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The adoption of pottery on Kodiak Island: Insights from organic residue analysis

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ABSTRACT

Pottery technology, originating in Northeast Asia, appeared in Alaska some 2800 years ago. It spread swiftly along Alaska's coastline but was not adopted on Kodiak Island until around 500 cal BP, as part of the Koniag tradition. While in the southeast pottery was used extensively, people on the northern half of the island did not adopt the technology. What drove these patterns of adoption and non-adoption on Kodiak Island? To better understand the role of ceramic technology in the Koniag tradition we used organic residue analysis to investigate pottery function. Results indicate that pottery was used to process aquatic resources, including anadromous fish, but especially marine species. Based on archaeological and ethnographic data, and spatial analysis of pottery distributions and function, we hypothesize that Koniag pottery was a tool inherent to the rendering of whale oil on the southeast coast of Kodiak Island, supporting previous suggestions by Knecht (1995) and Fitzhugh (2001). When viewed in the broader historical context of major technological and social transformations, we conclude that social identity and cultural boundaries may also have played a role in the delayed and partial adoption of pottery on Kodiak Island.

1. Introduction

The emergence and dispersal of pottery technology among hunter-gatherers is the focus of major debate (Craig et al., 2013; Jordan and Gibbs, 2019; Jordan and Zvelebil, 2009; Sturm et al., 2016). The debate has evolved from a Western-biased view of pottery as a tool inherent to agricultural sedentary societies (Arnold, 1988:109), to a discussion more centered on adaptations (Ikawa-Smith, 1979) and economic drivers (Brown, 1989). In exploring the reasons for pottery adoption, recent research has focused on pottery function through the analysis of organic residues preserved in and on the surface of the pottery vessel (Evershed, 2008). Such studies show a strong relationship between hunter-gatherer pottery and the processing of aquatic resources (e.g., Anderson et al., 2017; Gibbs et al., 2017; Lucquin et al., 2016a; Taché and Craig, 2015). Nonetheless, the spatiotemporal and contextual variability of the mechanisms behind pottery adoption remain poorly understood.

From its deeper origins in Late Glacial East Asia, pottery technology spread northward into Northeastern Siberia, and crossed the Bering Strait into Alaska some 2800 years ago (Ackerman, 1982; Anderson et al., 2017; Jordan et al., 2016). By 2500 cal BP it was widely distributed along Alaska's coastal margins (Dumond, 1969; Oswalt, 1955), ranging from Walakpa Bay in the High North (Stanford, 1976), to the Pacific coast of the Alaska Peninsula in the south (Dumond, 2011; Shirar et al., 2012; see Fig. 1). Interestingly, on the Kodiak Archipelago, pottery adoption occurred very late (ca. 500 cal BP) in its culture history (Clark, 1998). The enigma of the delayed pottery adoption on Kodiak is further mystified by its partial uptake (Clark, 1966a, 1998), restricted only to the southern half of the island (Fig. 1). These divergent patterns of adoption make Kodiak an interesting case study for the investigation of pottery adoption dynamics.

This is the first systematic study of Koniag pottery function using direct methods. In this paper we review the relevant theory and regional context of local ceramic traditions and we integrate this information with the results of lipid residue and stable isotope analysis of 30 pottery vessels from a selection of 11 Koniag sites. Through inter-site spatial

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analysis of pottery function we address the question why pottery adoption on Kodiak Island was delayed and restricted to the south. Based on our results we discuss some of the deeper social dynamics of pottery adoption, linking it to local status and social competition, participation in wider interaction networks, but also the emergence of group identities and cultural boundaries.

1.1. Ceramic Innovation and dispersal

The spread of an innovative technology such as pottery was no smooth diffusionist process, but a complex and contingent process driven by a diverse and varying set of processes (Brown, 1989; Jordan and Zvelebil, 2009; Reid, 1984; Rice, 1999). This contingency is best evidenced by phases of rapid dispersal followed by the formation of "stop lines", as well as by initial periods of pottery adoption, abandonment and later re-adoption. Examples include: the adoption, abandonment and return of pottery on Hokkaido Island (Robson et al., 2020, in press); the 5000-year delay in pottery spread from the east to the west side of Lake Baikal (Kuzmin, 2014; Piezonka et al., 2020); the widespread uptake of pottery in inner NE Asia, but delayed adoption on the coast (Fitzhugh, 2016; Kuzmin and Orlova, 2000).

Explanations for these patterns may be sought in the extent of exposure to the new innovation (Eerkens and Lipo, 2014), or can be approached from a "need-based" perspective (Frink, 2009; Pfaffenberger, 1992). However, the role of choice should not be overlooked. Indeed, there are many examples of the non-adoption of pottery by groups who were likely aware of its existence but chose not to use it. Examples are found in coastal California and Eastern Polynesia (Rice, 1999; Rocek, 2013; Sturm et al., 2016), in Finland (Hallgren, 2009), in Ireland and Britain (Elliott et al., 2020, in press), and along the Northwest Coast of North America (Marshall and Maas, 1997) and in the Aleutian Islands (Admiraal et al., 2019). Seal hunters of the Åland Islands in the Baltic used pottery, but there was a delay of millennia before it reached the nearby shores of Sweden. This uneven pottery adoption is explained through the concept of social identity by Hallgren (2009:388), citing Wenger (1999:164) who states that: "Our identities are constituted not only by what we are but also by what we are not".

Expanding on a cost-benefit model (Bettinger et al., 2006; Sturm et al., 2016; Ugan et al., 2003), we argue that strategic choices, status, social identities, and community dynamics lie at the core of technological innovation and adoption processes (Brown, 1989; Frink, 2009; Pfaffenberger, 1992; Rubertone, 2000). This is especially true in Circumpolar environments, where fundamental challenges complicate the maintenance of viable pottery traditions (Jordan and Gibbs, 2019). Cold and damp climates make drying and firing pottery difficult, there is often a (seasonal) lack of fuel or clay resources, and the need to produce pots in the short summer season clashes with other vitally important seasonal subsistence activities (Admiraal et al., 2020; Frink and Harry, 2008; Harry and Frink, 2009; Harry et al., 2009a,b; Jordan and Gibbs, 2019). Powerful motivations must have existed before Circumpolar peoples decided to invest in this new technology, insinuating the great benefit of pottery (Ugan et al., 2003). Given all the contingencies, the interplay of decision-making processes, and the technological affordances of new and existing material culture can best be examined at a more local scale. Especially where pottery starts to spread into new areas, or appears to be actively "rejected", or passively "ignored".

Variety in pottery adoption dynamics may be down to inhabiting different ecological zones, availability of raw materials, degree of mobility, the use of rival container technologies, maintaining different adaptive strategies, or reflect deeper expressions of identity. Intensification on several levels (e.g., resource exploitation, population increase, socioeconomic complexity) may have laid at the foundation of the adoption process by encouraging logistical mobility and more sedentary lifestyles, especially in highly productive coastal zones (Boserup, 1965; Fitzhugh, 2002, 2003; Morgan, 2015; Rice, 1999; Schalk, 1977; Steffian et al., 2006; Yesner et al., 1980; Yesner, 1998). This is an ideal context

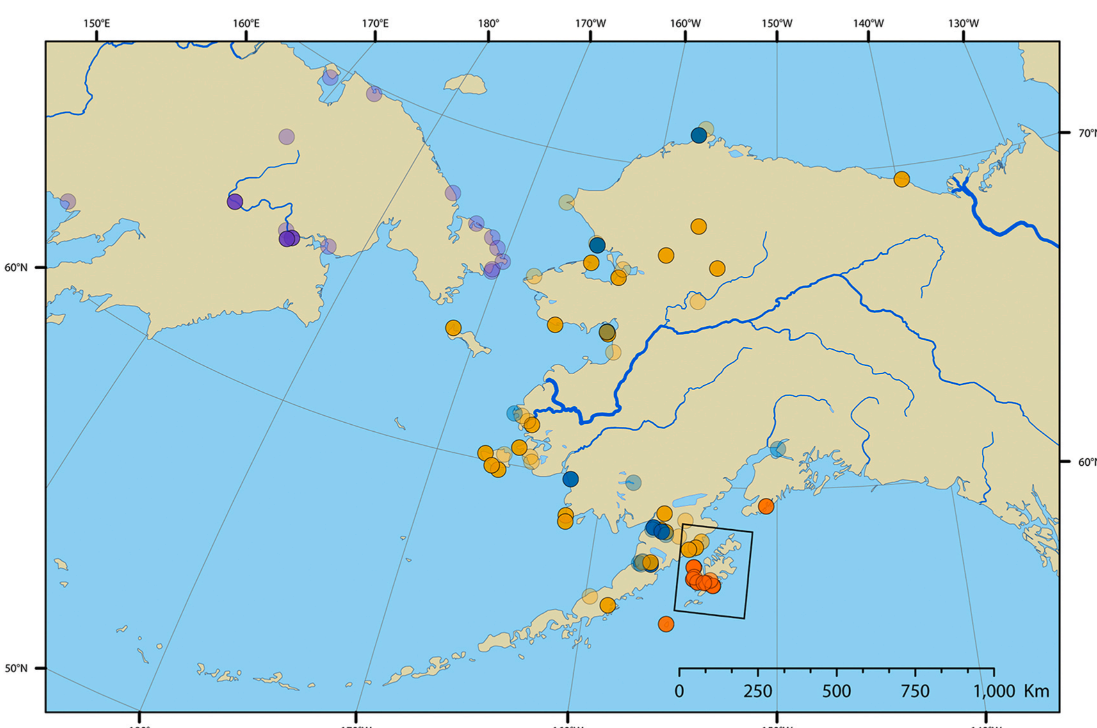


Fig. 1. Map of Alaska portraying pottery sites of the Norton (yellow), late prehistoric Thule and ancestral Yup'ik (blue), and Koniag (orange) traditions (note the limited southern distribution of pottery sites on Kodiak Island), and post-3000 cal BP sites across the Bering Strait in Northeast Siberia (purple). Translucent markers refer to sites that were not radiocarbon dated. Kodiak Island is marked by an indicator square corresponding to the outline of Figs. 6 and 7, a list of sites is available in Supplemental Table 1. Map by Frits Steenhuisen. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

for the development of a delayed-return, storage-based economy, as is evident on Kodiak Island (Fitzhugh, 2003:115), and may have generated cultural dynamics that resulted in the (partial) adoption of pottery.

