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Determining Initial Firing Temperatures of Thule Era (1000-250 ya) Pottery from Two Northwest Alaskan Archaeological Sites

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**Determining Initial Firing Temperatures of Thule Era (1000-250 ya) Pottery from Two
Northwest Alaskan Archaeological Sites**

By

Jonathan Duelks

An undergraduate honors thesis submitted in partial fulfillment of the

Requirements for the degree of

Bachelor of Science

In

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And

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Adviser: Dr. Shelby Anderson

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Abstract

This research was conducted to investigate the initial firing temperatures (IFT) of pottery from two archaeological sites in Northwest Alaska. Arctic ceramics are consistently described as low-fired technology in archaeological and ethnographic literature. However, regional and temporal variation in the quality and hardness of arctic ceramics suggests variation in firing temperatures. To describe all Arctic pottery as low-fired ignores variation in firing temperatures and ultimately in the production process. Sherds from two archaeological locales, the Cape Krusenstern site complex and the Ahteut village site, were selected to represent sites with differential access to fuel resources. IFT's were estimated by measuring color change in a stepwise refiring experiment. Preliminary results indicate that a majority of sherds from Cape Krusenstern had lower initial firing temperatures than did sherds from Ahteut. Additionally, this experiment indicates that (1) a majority of the sherds contained residual organic content, (2) shows the effects of the presence of organic content on a refiring experiment, and (3) confirms that vessels from these two sites were originally fired under reducing atmospheres. These results do provide a better understanding of the production process of arctic ceramics. The difference between the initial firing atmosphere and the refiring atmosphere, as well as the presence of organic content, may be masking the true indications of initial firing temperatures. Because of these confounding factors additional research, including alternative methods of estimating initial firing temperatures, are necessary. Beyond reconstructing the production process of Northwest Alaskan ceramics, understanding initial firing temperatures provides important information regarding environmental constraints on the ceramic production process and the methods precontact potters used to overcome them. This work also adds to our understanding of fuel use and management.

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Table of Contents

1 Introduction.....	1
2 Background.....	4
2.1 Brief History of Arctic Pottery Analysis.....	4
2.2 Pottery Production.....	7
2.3 Open Firing	8
2.4 Fuel Use and Availability.....	10
2.5 Ceramic Vessel Use in Ethnographic and Archaeological Contexts	12
2.6 Experimental Research.....	13
3 Study Sites	14
3.1 Cape Krusenstern	14
3.2 Ahteut Site.....	15
3.3 Clay Samples.....	19
5 Methods.....	21
5.1 A Low-Tech Approach To Determining Initial Firing Temperatures.....	21
5.2 Sample Selection	24
5.3 Preparation	24
5.4 Firing	26
5.5 Recording and Displaying Color Measurements	27
6 Results.....	29
6.1 Prefiring Sherd Descriptions	29
6.2 Refiring Results.....	30
7 Discussion	39
7.1 Estimations of Initial Firing Temperatures	40
7.2 The Effect of Atmosphere and Organic Content on Estimating IFT's	44
7.3 Future Research.....	51
8 Conclusion	52
References	55
Appendices.....	59

List of Figures

Figure 1. Map of study area showing Cape Krusenstern site complex, the Ahteut site, and the treeline (treeline generalized from Vierek et al. 1992).....	3
Figure 2. Sample #7 showing a sherd with multiple colors on one surface.....	25
Figure 3. Sample #15 showing an exterior surface color that differs from core color is visible in cross section view.....	26
Figure 5. Change in Hue throughout the refiring experiment for Cape Krusenstern archaeological and raw clay samples.....	31
Figure 6. Change in Value throughout the refiring experiment for Cape Krusenstern archaeological and raw clay samples.....	31
Figure 7. Change in Chroma throughout the refiring experiment for Cape Krusenstern archaeological and raw clay samples.....	32
Figure 8. Change in Hue throughout the refiring experiment for Ahteut site archaeological and raw clay samples.....	32
Figure 9. Change in Value throughout the refiring experiment for Ahteut site archaeological and raw clay samples.....	33
Figure 10. Change in Chroma throughout the refiring experiment for Ahteut site archaeological and raw clay samples.....	33
Figure 11. Sample #9 unfired.....	35
Figure 12. Sample #9 at 400°C.	35
Figure 13. Cross section color measurements for Sample #9.....	36
Figure 14. Sample #14 unfired.....	37
Figure 15. Sample #14 at 400°C.	37
Figure 16. Cross section color measurements for Sample #14.....	38

Figure 17. Unfired raw clay sample from the Cape Krusenstern site.	48
Figure 18. Raw clay sample from the Cape Krusenstern site at 400°C.	48
Figure 19. Unfired raw clay sample from the Ahteut site.....	49
Figure 20. Raw clay sample from the Ahteut site at 400°C.	49
Figure 21. Color change data for Cape Krusenstern raw clay sample.....	50
Figure 22. Color Change data for the Ahteut site raw clay sample.	50

List of Tables

Table 1. Sherd sample summary data	17
Table 2. Sample number and estimated initial firing temperature.....	41
Table 3. Summary of IFT estimates.....	42
Table 4. Summary refiring data including IFT, organic temper type, and color change at 400 °C	46

1 Introduction

This research was conducted to investigate the initial firing temperatures (IFT) of pottery from two sites in Northwest Alaska (Figure 1). Eighteen pottery sherds from two archaeological locales, the Cape Krusenstern site complex and the Ahteut site, were selected for analysis. These sherds represent vessels manufactured during the same time period, approximately 750 years ago, but in distinct biotic zones with significantly different fuel resources. The Cape Krusenstern site complex is located on the treeless coastal plain while the Ahteut site is on the wooded Kobuk River. The goal of this research is to (1) determine initial firing temperatures of arctic ceramics (2) to identify the difference, if any, in initial firing temperatures between sites with differential access to fuel resources and (3) to contribute data regarding the production and firing process of pottery to the growing body of research on arctic ceramic technology.

