulness in linking ceramic geochemical groups to geological source areas at the fine scales as initially hoped; yet, the clay analyses do tell us something about production practices. The ceramic groupings identified in this study are based primarily on the paste recipes used by potters, which did have some regional variation based on the distribution of different geochemical groups across the region. Clay and temper modeling further support this conclusion, indicating that people did not frequently use the mineral material (typically beach or river sand) located adjacent to the clay sources to temper their ceramic materials. Rather, people may have taken advantage of the natural tempering of clay deposits and added little or no additional mineral temper to the ceramics. The geochemical similarity between the clays and the majority of the ceramics (those in Group 2c) suggests that little mineral material was added to clays. If mineral temper was added, modeling indicates that the mineral temper they included was not collected in proximity to the sampled clay deposits. Furthermore, the low group probabilities for modeled combinations of Cape Espenberg clays and tempers suggests that people were not procuring ceramic raw materials in this location. The absence of modeled compositions resembling Group 1 or 3 suggests that ceramics from these groups may originate outside study area.

6.2 Ceramic Production Regions

Clay and ceramic geochemical analysis did identify several production regions. Most of the ceramic specimens fall into what we have referred to as Macrogroup 2 and its various subgroups. Group 2a samples were most common at central Kobuk and central Noatak sites (Ahteut and Maiyumerak, respectively), suggesting production in one or both of these locales and/or interaction between people living in these areas (Figure 7); there are several ethnographically known travel routes between the two river systems (Burch, 2005:282–285) that may have been used in the past as well. Clay sample SLA 393 from the lower Kobuk is associated with this group, however, which makes it difficult to draw any more specific conclusions about the source locale of Group 2a. Group 2b is relatively rare and is most abundant in the vicinity of the Kotzebue site; thus, we suggest that ceramics in this group likely originated at or near Kotzebue. Group 2c ceramics are most abundant along the north coast and at central Kobuk river sites. These likely originated somewhere in the north-central region. In addition, because all of the clay samples except SLA 393 cluster within this group, Group 2c ceramics could represent unmodified use of regional clays. Group 2d ceramics are most abundant at southern sites and probably originated in this region.