2. Kodiak Island

The earliest pottery in Alaska (ca. 2800 cal BP) is associated with the Norton culture (Anderson et al., 2017; Oswalt, 1955). At around 1000 cal BP a major shift in pottery technology occurs on the Alaskan mainland, possibly a result of the expanding influence of the northern Thule tradition (Dumond, 1969, 2011). When pottery was adopted on Kodiak at around 500 cal BP, it remained geographically restricted to the south. This was a time of increasing interaction between Kodiak Island and late prehistoric pottery-using groups on the Alaska Peninsula, from which Koniag pottery was likely adopted. Pottery technology does not spread beyond Kodiak Island and the northern Alaska Peninsula, it is largely absent from the wider Gulf of Alaska (Crowell, 2007), and is entirely absent from the Pacific Northwest Coast (Marshall and Maas, 1997).

2.1. Geography, ecology and resources

The Kodiak Archipelago is an island group in the North Pacific Gulf of Alaska (Fig. 1), separated from the Alaska Peninsula by the 30 km wide Shelikof Strait. The archipelago consists of the larger Kodiak Island, and many smaller islands (e.g., Sitkalidak, Afognak, Sitkinak, Chirikof, etc.) (Steffian et al., 2016). It has a maritime, cool and rainy climate (Nelson and Jordan, 1988). Rising sea levels of the early Holocene flooded glaciated valleys to form broken fjords, long inlets and sheltered bays. Many rivers drain the mountainous interior of Kodiak Island, with the major rivers and lakes occurring in the less mountainous and treeless southwest of the island (Karlstrom and Ball, 1969).

2.1.1. Terrestrial resources

Terrestrial animals are limited, with no large herbivores populating the island in prehistory until the introduction of cattle during the contact period (Crowell, 1997). However, the Kodiak bear *(Ursus arctos middendorffi),* a subspecies of the regular brown bear *(Ursus arctos),* is uniquely and abundantly present on Kodiak Island (Van Daele, 2003). Other terrestrial mammals include ground squirrel *(Citellus parryi)*, red fox *(Vulpes vulpes),* northern vole *(Microtus oeconomus)*, and ermine *(Lutra canadensis)* (Clark, 1958; Karlstrom and Ball, 1969). Forested areas of Sitka spruce *(Picea sitchensis)* are limited to the non-ceramic north of the island and only appeared some 1000–500 years ago (Heusser, 1960). Many plant foods are exploited by the present-day Alutiiq (the Native inhabitants of Kodiak Island): cow parsnip *(Heracleum lanatum);* nootka lupine *(Lupinus nootkatensis);* Angelica *(Angelica lucida);* Kamchatka lily *(Fritillaria camschatcensis*; an important dietary source of carbohydrates)*;* sour dock *(Rumex);* wild onion *(Allium schoenoprasum);* fireweed *(Epilobium augustifolium);* salmonberry *(Rubus spectabilis);* blueberry *(Vaccinium ovalifolium);* bearberry *(Arctostaphylos uva-ursi)* (Griffin, 2009; Russell, 2017)*,* and may also have been exploited in the past.

2.1.2. Marine resources

With its complex coastlines, rich in sheltered bays and estuaries, Kodiak is an absolute hotspot for marine mammals, and human subsistence here has always centered on these resources (Clark, 1975; Fitzhugh, 2002, 2003; Knecht, 1995). Sea lion *(Otariinae)* and seal *(Pinnipedia)* were important prey species in the Koniag tradition, as well as several species of cetacean: fin whale *(Balaenoptera physalus),* minke whale *(B. acutorostrata),* grey whale *(Eschrichtius robustus),* and humpback whale *(Megaptera novaeangliae)*. The latter two are known to follow the Alaska Current on their migration through the North Pacific and the Bering Sea during spring and fall. These animals pass Kodiak close to the southeast coast, where the continental shelf is steep, and they often stop to feed in the many bays. This makes whales a predictable resource in this particular part of the archipelago (Calkins, 1987). Marine fish was also important in the Koniag diet, with an abundant presence of deepsea fish such as cod *(Gadus macrocephalus),* sculpin *(Cottoidea),* and halibut *(Hippoglossus stenolepis)*, as well as additions of rockfish *(Sebastes)* and herring *(Clupea harengus)* (West, 2009). Furthermore, the lengthy littoral zone of Kodiak Island provided a wealth of shellfish. Sea otters *(Enhydra lutris)* were abundant, but were only sparsely exploited by people of the Koniag tradition, as opposed to earlier periods (Clark, 1998).

2.1.3. Riverine resources

Kodiak Island is home to several major river systems and numerous smaller creeks, all over the island, and continuously fed by high precipitation rates. These streams attract millions of Pacific Salmon *(Oncorhynchus),* that migrate from the ocean to spawn upriver every year from late spring to autumn. All five species of Pacific salmon are found in Kodiak's streams: pink *(O. gorbuscha)*; sockeye *(O. nerka)*; coho *(O. kisutch)*; chum *(O. keta)*; and Chinook *(O. tshawytscha)*. Other anadromous species are steelhead trout *(O. mykiss)*, and the relatively small Dolly Varden *(Salvelinus malma)* (Partlow, 2000; West, 2009).

3. Prehistoric cultural Trajectories

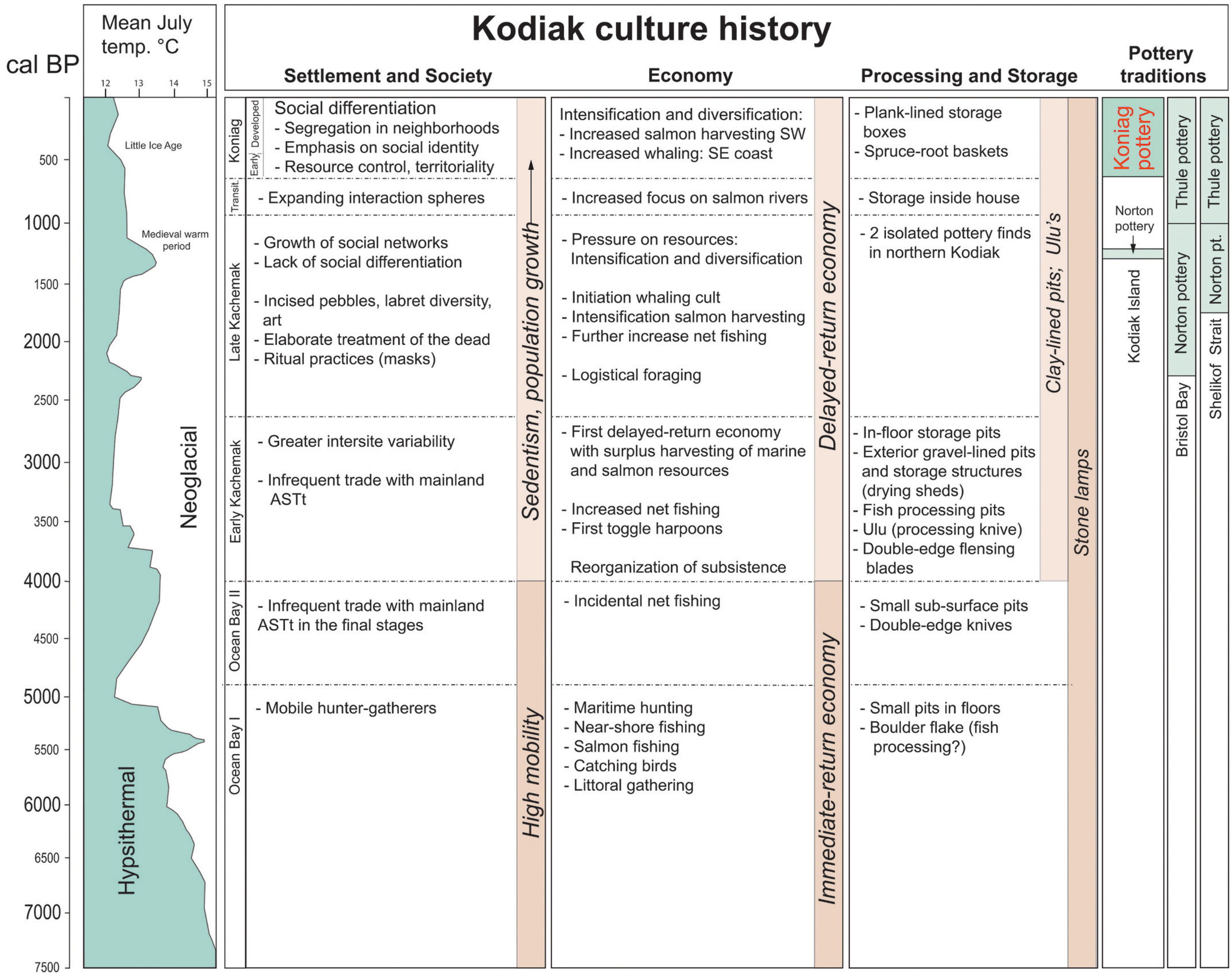
These abundant aquatic resources appear to have played a key role in supporting the dense human populations that are recorded throughout Kodiak Island prehistory, and attracted humans early on (Crowell, 1999; Fitzhugh, 2016). The first maritime adaptations arose on Kodiak Island already at 7500 cal BP with the mobile "Ocean Bay" tradition (Clark, 2001). From this early time onwards Kodiak has been populated by humans continuously (Clark, 1975; Scott, 1992; Steffian et al., 2016). During the "Early Kachemak" (4000–2500 cal BP) the first delayed-return economy led to decreased mobility and population increase (Fitzhugh, 2003; Steffian et al., 2006). These trends continue into the "Late Kachemak" (2500–950 cal BP) with expanding site sizes. Pressure on resources led to diversification and intensification of subsistence strategies, which also increased territoriality (Steffian et al., 2006). Whaling was initiated on Kodiak's southeast coast (Crowell, 1994), and salmon harvesting intensified in the southwest (Partlow, 2000, Table 1). Contact with the Alaskan mainland was frequent during the Late Kachemak. This is reflected in the presence of exotic raw materials (e.g., antler, coal, ivory, and basalt) on Kodiak Island (Margaris, 2009; Steffian, 1992), and it is seen in two isolated finds of Norton pottery in the north of Kodiak Island at Monashka Bay (Donta, 1995) and Crag Point (Clark, 1970).