Ceramic technology in the Arctic was once thought of as a low grade, expedient technology (Anderson et al. 2011, Frink and Harry 2008, Lutz 1971). Early research was largely descriptive, classifications and chronologies were created based primarily on form, decoration, and temper type (De Laguna 1939, Oswalt 1952, Dumond 1969, Lutz 1971). In more recent research there has been renewed interest in the study of arctic pottery to address research questions about past northern hunter-gatherer lifeways. For example, clay sourcing studies are being used to understand exchange networks (Anderson et al. 2011). Ethnoarchaeological research is addressing social functions of arctic ceramics (Frink 2009). Experimental research has been used to understand the manufacturing process, effectiveness of methods of cooking with arctic pottery, and technological choices made in response to the environmental factors (Harry and Frink 2009, Harry et al. 2009a, Harry et al. 2009b, Harry 2010).

One of the defining characteristics of arctic ceramics is that they are a low fired technology; it is this characteristic that drives much of recent the experimental research being

conducted This experimental research has focused on understanding vessel form, manufacturing process, firing process, and techniques used to compensate for the porous nature of low fired vessels. While all of this research is influenced by the low-fired characteristics of arctic pottery, the question of firing temperatures has yet to be specifically addressed. It is problematic to describe all arctic pottery as low-fired without any concept of firing temperatures. In addition, manufacturing techniques and characteristics associated with firing quality, such as hardness, varied over space and time (Giddings 1951, Anderson in review).

This research will attempt to determine initial firing temperature of pottery from Cape Krusenstern and Ahteut archaeological sites. Determining initial firing temperatures of vessels from two sites with differential access to fuel will help to illustrate the effects of fuel type and availability on the manufacture of Arctic ceramics. Similar initial firing temperatures between sites would indicate similarity in firing method and comparable fuel use in the firing process. A difference in initial firing temperatures between sites could indicate different production method and/or different fuel availability. This work will add to the growing body of literature that seeks to understand the complexities of arctic ceramic production. Additionally, this data will establish a foundation for studying fuel use in terms of cost and management in pottery production and the possible influence of fuel on technological development.

Figure 1. Map of study area showing Cape Krusenstern site complex, the Ahteut site, and the treeline (treeline generalized from Vierek et al. 1992).

2 Background

There are two distinct pottery traditions in Alaska, the Paleoeskimo and the Neoeskimo traditions. The earliest Paleoeskimo pottery dates to between about 2500 and 1000 BP, Neoeskimo pottery appears at about 1000 BP (Anderson in review:3) and is present in the archaeological record until metal pots replace ceramics in the late 19th century. On the coast of Northwest Alaska, however, there appears to be a gap in pottery production between 1900 and 1000 years ago (Anderson et al. 2011).

2.1 Brief History of Arctic Pottery Analysis

Early analysis of arctic ceramics was primarily descriptive and focused on creating a classification system that could be used to understand chronological position and geographic distribution of pottery styles. Variations of characteristics as they changed through time, such as form, decoration, and temper material, were used to identify sherds to specific cultures and time periods (Oswalt 1955). For instance Paleoeskimo pottery associated with Norton culture had two distinct decorative characteristics, linear stamped and check stamped; changes within these styles, such as check size, have been assigned to different time periods (Dumond 1969:21). These chronologies are still in use today.

Prior research paid little attention to manufacturing process, clay sourcing, fuel, and the function and social role of pottery. Ethnographic accounts did occasionally describe the manufacture of pottery by hand forming, the use of paddles, and the decoration of vessels. Descriptions of firing processes refer to vessels being placed near or in fires, but with firing times varying from hours to days (Giddings 1951: Oswalt 1955). Giddings (1951:102) proposed that the well-fired qualities of ceramic vessels from inland sites of the Arctic Woodland Culture were a result of either the quality of local clay or the greater availability of fuel as compared to

coastal sites. Similarly, Oswalt (1955:40) discussed early attempts at identifying a correlation between fuel wood (driftwood) availability and ceramic quality but acknowledges that results were inconclusive. Among these early studies there are also accounts of ceramic exchange throughout various parts of the Northwest coast of Alaska (Oswalt 1955, Dummond 1969). This early research on Alaskan ceramics, while instrumental in creating chronologies still used to day, left many questions unanswered.

The persistence of the use of pottery from its initial adoption ~2,500 BP to the replacement of ceramics by metal cookware has led some researchers to question old assumptions about arctic pottery (Frink and Harry 2008). Current research uses ethnoarchaeological and experimental research to understand the social, technological and functional aspects of arctic ceramics and to re-analyze old assumptions about the skills needed to make and use arctic pottery and the quality of Arctic ceramic technology (Frink and Harry 2008, Harry and Frink 2009, Harry et al. 2009, Anderson et al. 2011, Anderson in review). The idea that this pottery was an expedient and simple technology has been rejected as we have come to understand the complex technological choices made in creating a functional vessel under adverse conditions.

Physical characteristics of Arctic ceramics often interpreted as evidence of a crude design were in fact functional characteristics. Frink and Harry (2008) conducted experimental research replicating Arctic ceramic vessels in order to understand the functional aspects of vessel form. The straight walled and flat-bottomed form of later Thule vessels allowed newly formed unfired vessels to support their own weight during the extended drying process. Organic tempers help keep vessels porous and low firing temperatures prevent or limit sintering, the solidification and joining of clay and mineral particles that make up the clay paste which also reduces porosity (De

Jonghe and Rahaman 2003:187, Frink and Harry 2008:112-113). Both of these attributes would allow steam to escape during the drying and firing process which would preventing cracking. Additionally, relatively small vessels allowed for water for cooking to be boiled quickly over a smaller fire, conserving fuel. This also likely lent to the cultural preference for parboiled prevalent during the ethnographic period (Frink and Harry 2008:112-113).