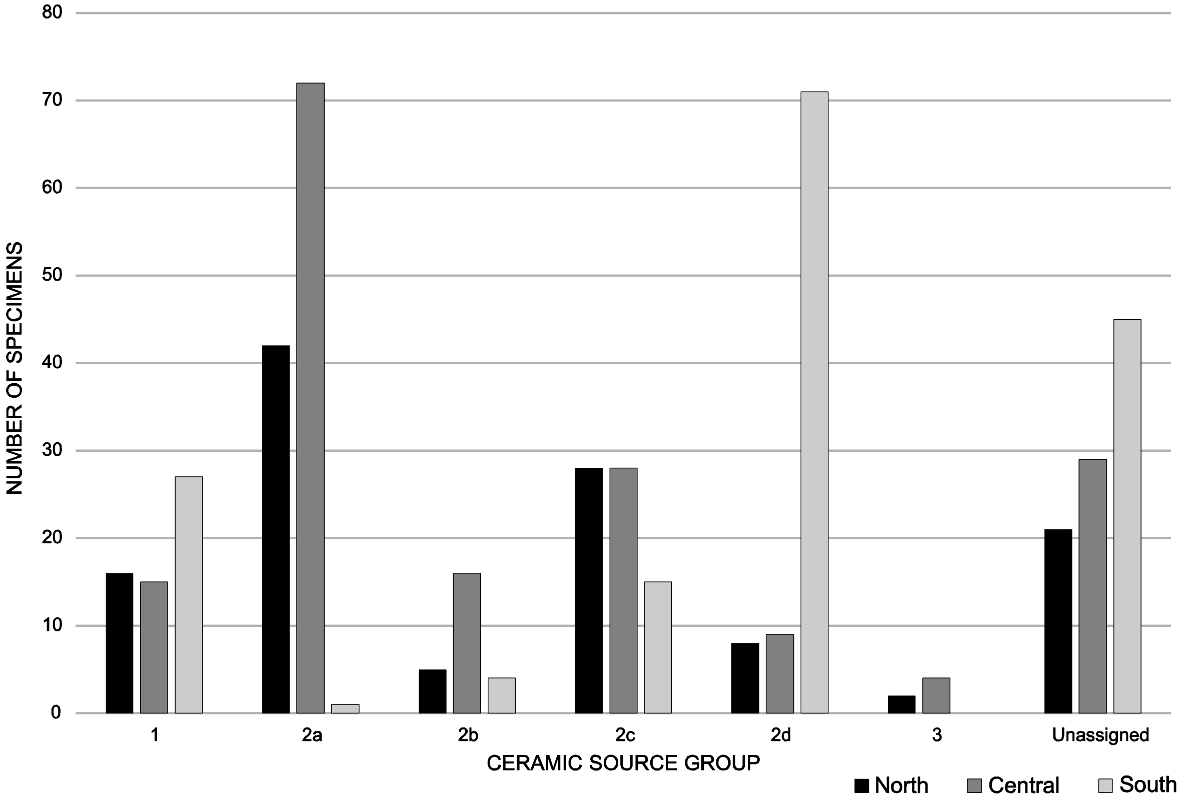

Figure 7. Source group abundance in each sub-region of the study area.

Group 1 and 3 ceramics are present in small numbers at several sites. At this point it is difficult to determine the origin of these ceramics with any certainty. Group 1 ceramics show significant enrichment in Ta. Deposits of Ta are reported on the Seward Peninsula and in the Kiana area of lower Kobuk (Swenson, 2012; Warner, 1985). Specimens assigned to Group 1 are present at sites from both these regions, but they are proportionally most abundant in Lopp Lagoon sites in the south. Group 1 is therefore tentatively assigned to the southern region, though additional analyses may show that Group 1 materials originated outside the study area. None of the modeled clay/temper samples are similar to Group 1, further suggesting that these may have come from outside the Kotzebue Sound region. Group 3 comprises only five ceramic specimens, and these too may have originated from outside the region. Group 3 specimens were found at the Cape Krusenstern site complex (1 out of 50 specimens from the site) and the Ambler Island site, located in the middle/upper Kobuk River (4 of 16 specimens from the site). Given the relatively large Cape Krusenstern ceramic data set it seems unlikely that the rarity of Group 3 ceramics is due to sampling issues at the site complex. None of the modeled clay/temper samples are similar to Group 3.

7.0 Conclusions

Analysis of an expanded ceramic data set more firmly establishes the ceramic geochemical groups identified by the pilot study (Anderson, et al. 2011). The original three macrogroups (1-3), three subgroups of Macrogroup 2 (2a-2c), and Macrogroup 1 and 2 outliers are now consolidated into three macrogroups (1-3), four subgroups of Macrogroup 2 (2a-2d), and specimens that cannot be assigned to any of these macrogroups or subgroups. The addition of clay and temper samples collected during a raw-material survey was informative, although not in the manner anticipated. Though clay and tempering materials were collected over a broad area, the clay specimens demonstrated remarkable geochemical homogeneity, as all but one clay specimen groups with Macrogroup 2c. This suggests that potters added little to no mineral temper to the clays and also that Macrogroup 2c ceramics were produced and distributed from the north and central areas of northwest Alaska to the south. Group 1 and 3 ceramics might be evidence of pottery having been brought into the region from elsewhere. Results suggest the possibility of areas of greater production (e.g., the central Kobuk River) perhaps due to an abundance of clay or wood fuels for ceramic firing.

Overall, it is apparent that ceramics circulated widely around the region over time. This work lays the foundation for further exploring the cultural processes that underlie these distributions. A comparison of ceramic stylistic distribution patterns and geochemical groups is forthcoming. Analysis of ceramic and raw material mineralogy will also further inform this study. Ceramic petrography may be of particular use in refining our understanding of the nature of inclusions present within ceramic sherds. This study of northern Alaskan ceramic production locales provides insight into the complexities of hunter-gatherer ceramic production and distribution.

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Supplementary Information 1:

Discussion of the clay/temper modeling to simulate ceramic compositions

Using procedures outlined by Bishop and Neff (1989) and Neff et al. (1988, 1989) the various clay and temper specimens were combined to model compositions likely to be created through the combination of materials. Modeling was performed in R v. 3.1 (R Core Team, 2014) using the formula:

$$S_i = PT(T_i) + PC(C_i)$$

Where S_i is the elemental abundance in the modeled ceramic, T_i is the elemental abundance of the tempering agent, and C_i is the elemental abundance of the clay. *PT* and *PC* are the proportions of temper and clay, respectively, and must sum to one.