3.1. The Koniag tradition

The transition from the Kachemak to the Koniag tradition (950 - 650 cal BP) is marked by several pronounced changes that are the topic of debate (Clark, 1975, 1992, 1998; Dumond and Scott, 1991; Fitzhugh, 2002, 2003; Mason and Max Friesen, 2017; Scott, 1992; Steffian et al., 2016; Workman, 1980). Recent research has sought to explain this in a context of cultural continuity, acknowledging an increasing outside influence, not through a rigorous population replacement, but through an expansion of social-political networks, trade, inter-marriage and the onset of raiding and warfare (Fitzhugh, 2003; Fitzhugh and Kennett, 2010; Steffian et al., 2016). This phase is often referred to as the Transitional Kachemak, based on Kachemak artefact continuity (Steffian et al., 2016). However, Koniag influences start to appear during this time, reflected in the introduction of the Koniag-style multi-room houses that hosted several activities, including sweat bathing, sleeping, cooking, but now also the processing of resources and storage of surplus products such as fish and aquatic oil (Knecht, 1995; Steffian et al., 2015, 2016).

During the Early Koniag (650-450 cal BP) the trends of expansion continue as reflected in population growth and site expansion, as well as

Table 1
Culture history of the Kodiak Archipelago, based on: (Clark, 1974, 1998, 2001; Dumond, 2011; Fitzhugh, 2003; Knecht, 1995; Steffian et al., 2016; Steffian and Saltonstall, 2001), and including mean July temperatures for the Gulf of Alaska (Mann et al., 1998).



in enlargement of houses, boats and tools. Large permanent villages are present on the coasts, but now also appear along salmon rivers further inland (Steffian et al., 2015:49–50). This reflects the further intensification of a diversity of subsistence practices. The surplus harvesting of resources demanded increased storage capacity, processing technologies, as well as a strategic organization of labour. Koniag houses at Karluk One are known to have had entire side rooms designated for the sole purpose of storing fish (Knecht, 1995; Steffian et al., 2015:215). The first signs of social differentiation arise during the Early Koniag with evidence in villages of segregation into neighbourhoods (Fitzhugh, 2003:205; Jordan and Knecht, 1988; Knecht, 1995).

During the Developed Koniag (450 cal BP – contact period) pottery was adopted in the south of the island. Multi-room houses expand further and now accommodate large extended families (Knecht, 1995). Warfare and raiding increased, and was connected to accumulation, but also status competition, and concerned distant enemies from the Aleutian Islands and even the wider Pacific Northwest coast (Fitzhugh, 2002, 2003:186; Knecht et al., 2002; Moss and Erlandson, 1992). The pressure on productive and predictable resource patches continued and led to a territorial status-based economy with leadership consolidation and the emergence of an elite class (Fitzhugh, 2003:233–234), and a major general focus on the accumulation and control of surplus resources (Steffian et al., 2016). There was intensive salmon fishing in the southwest, and increased whaling and marine mammal hunting on the southeast coast where migration routes bring prey species close to Kodiak's coast (Calkins, 1987; Knecht, 1995). This is reflected in the formation of large villages in both coastal and inland areas. Northern Kodiak saw a more generalized subsistence on these resources as they are more spread out in that part of the island.

In the southeast, the presence of large villages was likely related to this increase in whaling practices (Crowell, 1994). Whalers were a feared and revered elite that lived secluded from the community in caves during the whaling (summer) season. They formed a cult surrounded by ritual and mystery (Crowell, 1994; Heizer, 1938, 1943; Lantis, 1938). Koniag whale hunting was significantly different from other contemporary communal whaling practices in Alaska and Siberia (Coltrain et al., 2016; Crowell, 1994:220; McCartney, 1980), it was more individualistic. Whales were poisoned with an aconite/oil solution (monkshood: *Aconitum delphinifolium*). The whaler struck the surfacing whale with a poisoned dart in the fin or tail, after which partial paralysis caused it to drown and eventually wash up on shore. The whalers also used poisoned oil to 'seal the bay', which was believed to trap the whale inside (Crowell, 1994:223). The whalers were not involved in the processing of the whale, but claimed the kill through an owner's mark on the poisoned dart. They contributed large amounts of meat and whale oil to village feasts and for trading purposes (Crowell, 1994).

3.2. Koniag pottery

It was into these highly dynamic social environments, and in the context of expanding interaction spheres and intensified whaling activities that pottery was adopted in southern Kodiak during the Developed Koniag (Fitzhugh, 2003; Knecht, 1995, Fig. 2).

3.2.1. Technology and design

Koniag pots vary in size but are mostly cylindrical in shape (Fig. 2), and temper includes abundant gravel, small pebbles and crushed slate (Clark, 1966b; Crowell, 1997:159; De Laguna, 1939). Wall thickness is variable (7–23 mm in our samples). A relatively complete vessel from Rolling Bay (Fig. 2) was described by De Laguna (1939:334) to be 31 cm high, with a diameter of 21.5 cm of the rim, 25.5 cm at the shoulder (12 cm below the rim), and an estimated 9 cm at the base. Based on these measurements a maximum volume of 1.89 L was calculated (Senior and Birnie, 1995). Clark (1966b:160) reported a rim diameter of 37 cm, indicating a larger vessel that may have held up to 5.25 L of liquid. Heizer (1949:49) states that although Koniag pottery may seem crude, it is in fact "… an excellent technological product", that was made by the paddle and anvil technique and was well-fired to create a strong vessel. Numerous rim shapes are known, varying in complexity (Heizer, 1949:50; Fig. 2). While Koniag pottery shows technological similarities with late prehistoric pottery from the Alaska Peninsula, it appears to be better made (Heizer, 1949).

3.2.2. Predicting pottery function

Our main question concerns the function of Koniag pottery. The presence of thick layers of soot on the interior, rims, and sometimes exterior of the pottery hint at a use for cooking, as opposed to storing. The question remains, what was cooked? To date, few studies have looked into the function of pottery in extreme environments, but the few that have showed through organic residue analysis that pottery in marginal northern areas was predominantly used to process and store aquatic resources. Examples are found in Alaska (Anderson et al., 2017; Farrell et al., 2014; Solazzo et al., 2008; Solazzo and Erhardt, 2007), on Sakhalin Island (Gibbs et al., 2017), and in the Kuril Islands (Gjesfjeld, 2019). We predict that this trend extends to Kodiak Island, and that Koniag pottery was also used to process aquatic resources. We present two models for Koniag pottery function that reflect the two major subsistence foci of the Ceramic Koniag (Clark, 1966a), both testable through organic residue analysis:

A. Koniag pottery was used to process marine resources. This has been proposed before by Knecht (1995) and Fitzhugh (2001), and is supported by various lines of contextual evidence. Knecht (1995:372–375) based his theory for pottery function on pottery-site dispersal (i.e., on the southeast coast, close to marine mammal migration routes), on ethnographic reports (for an extensive review see: Anderson, 2019), and on the presence of thick greasy crusts that are lacking on contemporary oil lamps, indicating oil rendering versus (already rendered) oil burning. Fitzhugh (2001:154) builds on this and suggests that Koniag pottery was associated with the processing of whale blubber into oil. He suggests that "mass production of whale oil could have fed a developing trade network across the island and beyond, in which salmon from the more productive Karluk and Ayakulik rivers was traded for oil".

B. Koniag pottery was used to process salmon. Kodiak Island is home to some of the world's largest salmon rivers, located in the southwest of the island. The surplus harvesting of salmon is a practice known to have intensified during Koniag times (Partlow, 2000; West, 2009). Seasonal resource spikes were accompanied by the pressure to quickly harvest and process large quantities of resources (Fitzhugh, 2002; West, 2009). Pottery could have played a role in this process (e.g., for cooking, fermenting or oil rendering). This function is not unknown in Alaska among both early and late prehistoric ceramic traditions (Anderson et al., 2017).

The detailed archaeological record from Kodiak Island offers the opportunity to investigate both how and why pottery was adopted here during a period of major socio-economic transformation. We will do so through organic residue analysis of Koniag pottery, spatial analysis and integration of our results with contextual information.

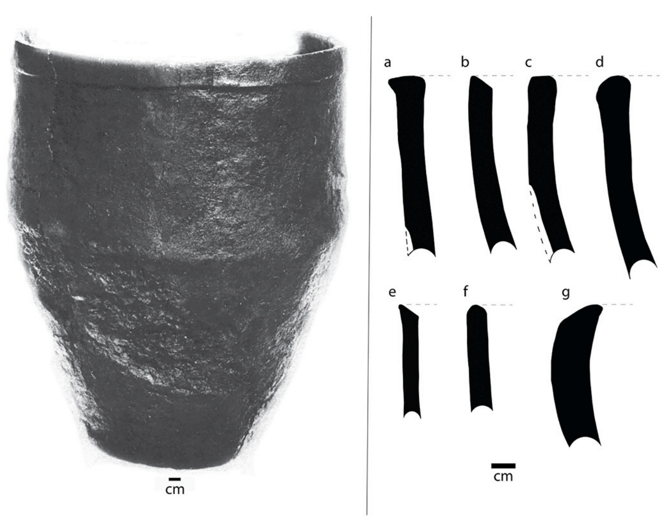


Fig. 2. left: Koniag pottery (33 cm high) from the Rolling Bay site: adapted from: Clark (1966b:Fig. 7), courtesy of the University of Wisconsin Press; right: cross sections of rim sherds from the Karluk One site, catalog numbers: a) 203, b) 797, c) 590, d) 621, e) 28, f) 94:2731, g) 95:1800, exteriors on the left.