These highly porous vessels should be incapable of holding and boiling water, yet all accounts of ceramics use in the arctic indicate that they were used for cooking and not storage. Application of seal oil and blood during manufacture and throughout use life are discussed in numerous ethnographic accounts of pottery manufacture (Giddings 1951:93, Harry et al 2009b:36, Anderson in review:9). Recent experimental research has tested the use of seal oil and blood in sealing porous arctic style ceramics. Seal blood and oil were applied prior to firing; afterwards the pottery was tested for tensile strength, thermal ability and ability to hold water. The results indicate that seal oil and blood increased durability, decreased time needed to boil water, and sealed the pottery well enough that the vessel could hold water (Harry et al. 2009).

The results of clay sourcing analysis combined with knowledge of geographically specific decorative styles indicate that pottery and clay were part of a large exchange network in Northwest Alaska (Anderson et al. 2011). Some areas reportedly had rather crude ceramic technology and traded for better quality ceramics with neighboring groups (Anderson et al. 2011). The study found that there is a clear geographic distribution of three distinct clay source macrogroups and that arctic potters sourced clay from multiple locations (Anderson et al. 2011:951-952). The use of clays from a variety of local and non-local sources during a period of increased sedentism suggests that raw materials were obtained through trade networks (Anderson et al. 2011:951-952).

Additional studies have explored the social role of arctic pottery production (Frink 2009). This recent body of literature illustrates the complexity of arctic ceramic technology. The knowledge associated with pottery production, clay sourcing, temper types, forming, drying and firing processes was valuable. Social bonds and roles of authority would have been created through apprenticeship systems. These studies have also explored the shift in social roles that occurred after the introduction of the metal cooking pot, which would have allowed for free time by eliminating the need to produce pottery and creating a change in social dynamics (Frink 2009).

2.2 Pottery Production

This discussion is focused on the Neoeskimo pottery as the samples used in this study date to this time period, approximately 750 BP. Neoeskimo pottery was generally thick walled, coarse, and friable with flat bases and gently flared or vertical walls. Organic materials such as grass, animal hair, and feathers and inorganic materials such as coarse sand, pebbles, and crushed rock were used as temper in Neoeskimo pottery. Ethnographically, seal and fish oil, blood, and dog excrement were used to seal the porous walls of arctic ceramics (Harry et al. 2009a:294, Harry et al. 2009b:34, Anderson in review:10), and recent experimental research has demonstrated the effectiveness of this practice (Harry et al. 2010:293-295). In the Nelson Island region of western Alaska, later period Thule vessel size generally ranged from 10 to 20 cm in height and 13 to 17 cm in diameter, with some larger samples up to 31cm in height and 25 cm in diameter (Frink and Harry 2008). (Add reference to vessel size in another geographic location to illustrate variety)

Ceramic production in the Arctic faced a number of limiting factors that would have required arctic potters to plan ahead, gather resources, and develop a process of manufacturing a

low-fired porous vessel that was capable of holding water. The cool and damp climate would have limited production to the short summer months when temperatures would be highest. Summer is also a busy time for other subsistence tasks, so potters' would have been juggling ceramic making with other important activities. The climate never reached warm or dry enough conditions to allow ceramics to dry in the sun. Various methods were used to dry ceramics; in some cases vessels were wrapped and set near fires to dry (Anderson in review:9-11). Vessels were turned and moved closer to the fire at a slow rate to avoid overheating and cracking. By some accounts this process could take months (Frink and Harry 2008), while others report the drying process taking one to two days (Harry et al. 2009).

Limited discussion of firing methods in the ethnographic literature describe the use of pit or open firings, covering vessels in oil soaked fuel, and firing durations lasting as short as a few hours and as long as the duration of a summer (Anderson in review:9-11). It is likely that the availability of fuel affected pottery production in the treeless landscape of Cape Krusenstern. Archaeological and ethnographic evidence show that driftwood, shrubs, bone, and oil were used as fuel for cooking and perhaps for ceramic firing (Lepofsky et al. 2003, Crawford 2012, Burch 2006).

2.3 Open Firing

Due to the lack of data on firing methods of Arctic potters it is necessary to draw knowledge of the production methods of hunter-gatherer potters from around the world to discuss the characteristics of open firings.

Open firings are built on the surface of the ground or in a shallow pit, but with no other permanent structure, i.e. a kiln. A bed of fuel is made on the ground, the vessel is placed over the

fuel, and more fuel placed on and around the vessel (Rice 1987:153). In open firings temperature and atmosphere are extremely variable and difficult to control (Rye 1981:96, Rice 1987:156).

The color of a finished ceramic vessel is determined by firing temperature and firing atmosphere as well as the color of the raw clay itself. As temperatures rise, physical changes occur within the vessel that create color change. Organic materials in clay may not burn out entirely if firing time is short and/or temperatures are low, this produces dark ceramics (Tite 2008:220).

Researchers observing open firings in communities across the world report that a firing generally lasts between 15 and 30 minutes (Rice 1987:154, Gosselain 1991:255, Tite 2008:219), but can last 50 minutes or more (Rye 1981:103). Gosselain (1992) summarizing the work of a number of previous thermometric studies reports flame temperatures of open firings ranging between 300°C to 900°C. Maximum temperatures of open firings are often achieved between 20-30 minutes (Rice 1987:156, Gosselain 1991:255, Tite 2008:219). Maximum attainable temperatures are relatively high although, heat is not evenly distributed in an open firing and temperatures subject to much variation. A strong wind may cause a temperature drop of up to 246°C (Rice 1987:156).