The probabilities of these modeled ceramic compositions belonging to the largest compositional groups used in this study are shown in Tables 1–16. Modeled compositions for the clay (SLA391) and temper specimen (SLA452) from the Middle Kobuk River/Ahteut region show consistently low probabilities of belonging to any compositional group. Though it must be noted that group membership probabilities show a consistent increase with the addition of more temper. Yet it seems unlikely that vessels comprised of more than 50% temper and less than 50% clay would realistically function.

Clay specimens (SLA368–371) from the Kotzebue/Cape Blossom area show reasonably high probabilities of belonging to Group 2c, and the mean elemental abundances of these four clays has a roughly 50% probability of group membership. However, the addition of specimen SLA435 as a tempering agent reduces the group membership probabilities to near zero. This likely relates to (1) the extreme concentration of Cr in temper specimen SLA435 (3523 ppm) relative to the clay specimens (μ = 156 ppm), and (2) the relative enrichment of other transition metals in the temper specimen. Thus, the addition of even a slight amount of this temper to this clay results in a modeled ceramic composition outside the range of any compositional group used here. Using the second temper specimen from Kotzebue/Cape Blossom (SLA436) as a component in the modeling process results in ceramic compositions much closer to the composition of Group 2c, and group-membership probabilities for these simulated ceramic compositions peak around a temper proportion of 20%.

All of the simulated compositions of raw materials collected from Cape Espenberg have exceedingly low group-membership probabilities for all compositional groups presented here. This is particularly interesting given the relatively large sample of ceramics from Cape Espenberg in the current dataset.

Similar to the situation with the first specimen of temper from Cape Blossom, the raw clays from Imuruk Lake shows moderate probabilities of membership in Group 2c; however, the addition of specimens SLA437 and 438 as tempering agents serves to reduce these probabilities significantly.

Excepting specimens from the Lower Kobuk and Upper Kobuk, simulated ceramic compositions from the Middle Kobuk valley show consistently high group membership probabilities for Group 2c. This strongly suggests that potters were routinely collecting raw materials from within the central portion of the river catchment basin.

One interesting outcome of the clay and temper sampling is that none of the combinations of clay and temper produced a modeled ceramic composition remotely close to that of Group 1. Specifically, the highest concentrations of Ta observed in clay and temper specimens came from the Upper Kobuk River

(Pah River, Mauneluk River, and Shungnak River mouths). Yet the average abundance of Ta in these specimens (≈ 1.08 ppm) is far less than that observed in Group 1 pottery (μ = 16.18 ppm). Thus, Group 1 pottery represents a combination of raw materials consistently (and significantly) enriched in Ta relative to anything documented in the widespread sampling of clays and tempering agents. A logical conclusion, then, is that the Group 1 pottery could not have been made from any of the raw materials sampled during the survey.

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R Core Team

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Table 1. Group-membership probabilities for raw clay (SLA391) as well as simulated ceramic compositions from the Middle Kobuk Valley (Ahteut) using SLA452 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA391	0.000	0.002	**0.188**	0.000
10%	0.000	0.000	0.000	0.000
20%	0.000	0.002	**0.004**	0.000
30%	0.000	0.014	**0.075**	0.000
40%	0.000	0.033	**0.368**	0.000
50%	0.000	0.037	**0.780**	0.000

Table 2. Group-membership probabilities for raw clays (SLA368–371) and simulated ceramic compositions from Kotzebue-Cape Blossom using SLA435 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA368	0.000	0.001	**6.971**	0.000
SLA369	0.000	0.000	**40.325**	0.000
SLA370	0.000	0.000	**10.534**	0.000
SLA371	0.000	0.000	**7.463**	0.000
μ of 4 clays	0.000	0.001	**52.335**	0.000
10%	0.000	0.000	**0.620**	0.000
20%	0.000	0.000	**0.004**	0.000
30%	0.000	0.000	0.000	0.000
40%	0.000	0.000	0.000	0.000
50%	0.000	0.000	0.000	0.000