4. Material and methods

To test these two models we investigated Koniag pottery through lipid residue analysis and stable isotope analysis. Clarifying pottery function is an essential step in understanding why pottery was adopted, or why it was not (Skibo, 2013). Organic (lipid) residue analysis has proven to be an excellent tool to investigate this, by determining the past contents of the pottery and subsequent function (Correa-Ascencio and Evershed, 2014; Evershed, 2008). Through lipid residue analysis we will be able to determine whether Koniag pottery was in fact used to process aquatic species, by identification of unique biomarkers in the lipid profile. Furthermore, by applying bulk and compound specific isotope analysis we will be able to cautiously differentiate within the aquatic spectrum between: a) marine species, including mammals and marine fish (enriched values), b) freshwater fish (depleted values), and c) anadromous fish (intermediate values). A detailed description of the method is found in Appendix A.

4.1. Sampling strategy

We collected samples from 30 Koniag vessels from a selection of 11 sites from the Kodiak Archipelago (Supplemental Table 2). In our sampling strategy we focused on sites that yielded abundant pottery and had good contextual information (Table 2). We collected samples from sites in the southwest (n = 5) and the southeast (n = 5), including coastal environments (n = 5), riverine settings (n = 2) and coastal sites on large river mouths (n = 3). We also collected samples from Koniag pottery at the Sand Mesa site on Chirikof Island, a distant and isolated island some 100 km to the southwest of Kodiak Island where people of the Koniag tradition lived and travelled frequently (Saltonstall and Steffian, 2005; Witteveen and Birch Foster, 2016). While the majority of the sampled

Table 2
Information of sampled sites (see Supplemental Table 2 for more extensive sample information).

Site name	Site ID (AHRS)	Location	Environment class	Archaeozoological information	Total pottery sherds
Karluk One	KAR-00001	SW - Karluk River	River mouth	**Salmon**, also Pacific cod and halibut	79
Old Karluk	KAR-00031	SW - Karluk River	River mouth	**Salmon**, also Pacific cod	10
Lower Flats Village	KAR-00187	S - Ayakulik River	Riverine	**Salmon**, also clam	113
Kusuuq Taquka'ag	KAR-00232	S - Ayakulik River	Riverine	**Salmon**, also: cod, irish lord, elderberry	13
Upper Station	KAR-00009	S - Olga Lake	Riverine	**Salmon**, also porpoise, whale, bear, seal, sea lion, bird, mussels, clam, flatfish, sea urchin	6
Rolling Bay	KOD-00101	SE - Sitkalidak Island	Coastal	**Marine**: whale, fur seal, harbor seal	>137 vessels
Younger Kiavak	KOD-00099	SE - Kiavak Bay	Coastal	**Marine:** whale, harbor seal, sea lion, sea otter	642
Refuge Rock	KOD-00450	SE - Sitkalidak Island	Coastal	**Marine:** fur seal, porpoise, herring, irish lord, Pacific cod, halibut, invertebrates	512
Kumluk	KOD-00478	SE - Midway Bay	Coastal	**Marine:** cod, marine mammals; also: salmon (limited)	196
Three Saints Bay	KOD-00083	SE - Three Saints Bay	Coastal	**Marine:** whale, seal, sea lion, porpoise, cod, flatfish, salmon, berries, roots. Domesticates: cows, goats, cabbage, potatoes.	200
Sand Mesa	XTI-00096	Chirikof Island	Coastal	**Indet.** Mention of ground squirrel, salmon	2

sites are prehistoric, the Three Saints Bay and Upper Station sites were historic settlements, and the Rolling Bay and Younger Kiavak sites extended from prehistory into the historic period. In total we collected 70 samples (35 ceramic, 35 foodcrust) from 30 pottery vessels, as well as 2 soil samples for reference, and a sample of (archaeological) berry seeds (Supplemental Table 2).

5. Results and interpretation of organic residue analysis

5.1. Lipid biomarkers

In order to determine the original contents of the pottery vessels, lipids (fats, oils and waxes) were extracted from samples of ceramic powder, as well as from adhering foodcrust samples, using an acid/methanol extraction procedure based on established protocols (Papakosta et al., 2015; Craig et al., 2013; Appendix A). All 73 samples were analysed by Gas Chromatography-Mass Spectrometry (GC-MS), and showed exceptional preservation with very high lipid concentrations: ceramic samples range from 25 to 6013 μg g^{-1} (mean = 2050 μg g^{-1}) and foodcrust samples from 391 to 52,313 μg g^{-1} (mean = 13,312 μg g^{-1}; Supplemental Table 3).

As expected, all samples exhibit a full range of aquatic biomarkers (i.e., indicators of the processing of aquatic species) consisting of ω-(*o*-alkylphenyl) alkanoic acids (APAAs) of carbon length 16 to 22, and all three isoprenoid fatty acids. APAAs (C_{20-22}) are formed during the prolonged heating at <270 °C of polyunsaturated fatty acids that occur in aquatic organisms (Hansel et al., 2004). Because APAAs do not form unless they are extensively heated, the presence of these compounds suggests the anthropogenic use of the vessel to process aquatic resources, and excludes the possibility of contamination. Isoprenoid acids are degradation products of phytol, originating from phytoplankton, and are compounds that are widely distributed in marine organisms. However, phytanic acid is also present in ruminant animal tissues. The proportion of SRR diastereomers of phytanic acid (SRR%) allows to differentiate between these sources (Lucquin et al., 2016b). The vast majority of Koniag pottery has high SRR% values, indicative of an aquatic origin of phytanic acid (Fig. 3). Two samples from Chirikof Island stand out with values that are more expected for ruminants, possibly reflecting contamination by the modern cattle on the island. Interestingly, SRR% values seem to differ slightly among sites, with lower values at the riverine sites of Kusuuq Taquka'ag (84.2) and Lower Flats Village (88.5), and high values at the coastal sites of Three Saint Bay (mean = 94.7), and Refuge Rock (mean = 96; Fig. 3), possibly this reflects the difference between high trophic marine mammals and

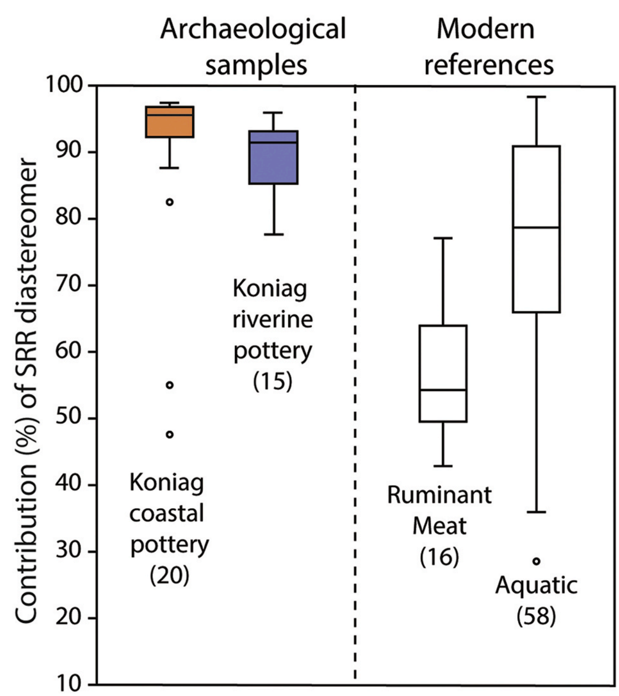


Fig. 3. Percentage of SSR diastereomer in total phytanic acid in Koniag pottery from coastal settings (orange) and riverine settings (blue), compared with modern ruminant and aquatic resources (Lucquin et al., 2016b). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

anadromous fish values, however this needs further research.

Further evidence for the processing of aquatic resources is seen in the presence of dihydroxy acids in acid extracts, following conversion to their TMS esters. These compounds are the degradation products of Z-monounsaturated alkanoic acids (Hansel and Evershed, 2009; Hansel et al., 2011). Dihydroxy acids were identified in 19 of 34 analysed samples. Of particular interest is the presence of 11,12-dihydroxydocosanoic acid in 10 of these samples. This compound derives from 11-docosenoic acid (cetoleic acid), the most abundant $C_{22:1}$ fatty acid isomer in aquatic organisms. Combined, these results constitute unequivocal evidence for the processing of aquatic resources in these pottery vessels.

The evidence for the processing of plant resources in the pottery is very limited. The presence of sterols (e.g., 7-dehydro-Stigmasterol, Stigmasta-3,5-diene, β-Sitosterol acetate) in five of the pottery samples may indicate some addition of plant materials, as does the presence of trace amounts of mid to long-chain alkanes, but mostly this contribution appears to be negligible. Interestingly, an archaeological sample of berry seeds (KAR1-3004 - possibly salmonberry), not associated with pottery, from House Floor 1 at the Karluk One site presented both aquatic (TMTD, phytanic acid) and plant biomarkers (e.g., α-Amyrin, Friedelan-3-one, β-Sitosterol: see Supplemental Table 3), and may form direct evidence for the practice of preserving berries in sea mammal oil as described by Knecht (1995:82).