The atmosphere in an open firing is likely reducing or highly varied. Fully oxidizing atmospheres are rare and if achieved they are difficult to maintain in an open firing (Shepard 1971:219, Rye 1981:96). In an oxidizing atmosphere where air is free to circulate iron in the clay is oxidized producing red or pink shades (Rice 1987:80-82). Black and gray pottery is produced in a reducing atmosphere where there is no airflow and oxidation does not occur (Tite 2008:220). The colors obtained during firing represent the atmosphere of the end stage of firing. It is possible to achieve some level of oxidization in a highly reduced vessel by removing it from the

Duelks

fire shortly after maximum temperatures are reached and allowing the vessel to cool in open air, creating a thin oxidized layer (Shepard 1971:217-219).

2.4 Fuel Use and Availability

It is necessary to understand the availability of fuel resources in the study of firing temperatures of Arctic ceramics as the availability of wood fuel in Alaska varies with location. Although different firing methods such as kiln or open firings require different amounts of fuel; it is accurate to say that, regardless of the firing method, fuel is the “greatest cost in pottery production” (Rice 1987:174, Anderson in review). There is some debate over whether or not the limited availability of fuel in Alaska contributed to the coarse and crumbly nature of Alaskan pottery (Anderson in review). However, it is certainly plausible that regional and temporal differences in pottery quality are due in part to varying fuel availability.

Much of the coast of Northwest Alaska, including the Cape Krusenstern site complex, falls outside of the tree-line, limiting its inhabitants access to fuel (Figure 1). Those people living above the tree-line would have relied exclusively on driftwood for wood fuel. Driftwood is and was available on many beaches along the coast as well as to interior sites along rivers. The Ahteut Site is located just below the tree-line along the Kobuk River, people living here had access to standing trees and driftwood (see below for a discussion of fuel availability at both study sites).

Fuel was a key resource beyond pottery manufacture for the people of Northwest Alaska. It was also used for oil rendering, heating, cooking, smoking, and warming saunas and steam baths (Wheeler and Alix 2010). Fuel availability played a major role in the placement of seasonal and permanent villages (Burch 1998, Lepofsky et al. 2003, Crawford 2012). Where local fuel sources were not adequate, it was obtained through trade and travel (Burch 2006:185).

Driftwood is the most widely studied fuel source in the archaeological contexts of Alaska (Alix et al. 2001, Alix et al 2002, Lepofsky et al. 2003, Shaw 2008, Crawford 2012).

Driftwood available to coastal peoples would have originated in interior Siberian and North American forests and been delivered through ocean current systems to the shores of the Alaskan coast (Dyke and Savelle 1999). Inhabitants of inland sites such as Ahteut could have harvested driftwood as it came down the Kobuk River. Driftwood is made available through a four-stage cycle of treefall, river transport, ocean circulation and coastal delivery. The cycle is subject to variation, with large climatic shifts and small seasonal changes capable of disrupting the cycle (Alix 2005). Inhabitants of the Ahteut site also had standing forests of birch and white spruce available from which they could harvest dead and dry wood (Giddings 1951:3,102). Spruce forests migrated into the Kobuk River Valley by 5000 BP (Anderson 1985:318). The abundant ash content seen in hearths at these sites indicates a relatively consistent supply of fuel and may provide the explanation for the presence of more well fired pottery vessels (Giddings 1951:113).

While driftwood often dominates charcoal remains recovered from hearth excavations (Lepofsky et al. 2003, Crawford 2012), ethnographically, local willow is commonly mentioned as a fuel source in Northwest Alaska, as well as bone and oil (Giddings 1951, Burch 1998, Burch 2008, Crawford 2012). Oil soaked fuel is described in numerous ethnographic accounts of pottery firing (Anderson in review). Beyond these few examples, the study of fuel use in Alaska is extremely limited. New research designed to identify fuel remains in archeological contexts is needed to better understand fuel use and the choices Alaskan hunter-gatherers made regarding fuel (see also Lepofsky et al. 2003, Shaw 2012).

2.5 Ceramic Vessel Use in Ethnographic and Archaeological Contexts

Alaskan ceramic vessels were used primarily for cooking (Anderson in review:12), although ceramic cups are referenced in several ethnographic sources and a few cup sized vessels have been found during excavation (Anderson in review:13-15). Direct and indirect fire boiling and stone boiling are all mentioned as cooking methods in the ethnographic record (Harry and Frink 2009:335, Anderson in review:13). Holes near the rim of some vessels may have been used for suspension during cooking (Anderson in review). Cooking with ceramics is often associated with the need to process foods such as nuts and meat, which are broken down and made more easily digestible through boiling. However, Northwest Alaskan people often ate meat raw or parboiled and nuts were unavailable. The cultural preference for parboiled foods is discussed in the ethnographic literature (Harry and Frink 2009:333). Nutrients such as vitamin C that are normally lost to cooking were preserved in meats that were only lightly cooked or parboiled. This was Arctic peoples only source of vitamin C (Frink and Harry 2008:113).

Archaeological remains of ceramics used for ceremonial or storage purposes are extremely limited or too fragmented to determine actual dimensions and use. A few cup size vessels and vessels containing animal bones have been identified. Ceremonial cups and pots are discussed briefly in the ethnographic record (Anderson in review:14).

Ceramic vessel function also varied geographically and was influenced by the availability of other resources. For instance along the Kobuk River birch bark baskets were used for stone boiling, and ceramic vessels were used for smaller scale cooking of liquid food (Giddings 1951:84). Due to preservation issues the remains of only one birch bark basket were recovered by during Giddings' excavations, however, 402 sherds comprising at least 62 vessels were recovered (Giddings 1951:95).