Table 3. Group-membership probabilities for raw clays (SLA368–371) and simulated ceramic compositions from Kotzebue-Cape Blossom using SLA436 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA368	0.000	0.001	**6.971**	0.000
SLA369	0.000	0.000	**40.325**	0.000
SLA370	0.000	0.000	**10.534**	0.000
SLA371	0.000	0.000	**7.463**	0.000
μ of 4 clays	0.000	0.001	**52.335**	0.000
10%	0.000	0.000	**68.218**	0.000
20%	0.000	0.000	**74.575**	0.002
30%	0.000	0.000	**70.330**	0.011
40%	0.000	0.000	**52.657**	0.048
50%	0.000	0.000	**24.614**	0.130

Table 4. Group-membership probabilities for raw clay (SLA367) and simulated ceramic compositions from Cape Espenberg using the mean of temper specimens SLA432 and SLA433 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA367	0.000	0.000	0.000	0.000
10%	0.000	0.000	0.000	0.000
20%	0.000	0.000	0.000	0.000
30%	0.000	0.000	0.000	0.000
40%	0.000	0.000	0.000	0.000
50%	0.000	0.000	0.000	0.000

Table 5. Group-membership probabilities for raw clay (SLA367) and simulated ceramic compositions from Cape Espenberg using temper specimen SLA431. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA367	0.000	0.000	0.000	0.000
10%	0.000	0.000	0.000	0.000
20%	0.000	0.000	0.000	0.000
30%	0.000	0.000	0.000	0.000
40%	0.000	0.000	0.000	0.000
50%	0.000	0.000	0.000	0.000

Table 6. Group-membership probabilities for raw clays (SLA372–375) and simulated ceramic compositions from Imuruk Lake using the mean of temper specimens SLA437 and SLA438 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA372	0.000	0.000	**16.734**	0.000
SLA373	0.000	0.000	**73.277**	0.000
SLA374	0.000	0.000	**19.238**	0.000
SLA375	0.000	0.000	**19.503**	0.000
µ of 4 clays	0.000	0.000	**80.831**	0.000
10%	0.000	0.000	**65.647**	0.000
20%	0.000	0.000	**28.130**	0.000
30%	0.000	0.000	**3.124**	0.000
40%	0.000	0.000	**0.058**	0.000
50%	0.000	0.000	0.000	0.000

Table 7. Group-membership probabilities for raw clays (SLA380–383, 388) and simulated ceramic compositions from Kobuk Village using the mean of temper specimens SLA442–444 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA380	0.000	0.002	**1.830**	0.000
SLA381	0.000	0.009	**0.652**	0.000
SLA382	0.000	0.000	**2.339**	0.000
SLA383	0.000	0.002	**2.847**	0.000
SLA388	0.000	0.000	**23.197**	0.009
μ of 5 clays	0.000	0.002	**10.739**	0.000
10%	0.000	0.006	**20.308**	0.000
20%	0.000	0.014	**33.040**	0.000
30%	0.000	0.033	**45.746**	0.000
40%	0.000	0.067	**54.026**	0.000
50%	0.000	0.115	**54.150**	0.000

Table 8. Group-membership probabilities for raw clay (SLA427) and simulated ceramic compositions from Cape Krusenstern using the mean of temper specimens SLA429–430 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA427	0.000	0.002	**52.005**	0.000
10%	0.000	0.004	**57.752**	0.000
20%	0.000	0.005	**59.095**	0.001
30%	0.000	0.007	**54.556**	0.001
40%	0.000	0.008	**42.720**	0.001
50%	0.000	0.008	**24.863**	0.001

Table 9. Group-membership probabilities for raw clay (SLA427) and simulated ceramic compositions from Cape Krusenstern using specimens SLA428 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA427	0.000	0.002	**52.005**	0.000
10pct	0.000	0.002	**54.260**	0.001
20pct	0.000	0.001	**41.861**	0.002
30pct	0.000	0.001	**21.203**	0.003
40pct	0.000	0.000	**5.900**	0.003
50pct	0.000	0.000	**0.804**	0.002