5.2. Bulk stable isotopes

The bulk carbon and nitrogen stable isotope data of foodcrust adhering to the pottery (Fig. 4; Supplemental Table 4) further supports the overall aquatic nature of the samples with 90% (26/29) of the $\delta^{13}C$ values above −25‰. These results are comparable to other sites in coastal regions where pottery was used to process aquatic resources (e.g., Farrell et al., 2014; Gibbs et al., 2017; Shoda et al., 2017). Nitrogen in the charred residues is derived from proteins and reflects the trophic level of the organism that was processed in the vessel although it is conceivable that $\delta^{15}N$ values are affected by diagenetic alteration (Craig et al., 2007). $\delta^{15}N$ values of our samples are, except two, all above 10‰ (i.e., ranging from 9.34 to 16.61‰, see Fig. 4) indicative of aquatic organisms, at the lower end of the marine range. These results are in line with reference data of anadromous fish, or non-ruminant species such as brown bear which are also known to have been exploited by people of the Koniag tradition for their meat, fat (i.e. tallow), gut, hides and dense, thick bones (Knecht, 1995:79). Interestingly, pottery from riverine sites generally produced slightly lower $\delta^{15}N$ values than coastal sites. Marine mammals with relatively lower trophic levels such as bearded and ringed seal, bowhead, right and fin whale, sea otter, and walrus, have corrected nitrogen values that range from 11.82 to 21.09‰ (based on reference values from: Admiraal et al., 2019; Byers et al., 2011; Coltrain et al., 2004). 90% (26 of 29 analysed foodcrust's) of the Koniag pottery samples fall within this range.

Atomic C/N ratios may indicate the contribution of proteins versus lipids and/or other non-nitrogenous compounds such as carbohydrates. Although highly variable, the atomic C/N ratios of all Koniag pottery food crusts are relatively high, indicative of a high lipid content, when compared to pottery from Sakhalin Island thought to have been used for cooking protein rich aquatic tissues (Gibbs et al., 2017). Our results are more comparable to stone bowls from the Aleutian Islands, thought to have been used to render marine mammal fat into oil (Admiraal et al., 2019), as well as to European Mesolithic 'blubber lamps' thought to have been used to burn marine mammal oil (Heron et al., 2013). This hints at a similar function for Koniag pottery. Other scenarios may also explain the increased atomic C/N ratios in our samples. These may be the result of the processing of plants (i.e., low in protein, high in carbohydrates; Bondetti et al., 2019), microbial degradation, or percolation by groundwater (Heron and Craig, 2015).

5.3. Compound specific isotopes

Lipid biomarkers and bulk isotope values provide unequivocal evidence for the processing of aquatic resources in Koniag pottery. By analysing stable isotopes of individual fatty acids $C_{16:0}$ and $C_{18:0}$ we further differentiate within the aquatic spectrum based on habitat (marine, anadromous or freshwater). $\delta^{13}C$ values of marine species (mammals and marine fish) are relatively enriched when compared to anadromous species such as salmonids, and even more so when compared to freshwater species. In the introduction we proposed two models for Koniag pottery function, A: to process marine resources, and B: to process salmon; both major subsistence strategies on Kodiak. The compound specific isotope results allow us to test this and show that Koniag pottery was used for both (Fig. 5; Supplemental Table 4).

5.3.1. Evidence for the processing of marine resources

The majority of samples are distributed within the marine range (70%), and many of these samples are from coastal sites. However, marine results were also obtained from pottery from sites where seasonal salmon-harvesting is well documented, such as at Karluk One (Steffian et al., 2015) and Old Karluk, here classified as riverine because of their prominent location on the highly productive Karluk River mouth (Table 2; Steffian and Saltonstall, 2016). In fact, the analysed pottery sherds from Old Karluk were found in a midden of exclusively salmon bones (Steffian and Saltonstall, 2016; West, 2009), but still plotted marine. Interestingly, the Karluk One house (HP1) where the pottery was found, also yielded most of the oil lamps found at the site, as well as a lot of sea mammal hunting gear. This may represent a resurgence in sea mammal hunting at this site during the Little Ice Age (Knecht,

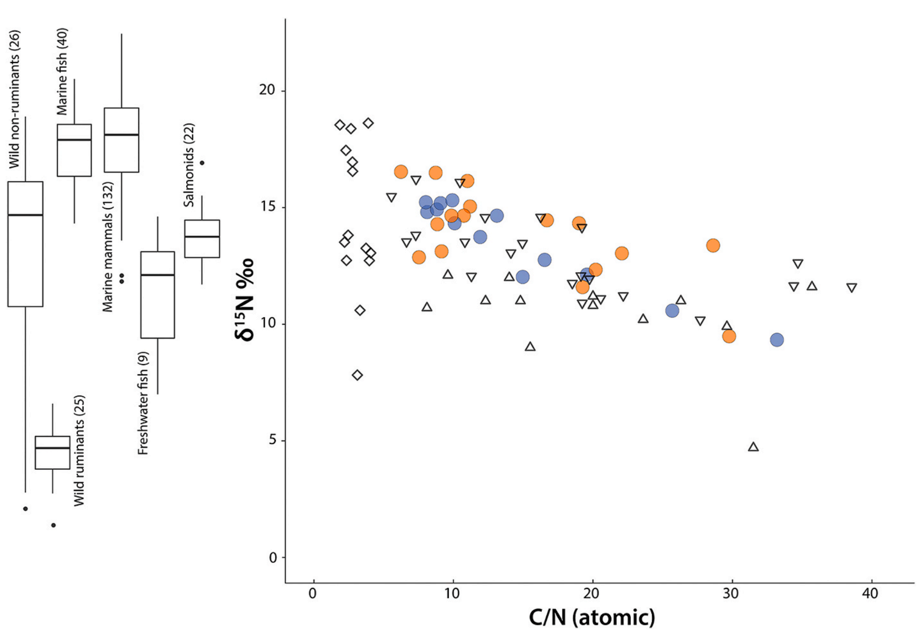


Fig. 4. Bulk isotope results of Koniag pottery from coastal settings (orange circles) and riverine settings (blue circles) compared with Sakhalin pottery (open diamonds; Gibbs et al., 2017), European oil lamps (open upward triangles; Heron et al., 2013; Piezonka et al., 2016; Oras et al., 2017), and Aleutian stone bowls (open downward triangles; Admiraal et al., 2019) against archaeological bone collagen reference data from northern North America (Admiraal et al., 2019; Britton et al., 2013; Byers et al., 2011; Choy et al., 2016; Coltrain et al., 2004, 2016; Misarti et al., 2009; West and France, 2015). The collagen $\delta^{15}N$ values were adjusted by +2‰ to correct for the collagen to tissue offset in order to make these values more comparable with the food crusts (Fernandes et al., 2015). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

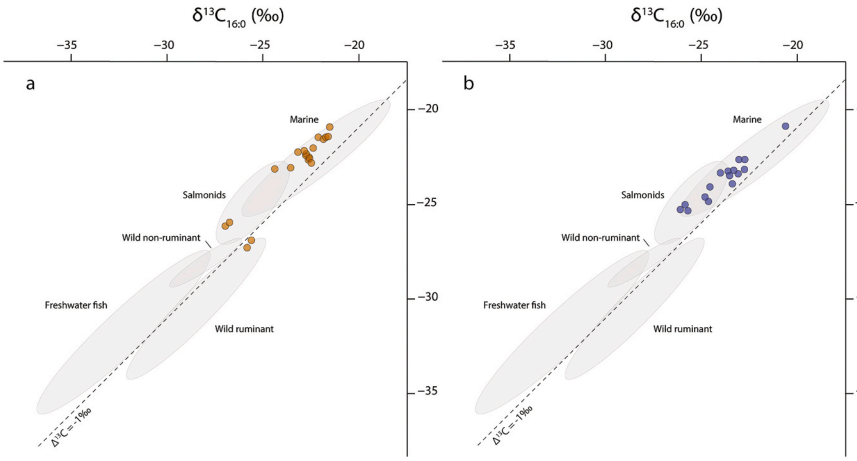


Fig. 5. Gas chromatography–combustion–isotope ratio mass spectrometry results showing isotopic values of $C_{16:0}$ and $C_{18:0}$ fatty acids of Koniag pottery from (a) coastal sites (orange: Rolling Bay; Three Saints Bay; Chirikof Island; Kumluk; Refuge Rock), and (b) riverine sites, including inland and river mouth locations (blue: Upper Station; Karluk One; Old Karluk; Lower Flats Village; Kusuuq Taquka'ag). This data is compared to reference data of modern tissue and bone from the Northern Hemisphere plotted in 68% confidence ellipses (Choy et al., 2016; Craig et al., 2011; Cramp et al., 2014; Horiuchi et al., 2015; Lucquin et al., 2016b; Paakkonen et al., 2017; Spangenberg et al., 2010; Taché and Craig, 2015). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