2.6 Experimental Research

Just as the analysis and interpretation of Alaskan ceramics began with classification and description rather than explanation of technological choices, early experimental analysis was focused on re-creation without attempting to identify technological choices made by potters in local and regional contexts (Harry 2010:14). The results of early experimental could not be used to interpret a wide variety of ceramics from different contexts because it would potentially miss the social and environmental factors that influenced the creation of individual pottery styles. The new program of experimental archaeological analysis goes beyond recreation, using individual experiments ,built off of prior research and contribute to a larger body of work with the intention of identifying universal principles of technology and behavior (Harry 2010:14).

An important aspect of current experimental research in the interpretation of data, is that it has to be acknowledged that the conditions of experimental production do not precisely match the environmental and social conditions of archaeological production. These differences should be taken into account and data from a single experiment will not be used to interpret all ceramics, but will add to the growing body of research on hunter-gatherer ceramics (Harry 2010:14-15).

With the increase in experimental research in recent years, significant advances have been made toward understanding arctic ceramic technology, yet the question of initial firing temperatures still remains and the label of “low fired technology” is a generalization and imprecise descriptor. By building on the existing research on Arctic ceramic technology and conducting refiring experiments (see methods section below) I will determine initial firing temperatures of pottery samples from Northwest Alaska.

3 Study Sites

3.1 Cape Krusenstern

The samples of pottery used in this research were collected over the course of four field seasons (2006-2010) at the Cape Krusenstern beach ridge complex on the northwest coast of Alaska (Anderson and Freeburg 2013b). The early research of J. Louis Giddings and Douglas D. Anderson at Cape Krusenstern established the initial occupation beginning 4200 years ago (Giddings and Anderson 1986). Once people arrived, the use of the beach ridge was nearly continuous with the material cultures of Denbigh, Choris, Norton-near Ipiutak, Ipiutak, Thule, Kotzebue and historic Inupiat all represented in the archaeological record. The initial chronology was established based on the horizontal stratigraphy of the beach ridge and relatively few radiocarbon dates. Recent research at Cape Krusenstern conducted by Anderson and Freeburg (2013, 2014; Freeburg and Anderson 2012) refined that chronology with 151 radiocarbon dates, providing finer detail on individual site occupations and confirming the nearly continuous occupation of the beach ridge complex (Anderson and Freeburg 2013a).

The assemblages of earliest occupation sites at Cape Krusenstern through those of ~2500 years ago represent short term seasonal hunting camps of coastal foragers. After this period, the archaeological record shows evidence of an increasing maritime adaptation characteristic of other northwest Alaskan sites at this time. The appearance of semi-subterranean house features and year round, multi-house settlements begins ~2000-1700 years ago and is seen as an indication of population growth. As sites continue to grow between ~1700-1500 years ago, we also see evidence for increased territoriality, economic and social complexity, and larger populations (Anderson and Freeburg 2013a, 2013b:296). These more permanent settlements along the beach ridges coincide with the growing shift towards a marine mammal subsistence strategy. (Anderson and Freeburg 2013:52-53). The Cape Krusenstern site complex is located

Duelks

above the tree line. Driftwood, shrub brush, bone, and oil would have been the only sources of fuel available to arctic potters.

The samples selected for this study come from post-1500 BP sites on Cape Krusenstern, from a variety of contexts including; house occupation features, campsites, and activity areas. Ceramics from the Cape Krusenstern site complex are ideal for studying initial firing temperatures because fuel availability was relatively limited and driftwood availability could fluctuate based on weather patterns as mentioned above.

3.2 Ahteut Site

Five sherds representing an inland pottery sample are from the Ahteut village site excavated by Giddings during his 1947 field season in the Kobuk River (1951).

Giddings created a chronology for Kobuk river village sites based on a 970-year tree ring record (Giddings 1951, Shirar 2011:3). A series of dates based upon charred timbers from excavated house features placed the occupation of Ahteut at between AD 1200 and AD 1250 (Giddings 1951:108). In 2011 Scott Shirar's research at village sites along the Kobuk and Noatak Rivers added thirty radiocarbon dates the chronology of the region. These new dates were then used to test Giddings' tree-ring chronology (Shirar 2011:3). The radiocarbon chronology generally supports Giddings dendrochronology while expanding and refining the occupation periods of some sites, including Ahteut (2011:13). Two radiocarbon dates taken from Ahteut House 10S place the occupation period to between AD 1100 and AD 1300 (Shirar 2011:12). Thermoluminescence dates of sherds from House 10s push the occupation further back to as early as AD 490± 210 (Anderson 2011:52).

Ahteut, a year round village site with over one hundred house pits, is located in the middle portion of the Kobuk River (Giddings 1951, Shirar 2011:7). The tool assemblage at

Ahteut is that of terrestrial, freshwater, and marine adapted hunting (Giddings 1951). The Kobuk would have provided large runs of salmon, whitefish, sheefish, and trout, which made up a large part of the inhabitants' diet year round (Shirar 2011:2). Giddings suggests that coastal marine hunting took place during winter months, while fish and terrestrial animals were relied on more heavily and throughout the rest of the year (1951:112-113).

The ecology of the Kobuk River is quite different from Cape Krusenstern. Boreal forests of birch, white spruce with thickets of alder and willow surround the middle and upper Kobuk, thinning out towards the coast (Giddings 1951:34, Shirar 2011:2). The standing forests would have provided a consistent supply of dead and dry wood for use as fuel and construction material (Giddings 1951:102) and driftwood was also available as it came down the Kobuk River (Shirar 2011). Although standing trees were available they were not used for house construction, instead driftwood was the main building material, and likewise, may have been a preferred fuel source (Shirar 2011:7). Fuel studies conducted at other sites in Alaska indicate that when both standing forests and driftwood were available, driftwood was still the preferred fuel and building material (Lepofsky et al. 2003, Shaw 2008). Ethnographic and archaeological records provide evidence that people understood that specific tree species were better suited for specific tasks such as tool use or as fuel. So driftwood provided a wider range of taxa to meet various technological needs (Alix and Brewster 2001, Lepofsky et al. 2003:126)

All five samples used in this study were associated with house features from the Ahteut village (Table 1). Ceramics from the Ahteut site are ideal for a comparative study of Northwest Alaskan ceramics. The sites location along the middle Kobuk River gave access to resources such as abundant fuel and birch trees for bark baskets and vessels that were unavailable to those living in the Cape Krusenstern site complex.