Table 10. Group-membership probabilities for raw clays SLA392–393 and simulated ceramic compositions from Lower Kobuk using the mean of temper specimens SLA453–455 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA392	0.000	0.000	**0.224**	0.000
SLA393	0.000	**0.892**	0.000	0.000
μ of 2 clays	0.000	0.000	**0.491**	0.000
10%	0.000	0.001	**0.617**	0.000
20%	0.000	0.004	**0.664**	0.000
30%	0.000	0.010	**0.589**	0.000
40%	0.000	0.015	**0.414**	0.000
50%	0.000	0.013	**0.218**	0.000

Table 11. Group-membership probabilities for raw clays (SLA378–379) and simulated ceramic compositions from Mauneluk using specimen SLA441 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA378	0.000	0.000	**15.566**	0.000
SLA379	0.000	0.000	**0.749**	0.000
μ of 2 clays	0.000	0.000	**20.650**	0.000
10%	0.000	0.000	**25.013**	0.000
20%	0.000	0.000	**26.246**	0.000
30%	0.000	0.000	**23.240**	0.000
40%	0.000	0.000	**16.464**	0.000
50%	0.000	0.000	**8.555**	0.000

Table 12. Group-membership probabilities for raw clays (SLA378–379) and simulated ceramic compositions from Mauneluk using specimen SLA448 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA378	0.000	0.000	**15.566**	0.000
SLA379	0.000	0.000	**0.749**	0.000
μ of 2 clays	0.000	0.000	**20.650**	0.000
10%	0.000	0.000	**38.380**	0.000
20%	0.000	0.000	**54.151**	0.000
30%	0.000	0.000	**61.144**	0.000
40%	0.000	0.000	**56.069**	0.000
50%	0.000	0.000	**37.708**	0.000

Table 13. Group-membership probabilities for raw clay (SLA390) and simulated ceramic compositions from the Middle Kobuk/Onion Portage area using specimen SLA450 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA390	0.000	0.014	**25.278**	0.000
10%	0.000	0.023	**39.832**	0.000
20%	0.000	0.027	**47.708**	0.000
30%	0.000	0.021	**44.894**	0.000
40%	0.000	0.010	**31.358**	0.000
50%	0.000	0.003	**13.864**	0.000

Table 14. Group-membership probabilities for raw clays (SLA376–377) and simulated ceramic compositions from the Upper Kobuk/Pah River area using specimen SLA439 as temper. Probabilities based on concentrations of 33 elements. Pah River (SLA440).

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA376	0.000	0.005	**26.354**	0.000
SLA377	0.000	0.000	**6.783**	0.000
μ of 2 clays	0.000	0.000	**37.313**	0.000
10%	0.000	0.001	**43.975**	0.000
20%	0.000	0.003	**40.595**	0.000
30%	0.000	0.008	**27.418**	0.000
40%	0.000	0.014	**11.641**	0.000
50%	0.000	0.016	**2.639**	0.000

Table 15. Group-membership probabilities for raw clays (SLA376–377) and simulated ceramic compositions from the Upper Kobuk/Pah River area using specimen SLA439 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA376	0.000	0.005	**26.354**	0.000
SLA377	0.000	0.000	**6.783**	0.000
μ of 2 clays	0.000	0.000	**37.313**	0.000
10%	0.000	0.001	**35.566**	0.000
20%	0.000	0.001	**19.551**	0.000
30%	0.000	0.001	**5.440**	0.000
40%	0.000	0.001	**0.736**	0.000
50%	0.000	0.000	**0.054**	0.000

Table 16. Group-membership probabilities for raw clays (SLA384, 386, 387) and simulated ceramic compositions from the Upper Kobuk/Shungnak area using the means of specimens SLA445–446 as temper. Probabilities based on concentrations of 33 elements.

ANID	Group 1	Group 2a	Group 2c	Group 2d
SLA384	0.000	0.066	**0.264**	0.000
SLA386	0.000	0.000	**0.415**	0.003
SLA387	0.000	0.000	**1.851**	0.000
μ of 3 clays	0.000	0.001	**8.515**	0.000
10%	0.000	0.003	**12.727**	0.000
20%	0.000	0.007	**11.218**	0.000
30%	0.000	0.010	**5.698**	0.000
40%	0.000	0.008	**1.561**	0.000
50%	0.000	0.004	**0.226**	0.000