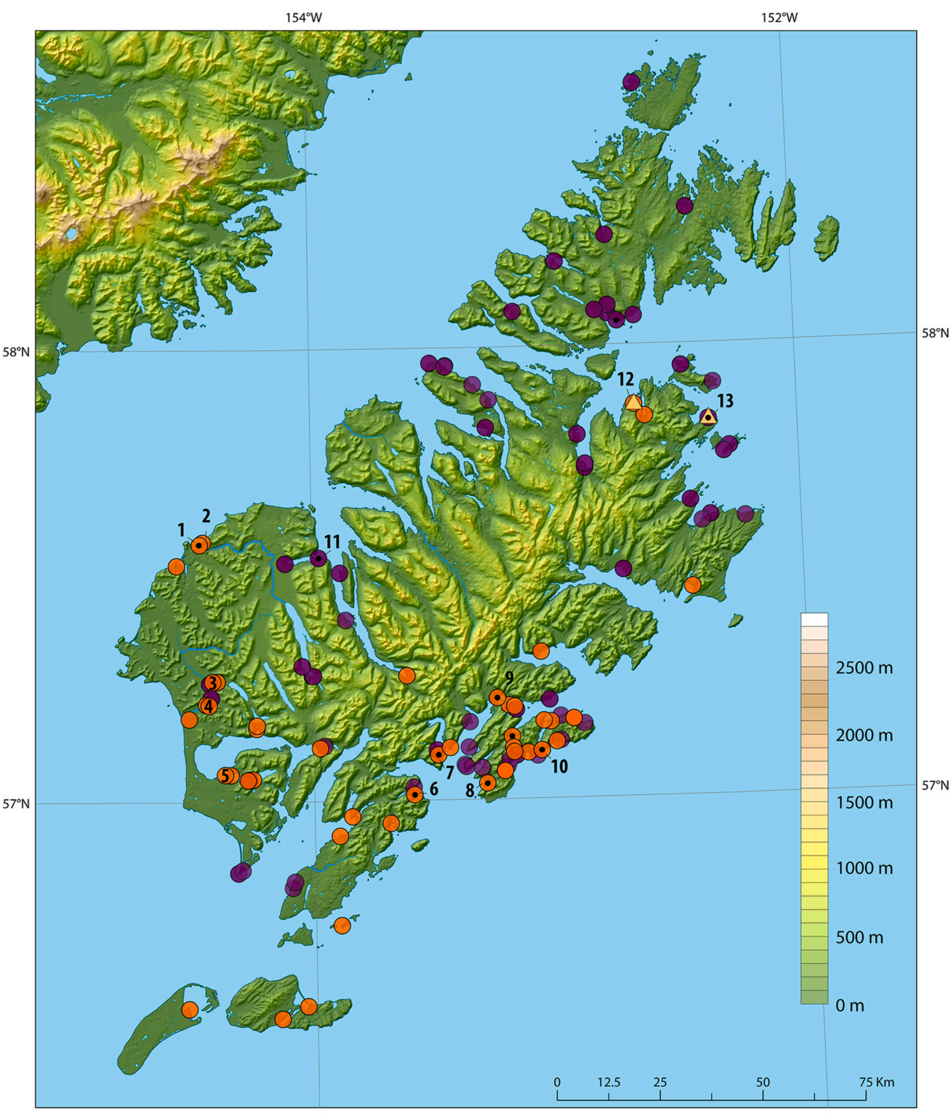


Fig. 6. Map of Kodiak Island showing Koniag sites with pottery (orange) and without pottery (purple). Black dots refer to the presence of clay-lined pits at Koniag sites, yellow triangles refer to isolated finds of Norton pottery during the Late Kachemak period. Marked sites sampled for this study: (1) Karluk One, (2) Old Karluk, (3) Lower Flats Village, (4) Kusuuq Taquka'ag, (5) Upper Station, (6) Younger Kiavak, (7) Three Saints Bay, (8) Rolling Bay, (9) Kumluk, (10) Refuge Rock. Non-pottery sites mentioned in the text: (11) the Uyak site, (12) Crag Point, (13) Monashka Bay 1 (see Supplemental Table 5). Map by Frits Steenhuisen. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

1995:321), although it is not possible to make a distinction between marine fish (excluding anadromous species) and marine mammals on the basis of our results. Contextual site information provides support, with an abundance of whale and pinniped bones present at the Rolling Bay and Kiavak sites on the outer coast, while marine fish (i.e., cod) is abundant in the faunal assemblages at Kumluk and the historic Three Saints Bay site, sites that are on the coast, but somewhat more sheltered. At the sacred site of *Awa'uq* (meaning: 'to become numb' in Alutiiq

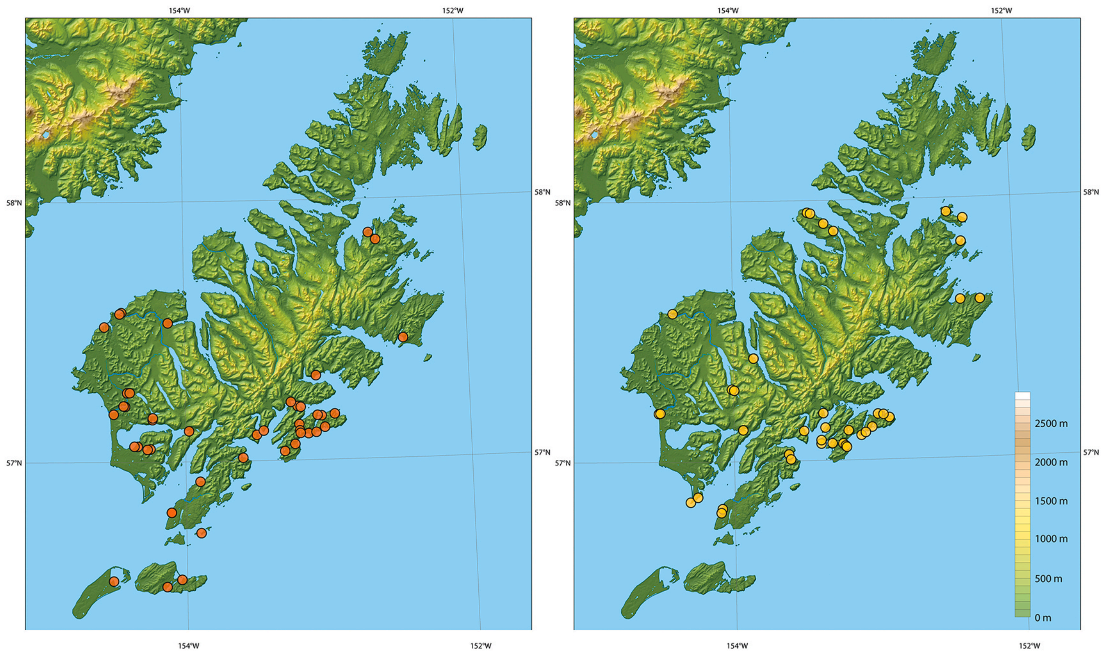


Fig. 7. (left) Koniag sites with pottery: orange, (right) Koniag sites with reported whale bones: yellow. Based on data from the Alaska Heritage Resources Survey database (AHRS, 2020) (see Supplemental Table 5). Map by Frits Steenhuisen. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

language) or "Refuge Rock", pottery was presumably used to store water during the Russian attack, and subsequent bloodbath led by Gregori Shelikhov in August 1784 (Knecht et al., 2002). However, rich concentrations of lipids show marine values. Possibly the pottery had another function before the tragic event on Refuge Rock, where there is also abundant evidence for marine mammal hunting, especially fur seal (Etnier, 2011).

5.3.2. Evidence for the processing of riverine resources

Some samples show more depleted values that are comparable to modern salmonid values, correlation to the bulk isotope results of these samples shows high variability. It is not surprising that these more depleted $\delta^{13}C$ values are all found at riverine sites that have been defined as salmon fishing settlements (Table 2). To illustrate, at Kusuuq Taquka'ag and Lower Flats Village salmon was the most abundant species in faunal assemblages (>95%; Steffian and Saltonstall, 2001). Interestingly, at Lower Flats Village a pottery vessel was excavated with clams and other marine foodstuffs still inside the vessel. A single sample of this site showed depleted carbon isotope values indicative of anadromous fish or mixing. It is possible that the fattier salmon lipids overshadow the marine signals from less lipid rich resources like clam. More extensive testing is needed to explore the contribution of seafood at this site. The pottery from Chirikof Island, the southwest extreme of Koniag pottery occurrence, also showed salmonid values, while one sherd plotted marine.

5.3.3. Evidence for the processing of ruminant animals

Interestingly, there are two samples that show $\delta^{13}C$ values indicative of the mixing of ruminant and marine resource. These samples are from the coastal sites of Three Saints Bay and Rolling Bay, both known to have extended into the historic period (Clark, 1966b). At the Russian settlement of Three Saints Bay domesticated animals, including cattle and goat, were present. While these animals are thought to have been exclusively for consumption by the Russian settlers (Crowell, 1997), it is possible that they were processed by the Alutiiq people living at this site, in their traditional pottery, and along with aquatic resources as reflected in the lipid profiles of these samples (Supplemental Table 4).

5.3.4. Evidence for the processing of plants

Very few of the samples yielded plant biomarkers (n = 5, see Supplemental Table 3), and only one sample provided multiple biomarkers indicative of plants (RB53-80: 7-dehydro-Stigmasterol, β-Sitosterol acetate, Stigmasta-3,5-dien-7-one). This lack of plant biomarkers may be the result of masking as lipid concentrations in starchy plants and legumes are relatively low compared to other macronutrients (i.e., carbohydrates and proteins). Therefore, when mixed with aquatic oils, the lipid component of these plants may be difficult to detect using isotopic approaches (Reber and Evershed, 2004).

Interestingly, the offsets between fatty acid $\delta^{13}C$ values (e.g. mean $\delta^{13}C_{16:0\text{-}18:0}$) and the corresponding bulk $\delta^{13}C$ values in foodcrusts from the same sherds were highly variable ($\Delta^{13}C_{16:0\text{-}18:0\text{-}bulk}$; −3.84 to 2.93; see Supplemental Table 4). Samples with smaller offsets (n = 14; −0.70 to 0.93) generally had higher atomic C/N ratios (mean ~16.8). This is expected were the foodcrusts are mainly formed from fatty adipose tissues or aquatic oils, as both analytic techniques are, in effect, measuring the $\delta^{13}C$ value of the lipid component. In contrast, foodcrusts derived from a higher proportion of protein-rich tissues, such as fish muscle protein, would be expected to have a higher $\Delta^{13}C_{16:0\text{-}18:0\text{-}bulk}$ offset due to isotopic difference between lipids and proteins. Indeed, larger offsets were observed in 12 samples all with relatively lower C/N ratios. Three Koniag pottery samples (KOD450-84; RB53-80; and KAR31-74) yielded a positive offset between 1.43 and 2.93, and a high C/N ratio (19.2–29.7) and relatively lower $\delta^{15}N$ values (9.5–12.15; Supplemental Table 4). Such values may indicate that the foodcrust was formed from charring both aquatic oils and starchy plants. One of these samples (RB53-80) contained plant biomarkers (Supplemental Table 3), providing some corroborative evidence. Ethnographic information addresses the frequent mixing of plant resources with aquatic oils during contact times on Kodiak Island, including ground roots rich in carbohydrates (Holmberg, 1985:42). Due to a lack of more widespread occurrence of plant biomarkers, this discussion remains highly speculative. Nonetheless, comparing $\delta^{13}C_{16:0\text{-}18:0}$ to $\delta^{13}C$ bulk values is an interesting avenue of interpretation that deserves additional research.