Table 1. Sherd sample summary data

Catalog Number	Sherd Number	Site	Context	Date	Organic Temper Type
CAKR 13617c	1	Cape Krusenstern	House Pit 3B	Adjacent House 25 770+/-120 Uncalibrated BP	None
CAKR 14514d	2	Cape Krusenstern	Giddings and Anderson House 25	AD 1300-1400 G&A date phase: Late Western Thule	Unknown
CAKR 14001	3	Cape Krusenstern	Surface Scatter 2B	524±12, 503±24, 432±29 assumed uncalibrated BP	Unknown
CAKR 13148	4	Cape Krusenstern	Surface Scatter 2b/Hearth 2B	~497 Cal BP	Unknown
CAKR 14026b	5	Cape Krusenstern	Surface Scatter 1B	~1495 cal BP	Unknown
CAKR 14455c	6	Cape Krusenstern	Cache Pit 2A	Nearby dates 933+/-33, 777+/-50, 746+/-31	Unknown
CAKR 14503c	7	Cape Krusenstern	Giddings and Anderson House 8	AD 1300-1400 G&A date phase: Late Western Thule	N/A
CAKR 14515e	8	Cape Krusenstern	Giddings and Anderson House 27	AD 1300-1400 G&A date phase: Late Western Thule	None
CAKR 14821	9	Cape Krusenstern	N/A	N/A	Feather
CAKR 14683	10	Cape Krusenstern	House 2A	~515 cal BP	Feather

Duelks

CAKR 15147	11	Cape Krusenstern	N/A	N/A	Feather
CAKR 14879	12	Cape Krusenstern	House 1A	~381 cal BP	Feather
CAKR 14343II	13	Cape Krusenstern	Surface Scatter 1B	~1495 cal BP	Unknown
SLA 013-2230	14	Ahteut	House 3N	740-700 BP	Unknown
SLA 012-2229	15	Ahteut	House 2N	740-700 BP	Unknown
SLA 018-2405	16	Ahteut	House 10S	Approx. 900-680 BP, TL Date 310- 110 BP	Feather
SLA 120-2226	17	Ahteut	House 3N	740-700 BP	Unknown
SLA 121- 2227a	18	Ahteut	House 3N	740-700 BP	Unknown
CAKR Raw Clay		Cape Krusenstern	North CAKR Lagoon		
Ahteut Raw Clay		Ahteut	Middle Kobuk River		

Note that all sherds have a catalog number associated with the larger collection and a sample number (1-18) assigned for this experiment. For ease of discussion, all sherds will be referred to by their assigned sample number i.e. S1, S2, S3 etc. Sherds S1-S13 are from the Cape Krusenstern site and sherds S14-S18 are from the Ahteut site. See Table 1 for catalog numbers and associated sample numbers.

3.3 Clay Samples

Clay samples were taken near the Ahteut and the Cape Krusenstern site complex to be refired along with the archaeological sherds. Clay samples were collected by Anderson (2011) as part of an extensive survey of clay sources in Northwest Alaska. The clay deposits were located through geologic and ethnographic data (Anderson 2011:73). The clay sample from Cape Krusenstern is from a sedimentary glacial deposit near the North Lagoon. The clay sample associated with the Ahteut site is from a nearby sedimentary glacial deposit located along the Kobuk river (Anderson 2011:72-75).

Using raw clay samples in refiring experiments is necessary for a comparison of the color changes that occur in raw clay and those that occur in the archaeological samples (Matson 1971:65). Firing raw clay also demonstrates the requirements for full oxidation (Shepard 1971:219).

4 Hypotheses and Expectations

Accounts of the quality the hardness of pottery are varied spatially and temporally. Coastal sites like Cape Krusenstern would have relied on driftwood supplemented by shrubs, bone, and oil for fuel. Ahteut, an inland river site, would have access to both standing forests and

driftwood as well as shrubs, bone, and oil. As discussed above, a majority of the Alaskan pottery is generally described as low quality, coarse and crumbly. The exceptions are the Neoeskimo pottery from the mid and upriver sites on the Kobuk and Bering Sea Paleoeskimo sites which Giddings describes as being of a superior quality or hardness than others (1951:102-103).

Anderson (in review) reports that SEM analysis shows that firing temperatures could be high enough for the sintering process to begin. The expectations of this study are that (1) because of the difference in fuel availability sherds from the Ahteut site will have higher IFT's than sherds from the Cape Krusenstern site complex, and (2) That all samples will have IFT's on the lower end of temperatures attainable in an open firing 300°C -900°C.

There are three factors known about Northwest Alaskan ceramic production that inform the expectations of this experiment. (1) Fuel availability has been cited as contributing factor to the friability of Arctic vessels. It is known that access to fuel varied geographically and that the sherds sampled for this study represent sites with differential access to fuel resources. Therefore it is possible that vessels from the Ahteut site have higher IFT's than vessels from the Cape Krusenstern site complex. (2) There are no permanent firing features in Northwest Alaska. Kilns have not been identified in the archaeological record and are not mentioned ethnographically and although a few possible pit-firing features have been identified they have not yet been confirmed as ceramic production features. Regardless of the presence of permanent pit-firing features, it can be assumed that IFT's fall within the possible temperatures (300°C to 900°C+) attainable in an open or pit firing. The limited availability of fuel coupled with the severe environment, it is expected that overall Northwest Alaskan vessels IFT's are below the upper limits (800°C - 900°C) of open firings. Given the known differential access to fuel between sites, it is expected that Ahteut vessels may have higher IFT's than Cape Krusenstern vessels.

The third factor informing the expectations of this experiment is related to paste ingredients and the characteristics of low-fired ceramics. The sherds used in this study are predominantly black and gray which is either the result of organic content still present in the paste due to low firing temperatures, a reducing atmosphere, or a combination of the two. A majority of the sherds used in this study were tempered with organic material (Table 1). It is also highly likely that the firing atmosphere was reducing given the nature of open firings discussed previously. The combination of these two factors may make estimating IFT's difficult. However if IFT's are not possible due to confounding factors of atmosphere and the presence of organic materials, it may still be possible to make statements about both firing atmosphere and organic content which are otherwise assumed but not tested.

5 Methods

5.1 A Low-Tech Approach To Determining Initial Firing Temperatures

There are a variety of methods that can be employed to assess original firing temperatures of ceramics. These include analysis of physical properties, chemical analysis, mineralogy, and thermal analysis, including experimental refiring, color measurements, and thermal expansion (Rice 1987). For this study initial firing temperature will be estimated based on physical properties, i.e. color. The method of color change identification to estimate initial firing temperatures will be used because it is a relatively simple and cost effective test, it does not require prior knowledge of clay mineral constituents, requires only minimal equipment- (i.e. kiln and color charts, and is an effective method for pottery that was fired between 400°C and 1000°C (Rice 1987:426). Other methods may be used to support or test the results of this method. Measuring thermal expansion with a dilatometer has been especially effective when estimating IFT's of low fired ceramics (Zhu et al. 2014), and spectrophotometry can be used to measure

color changes at a higher resolution than is possible by a human observer (Mitri 1998:46, Mitri and Davit 2004).

The underlying principle of this study is that when clay is initially heated above several hundred degrees Celsius during the production of ceramics, physical and chemical changes occur in the clay. One of these changes is the color of the ceramic paste. Physical changes that occur during the initial firing of a vessel will be halted at the highest temperature reached and will not occur again until that temperature is exceeded (Rice 1987:427). During the refiring experiment the color of the sherds is measured, then all sherds are fired at increasing temperatures in increments of 50-100°C. beginning at 400°C up to at least 1000°C (Rice 1987). Sherds are removed at each interval and color measurements are taken. The color of the ceramic paste will change when the initial firing temperature is exceeded. The initial firing temperature is then estimated at a range of 50°C to 100°C below the temperature at which color change occurred during refiring. There is no established standard for how much change needs to occur to indicate the experiment has exceeded initial firing temperature. In her description of the experimental method Rice (1987:427-428) simply states that “little to no change” at a given refiring temperature indicates that IFT has not been exceeded, and “marked change,” indicates that IFT has been exceeded. Color change in low-fired pottery is a result of the relative degrees of oxidation of carbon and iron in the clays (Rice 1987:343).

Along the color scale, dark gray colors in pottery have a low Chroma and Value, and indicate incomplete oxidation. This can be a result of (1) a reducing atmosphere, (2) a short firing time and/or (3) low firing temperatures. Conversely higher Value and Chroma indicate less organic material. If possible, it is suggested that non-archaeological clays from the same source are fired along with the archaeological samples for comparison. During analysis,

variations in Hue, Value, and Chroma will be noted individually as each can indicate different aspects of firing conditions (Rice 1987:343-344).

Identification of firing temperatures by color variation is subject to a number of variables that should be mentioned and will be accounted for during the experimental process and analysis. Some of the disadvantages of this method are, that color can be sensitive to variations in duration of firing and of atmospheric conditions during the process. Another disadvantage is that in low fired ceramics, with a temperature range from $\sim 400^{\circ}\text{C}$ to 500°C (and possibly up to $\sim 700^{\circ}\text{C}$), color changes may be affected by organic content of the pottery. And because firing temperatures and conditions of non-kiln fired pottery can be so variable, results from this study will be reported as average or most common measurement and described within their range of variation (Rice: 1987:343-345).

Potential problems that may arise in this refiring experiment include differences in firing atmosphere and observer error. As discussed above, the firing atmospheres affect the range of colors possible in a fired ceramic vessel. A reducing atmosphere will produce black, gray or white paste; an oxidizing atmosphere will produce red, orange and pink paste. If the refiring atmosphere does not match the original firing atmosphere the color change observed will be, in part, a result of the oxidizing or reducing atmosphere and will make estimating IFT's difficult (Rice 1987). The highly variable but generally reducing atmosphere common in open fires were not emulated during this experiment. Firing time and temperature in an open fire would have been too difficult to control. A furnace had to be used so that temperature and firing time could be controlled. The furnace used in the experiment had an oxidizing atmosphere.

When recording color measurements using Munsell color charts observer error can create inconsistencies in data when more than one person is taking the measurements. For this reason

Duelks

all color measurements were recorded by myself under the same lighting conditions for each measurement at each stage.

5.2 Sample Selection

Sherds selected for this study had been granted destructive analysis permission for previous analysis, due to the destructive nature of the refiring experiment. Sherd samples over four centimeters were selected for this study to ensure that a portion of all sherds remained intact for future research. Precise sourcing data is known and thin sections have been made for the samples used in this analysis.