6. Discussion

6.1. Patterns: integration of results and spatial analysis

6.1.1. Functional patterns

The analysis of 30 Koniag pottery vessels from 11 sites have yielded consistently clear results. All pottery was used to process aquatic resources, while the addition of ruminant resources is evident at the historic Three Saints Bay and Rolling Bay sites. Two models were presented in the introduction: (a) pottery was used to process marine resources; (b) pottery was used to process salmon. Compound specific isotope results have allowed for differentiation between these sources. While our data supports both, a majority of 70% supports a marine function for Koniag pottery. Some samples are slightly more depleted than others, this indicates a varying contribution of anadromous fish to these samples. As plant biomarkers were very few in these samples, we deem it unlikely that this caused their depleted nature, although it is possible that masking complicated the identification of these compounds, that are not as rich in lipids as their aquatic counterparts. With the exception of the Chirikof Island samples, all substantive pottery sites on the southeast coast presented marine results. Anadromous results are limited to inland and southwest sites on the Karluk River mouth, and in most cases still show evidence of mixing with marine sources.

6.1.2. Spatial analysis of pottery distribution

To better understand the uneven distribution of pottery on Kodiak Island, and the variability in our organic residue results we explored patterns in site distribution and function through spatial analysis. We selected a total of 107 Koniag sites from the Alaska Heritage Resources Survey database (AHRS, 2020; Supplemental Table 5), based on credibility and testing extent. We then plotted ceramic (n = 43) and non-ceramic (n = 64) Koniag sites on a map (Fig. 6). Sites with pottery clearly cluster into the southern part of the island, especially in the southeast. Most of the north lacks pottery, with a few exceptions (AHRS, 2020; Clark, 1970).

We then classified the pottery sites into *coastal* (74% n = 32) and *inland* (26% n = 11) to understand geographic diversity. The coastal sites are diverse and include locations such as sheltered landing areas in bays and deep inlets, but also defensive sites and smaller islands, and some on river mouths. The inland sites are all located near freshwater sources, either at major salmon rivers, smaller streams, or at large inland lakes. To get a sense of the intensity of pottery use between coastal and inland sites we selected sites with a substantial number of sherds (>50), and a relevant presence of pottery (>10%) relative to the total number of artefacts (sherds/artefacts). This includes Three Saints Bay (11%, 200/1813), Kumluk (56%, 196/350), Refuge Rock (57%, 512/902), and Lower Flats Village (93%, 113/122). Of all Koniag sites, pottery was most abundant at the Rolling Bay site with an estimated minimum of 137 vessels (no number of sherds specified), and at the Younger Kiavak site with at least 59 vessels (48%, 642/1335; Clark, 1966a). The majority of sites with intensive pottery use are located on the southeast coast (n = 5), only Lower Flats Village is located inland (Fig. 6). In the southwest pottery is less abundant, with a glaring absence at sites on the well-surveyed Karluk River (excluding the Karluk One and Old Karluk sites on the Karluk River mouth), but showing a relative abundance at the Ayakulik River (Steffian and Saltonstall, 2004).

6.1.3. Understanding the spatial correlation of whaling and pottery use

The migratory routes of sea mammals may play a significant role in pottery distribution as suggested by Knecht (1995:375). Grey whales, humpback whales and fur seals are known to follow the Alaska Current, bringing them close to Kodiak's southeast coast where they often stop to feed in one of the many sheltered bays. Furthermore, the colder temperatures of the Little Ice Age (ca. 1350–1900) may have shifted some migratory routes of sea mammals further offshore, making other areas unsuited for hunting these species (Knecht, 1995). To explore the relationship between whaling and Koniag pottery we plotted occurrences of whale faunal elements at Koniag sites (AHRS, 2020) on a map (Fig. 7; Supplemental Table 5). We excluded whale bone tools, which may have been widely dispersed throughout the island. The sites (n = 31) are not necessarily whaling sites, but present whale faunal material in a Koniag context. Nonetheless, our simple spatial analysis does confirm that these sites cluster along the southeastern coast, especially on Sitkalidak Island. Interestingly, while there is no significant intra-site co-occurrence of pottery and whale remains (n = 9 of 43 pottery sites), the general distribution across the island matches the location of pottery sites very closely (Fig. 7). This could reflect different locations of butchering whales versus large settlements where the resources (e.g., meat and blubber) would have been transported to.

6.2. Koniag pottery function

Knecht (1995:375) and Fitzhugh (2001:154) suggested that Koniag pottery was used for the rendering of marine mammal (whale) oil, a function that is supported by the majority of our lipid data. The ability to directly heat pottery was a great advantage in this process, and Koniag pottery would have provided the capacity to process the large amounts of resource provided by these big mammals. Blubber (fat) could be rendered into oil using two methods: 1) by storing it in pits where it slowly self-rendered into oil, a method with a success rate highly dependent on stable local temperatures, and above all, time consuming (Frink and Giordano, 2015; Admiraal et al., 2019); or 2) by hot-rendering using a container over direct heating (Admiraal et al., 2019). The technological advantage of pottery in the process of fat-rendering offered control and saved time, which allowed scaling up and intensifying the practice. This resulted in more oil for the local people, but also greater surplus of this valued commodity for interregional trade as is well-documented ethnographically in the wider Gulf of Alaska region along the highly territorial "grease trails" (Davydov, 1977:3; De Laguna, 1978:209; Hirch, 2003).

Oil was a commodity of major importance to communities in environments where fresh vegetables, that provide essential nutrients and vitamins, are scarce (Admiraal and Knecht, 2019; Frink and Harry, 2008; Hirch, 2003; Johnson, 2004), and its importance in the Koniag tradition is evident in ethnohistoric sources. Davydov (1977:175) states that "without [oil] they could barely exist and would never be happy". They consumed it directly, by dipping dried salmon in sea mammal oil. Knecht (1995:89) describes this as the Koniag "staple food … which provided both calories and protein". A traditional delicacy consists of berries, mixed with mashed fermented fish eggs, and seal oil (Knecht, 1995:82). Davydov (1977:175) reported that strips of blubber were chewed by elderly people and children, they spit the fat in a container and cooked it with berries and ground roots. This mixture was then stored in a seal bladder for consumption in winter (Holmberg, 1985:42). Furthermore, storage strategies of plant resources, such as edible roots, stems, berries and leaves, generally involved the use of oil (Davydov, 1977:175; Fitzhugh, 2003:31; Holmberg, 1985:41–42). Merck (1980:160) describes: "From August to September they pick berries … There is a kind of sorrel which they squash and boil until it is thick. They store it in holes in the ground in layers, together with whale blubber, for the winter". Finally, oil was used as fuel to burn in lamps for heating and light. An account by Khvostof and Davydov (1810:104) possibly refers to the use of lamps or pottery: "From clay they make saucers in which they burn whale fat" (see Heizer, 1949:48).

Thus, oil was used for direct consumption, for storage purposes, and as fuel. But how was it made? We argue that this was the specialized function of Koniag pottery vessels, as suggested before by Knecht (1995) and Fitzhugh (2001). It was inherently connected to the intensification of (whale) oil production in large coastal sites where pottery was abundant, on the outer southeast coast of Kodiak Island. These statements are supported by our lipid residue results that indicate marine resource processing on the southeast coast, and show high lipid concentrations and high C/N ratios, reflective of the processing of an oily substance.

6.2.1. Functional insights into “rival” technologies

Exploring the function of other, similar technologies can shed light on the use strategies of pottery. A variety of storage and processing pits, as well as a few bowls and spruce-root baskets from well-preserved sites (e.g. Karluk One), are known for the Koniag tradition. Some storage pits are lined with baleen and rye grass, and are often filled with the remains of invertebrates (e.g., clam, mussel, chiton, sea urchins) (Knecht, 1995:718), reflecting a possible use for (dry) storage. Of interest here is the use of clay-lined pits, or *Chekalina,* as they were called by the Athabascan Indians of Cook Inlet (Birket-Smith and De Laguna, 1938:445; Heizer, 1956:30; Rostlund, 1952). These pit-features are widely known in both Kachemak and Koniag contexts throughout the archipelago (Steffian et al., 2006), and co-occur with pottery at several of the sites tested here (i.e., Karluk One, Younger Kiavak, Three Saints Bay, Kumluk, and Refuge Rock; see Fig. 6). We showed that the pottery at these sites was used to process marine resources, likely to render oil. As it seems unlikely that two rival-technologies would co-occur at the same site, we suggest that clay-lined pits had a different function, supporting Heizer’s (1956:30) similar statement.

Processing mass-harvested resources needed to be done efficiently and fast. Primary methods of the Koniag tradition to process fish included fileting, drying and smoking, and finally storage in a separate room of the house, or storage structure (Holmberg, 1985:41). Other known methods of processing aquatic resources are fermentation and oil rendering, which requires the use of a container. Clay-lined pits are thought to have been used for fermentation (Birket-Smith and De Laguna, 1938; Heizer, 1956). Ethnohistoric sources report: “Salmon were put into them, allowed to decay, and permitted to freeze once. The freezing killed the maggots and the mass was then considered edible” (Heizer, 1956:30). Indeed, they first appeared during the Kachemak, when surplus salmon harvesting was first introduced (Steffian et al., 2006, Table 1), and the pits became larger during the Early Koniag when fishing practices intensified (Knecht, 1995:718). However, pits were likely used to store and process a variety of resources, Holmberg (1985:41) reports that whale meat was cooked and then stored in “holes in the earth” where it was left to ferment. Indeed, also Merck (1980:160) discusses “holes in the ground”, used for the storage and fermentation of mixtures of berries and aquatic fats. The use of clay-lined pits for storage and fermentation seems suitable, as no direct heating is required. Pottery, on the other hand, was an ideal tool for the hot-rendering of oil (Admiraal et al., 2019; Frink and Giordano, 2015).

6.3. Processes: socio-economic drivers of pottery adoption

We have argued that Koniag pottery was a specialized tool for the rendering of whale fat into oil with a major benefit over other container technologies being the ability to directly heat pottery. This could have made pottery a welcome innovation in a community that dealt with the processing of surplus products such as whale blubber. This function is linked to cuisine, storage, and fuel. While its function partly explains the uneven distribution of pottery across Kodiak Island, connected to Koniag whaling activities (Fig. 7), fatty marine mammal resources needed processing throughout the entire island, and so several social processes involving the adoption of pottery need to be considered.

6.3.1. Status, aggrandizers and intensified social competition

While pottery has important benefits that undoubtedly played a significant role in its adoption in a need-based context, the role of social drivers of pottery adoption on Kodiak Island are significant (Brown, 1989; Frink, 2009; Hoopes, 1995). The delayed-return, storage-based economy of the Koniag tradition presented an ideal setting for the introduction of an innovative technology that could not only increase efficiency, but also add to social status and wealth (Fitzhugh, 2003:113; Morgan, 2015; Yesner et al., 1980). The use of pottery links to the socio-politics of surplus resources, especially valued ones, in trans-egalitarian marine societies. Whale oil was such a commodity, derived from the competitive practice of whaling in the southeast (Crowell, 1994; Heizer, 1938; Lantis, 1938). It was accumulated, controlled, and redistributed and might have led to a renowned status of the coastal communities in this part of Kodiak. Oil was important in feasting as well as in routine household activities, and pottery allowed for its intensified and controlled production.

6.3.2. Expanding regional socio-political interaction spheres

During the Koniag tradition interaction spheres in Southwest Alaska expanded. Increased raiding, and inter-marriages with groups from the mainland could have introduced, or intensified, influences. Especially a household/processing technology like pottery, assumingly associated with women’s tasks (Frink, 2009), could have entered Kodiak through inter-marriage. It has been suggested by Clark (1966b:173) and Fitzhugh (2003:129) that variation within the Koniag tradition on opposite ends of the island, reflect influences in the south from pottery-using prehistoric groups on the Alaska Peninsula, while interaction spheres in the north were more directed towards the Kenai Peninsula, Prince William Sound, and wider Southeast Alaskan Tlingit communities. These communities did not use pottery but were known to transport oil in sea lion bladders (Gideon, 1989:80). Dumond and Scott (1991) argued a similar scenario, identifying the pottery using groups from the densely populated Ugashik River and Becharof Lake area on the Alaska Peninsula as ancestral to the Ceramic Koniag, explaining the limited uptake of pottery on Kodiak Island.

On the Alaskan mainland, marine mammal oils are historically well-known to have been traded from coastal communities to the inland (Hirch, 2003). It is quite possible that a similar situation existed on Kodiak, where whale oil from the southeast coast was traded to other regions on the island, as proposed by Fitzhugh (2001:154). This may be reflected in the low numbers of pots at inland sites, indicating that these pots were possibly not produced there, but brought in holding a trade product such as whale oil. Subsequently, the pottery may have been reused to process more local resources such as salmon, resulting in more depleted carbon isotopes, as seen in our data. This pattern becomes especially apparent when considering the contrast with the southeast coast, where the use of pottery was much more systematic with much higher pottery abundance (e.g., at least 200 vessels at Rolling Bay and Younger Kiavak combined; Table 2). It would be of interest to source Koniag pottery clay origins, to further explore this hypothesis.

6.3.3. Social boundaries within Kodiak Island

We argue that a particular activity region was in place along the southeastern coast of Kodiak that included whaling and blubber rendering using pottery. The above discussion however does not fully explain why pottery technology was not transferred to other groups of people on Kodiak. What was happening along the frontiers of this limited pottery adoption area? We explored the existence of social boundaries on Kodiak to better understand the non-adoption of pottery in northern Kodiak. While many similarities in artefact types and stylistic aspects of those artefacts indicate a shared sense of common culture throughout the Kodiak Archipelago, and even the greater Gulf of Alaska (Steffian et al., 2016), some variety in material culture, linguistics and the presence of raw materials illustrates a possible division between the north and south of Kodiak.

Labret styles of the Late Kachemak show spatial differentiation of social identity (Steffian and Saltonstall, 2001:25). Furthermore, a subtle, but culturally significant difference in the Koniag Alutiiq dialect is apparent between the north and south (Fine, 2019; Laktonen-Counceller, 2012). This is compelling, as different dialects may reflect differing social identities within the wider Alutiiq language group (Ochs, 1993). Much like certain stylistic features, artefact types, or raw material use, that also infer spatial differentiation on Kodiak. Saltonstall suggests there may be a deep history of social divisions on Kodiak, as is reflected in the absence of red chert in Ocean Bay sites at Kiliuda Bay and Old Harbor, whereas the raw material is ubiquitous in sites of the same age near Kodiak city (Patrick Saltonstall, personal communication, 2019). Differences between north and south Kodiak are also reflected in the limited occurrence of incised slate figurines, mostly restricted to the northwest during the Transitional Kachemak and Early Koniag (Clark and Isaacs, 1964; Donta, 1995; Heizer, 1952). Most striking however, remains the uneven uptake of pottery technology during the Developed Koniag.

It is very probable that a localized sense of community and social identity played a significant role in the adoption or non-adoption of pottery technology on Kodiak Island. This is seen elsewhere in the world as well, for example among hunter-gatherer groups of the Baltic shores of northern Scandinavia. Here, at the northwestern frontier of pottery dispersal in Eurasia, one group used pottery, while a neighbouring group did not. Hallgren (2009:389) explains the reluctance to adopt pottery by the people of Mälardalen in a simple way: "because they were not people that practiced the craft of pottery", and stresses that social identity is not only defined by the practices we take part in, but also by those we choose not to engage in. On Kodiak Island Clark (1966b:172) observes differences between the Rolling Bay and Kiavak sites, and notes that "there was a high level of variability from community to community". The presence or absence of pottery may be an indicator of such a social identity. Pottery could even be described as a symbol of (group) identity, as it is a highly visible and recognizable artefact class. The adoption of pottery by one group, in itself, may have been the reason for another group to decide not to adopt. The limited distribution of pottery on Kodiak Island, along with other indicators of differences between the north and south, supports this idea of pottery, not only as a useful processing tool, but also as an artefact that is connected to social identity.

6.3.4. *Timing of pottery adoption*

We suggest that the timing of pottery adoption on Kodiak Island is inherent to expanding interaction-spheres and social boundaries. Importantly, Kodiak Island material culture translates into a continuous, highly independent and in situ cultural development (Clark, 1975; Fitzhugh, 2002, 2003:113; Knecht, 1995; Steffian et al., 2016). Nonetheless, contact with the mainland is apparent, even frequent, already in the Kachemak tradition, and knowledge of clay-technology was present in the Early Kachemak period through the use of clay-lined pits (Steffian et al., 2006). Furthermore, two minor, but early finds of pottery are recorded in the north of Kodiak Island at Monashka Bay and Crag Point during the Late Kachemak. This indicates that (limited) knowledge of pottery technology was present on the island as early as 1570 ± 60 BP (Donta, 1995; Clark, 1970; Mills, 1994:143). This illustrates the important role of choice. The adoption of pottery on Kodiak Island was the result of choice, and influenced by a complex combination of processes, including expanding interaction spheres and the intensification of whaling and subsequent trade in whale oil.

7. Conclusion

The adoption of pottery on Kodiak Island was late and spatially restricted to the south. Through organic residue analysis and stable isotope analysis of 30 Koniag pots we have demonstrated that pottery on Kodiak Island was used for the processing of aquatic, mainly marine, resources. We identified spatial patterns of pottery use and sherd abundance, reflecting a *core region* of pottery use on the southeast coast of Kodiak Island. Whaling practices intensified in this specific region, temporally coinciding with pottery adoption. We argue that these phenomena may have been connected, with pottery in demand due to its ability to efficiently render whale blubber into oil, supporting the argument of Knecht (1995:375) and Fitzhugh (2001:154). Indeed, site-based analysis of our residue results showed that pottery in the southeast core region was predominantly used to process marine resources, while pottery at inland riverine locations presented evidence of the addition of anadromous fish to the sample. Possibly, whale oil in pottery vessels was traded to other areas on the island, where the pottery was reused. This could explain deviating isotopic signatures indicating salmonid processing at riverine sites in the southwest.

We argue that the local intensification of whaling and surplus rendering of oil presented a niche for pottery adoption in the southeast, and that external influences (e.g., through inter-marriage) from the Alaska Peninsula inspired the adoption. We further suggest that cultural boundaries on Kodiak Island, linked to different social identities, different economic practices, but also linked to differing external interaction spheres, played an important role in the non-adoption of pottery by northern groups. Differences between the north and south are most pronounced in pottery dispersal, but are in fact also reflected in variability in linguistics, labrets, and use of raw materials. In conclusion, by investigating pottery function and reviewing several other lines of evidence, the reasons for the delayed and partial adoption of pottery on Kodiak Island have become much clearer. Nonetheless, many intriguing questions concerning this subject remain, and offer a wealth of possibilities for novel research in the future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quaint.2020.06.024.

Data availability statement

The authors confirm that the original data presented are made available in the Supplemental Materials of this article (i.e., Supplemental Table 3 (lipid data) and 4 (isotope data)).

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