5.3 Preparation

Samples were cut using a wet cut diamond coated stone saw and set out to dry for three days following cutting. Dental picks and wooden scrapers were used to remove any visible residue from the sherd. Beginning color measurements were taken on the exterior, interior, and cross section surfaces of each sherd using a Munsell soil color chart. Cross section surface refers to the freshly cut surface which reveals the firing core. All color measurements were collected in the same room with consistent lighting of a magnifying lamp and recorded by a single observer for consistency. Because of the variability in color that may occur within a single sherd, multiple color measurements were taken when necessary and indicated as “mottled” when recorded. Surfaces with more than one visible color (Figure 2), for instance were recorded as 2.5Y2.5/1-2.5Y5/1 (mottled). Interior color of ceramics often varies from the exterior surfaces in ceramics and this is visible in cross section surfaces. Where this was the case all colors were recorded with distinction between surface color and core color as 10YR5/1-10YR4/1 (4/1 exterior surface)

Duelks

(Figure 3). Exterior, interior, and cross-section surfaces were then photographed with a Nikon Coolpix S9300. Two photographs were taken for each surface, once with color and gray scales visible in the photo and once again with only a 5 or 10 cm scale visible in frame.

Figure 2. Sample #7 showing a sherd with multiple colors on one surface.

Figure 3. Sample #15 showing an exterior surface color that differs from core color is visible in cross section view.

5.4 Firing

Sherds were fired using a Thermolyne Furnatrol-133 2000° furnace. Sherds were placed in heat safe ($<1100^{\circ}\text{C}$) ceramic crucibles that were fired in 100°C increments for twenty minutes from 400°C to 500°C . Above 500°C , there was a loss of $\sim 20^{\circ}\text{C}$ when the furnace was opened to add and remove sherds. From 600°C to 900°C , sherds were fired for twenty-five minutes to keep the maximum refiring temperatures at 100°C increments. According to the initial experiment design all samples were to be fired to 1000°C , but refiring was stopped at 900°C as the ceramic crucibles began to crack. All sherds were removed from the furnace after firing time and allowed to cool in open air at room temperature. After each firing the same series of color measurements and photographs, discussed above, were taken.

5.5 Recording and Displaying Color Measurements

Many archaeologists are familiar with the Munsell color charts. A brief overview of the Munsell system follows in order to explain the charts used to display the change in color throughout the course of the refiring process. The Munsell color system records three categories of color; Hue, Value and Chroma. Hue refers to the colors i.e. yellow (Y), yellow-red (YR), red (R), etc., which have one or more numeric representations such as 2.5Y, or 5Y. Value records the lightness or darkness of a color where 10 represent white and zero represents black. Chroma records the strength of a color with eight representing the brightest true color and zero, a neutral gray (Matson 1971:67). Using the numeric assignments for the categories of color, the changes in color measurements throughout the refiring experiments were plotted on an XY axis for a representation of change over time (Figure 4). The numeric value of Hue, Value, and Chroma were plotted on the Y-axis from zero to 10. The X-axis represents each stage of firing, from the unfired color of a sherd to its final color at 900°C. Following this format three color graphs were made for each sherd surface; exterior, interior and cross section. The same format was used to display the color change of the raw clay samples from Cape Krusenstern and Ahteut. These charts provide a visual representation of the color change of specific sherds throughout the firing process.

Figure 4. Example of color measurements plotted on XY axis showing the change in color throughout the refiring experiment. The first color measurement taken on the exterior surface of Sample 1 reads: 2.5Y5/1, the second color measurement at 400 C reads GLEY1-2.5N. For measurements on the Munsell GLEY pages, Hue is either GLEY1 or GLEY 2, and the lowest Chroma value is denoted by the letter N. To plot this along the X axis N is denoted as the number 1.

Additional sets of charts were made to display the color change of all sherds from each site, Cape Krusenstern and Ahteut. In these charts, firing and color data from every sherd is included; Hue, Value, and Chroma are separated for clarity. The numeric value of Hue, Value, and Chroma are plotted on the Y-axis from zero to 10 and the X-axis represents each stage of firing, from unfired to 900 °C. One set was made for each site. These charts represent the collective color change data for ceramics from each site and include the color measurements for the raw clay samples associated with each site for comparison (Figure 5-Figure 10)

6 Results

6.1 Prefiring Sherd Descriptions

Prior to the refiring experiment all of the samples in the study displayed dark gray or very dark brown to black (2.5Y2.5/1, 10YR2/1) cores, according to Munsell color descriptors. Those dark colors are characteristic of open firings and a reducing atmosphere (Rye 1981:119, Shepard 1971:217) and/or of firing temperatures too low to burn out or completely oxidize all of the organic material present in the clay (Matson 1971:66, Rice 1987:334, Tite 2008:220). Uneven color within a single vessel, seen in many of the sample sherds, may be due to an unstable atmosphere of an open firing (Shepard 1971:214).

Six of the 13 sherds from the Cape Krusenstern site, S3, S5-7, S11, and S12, as well as all five sherds, S4-S18, from the Ahteut site had higher values for the variables, Value and Chroma, leaving a lighter interior or exterior surface that is also visible on the interior and exterior edges of the cross section surface. This was most prominent in the five samples from the Ahteut site. This color pattern fits Rye's (1981:116-118) description of pottery fired in either a reducing or oxidizing atmosphere with organic material present in the clays. This pattern results from an oxidizing atmosphere introduced at the last stage of or immediately following a firing. A sharply defined oxidized layer may form on the surface when vessels fired in a reducing atmosphere are removed from the fire at high temperatures and allowed to cool in open air or when a vessel is left over a fire that turns to coals, which creates an oxidizing atmosphere (Rye 1981:116-118).

6.2 Refiring Results

In the following sections the cross section data is used to interpret results. This is because residue build up and post depositional wear on the interior and exterior surfaces may obscure the original color of the vessel. The general trends in color change throughout the experiment can be seen in Figure 5Figure 10. Color change occurs in both archaeological sherds and raw clay samples at nearly every stage until 800°C is reached, with colors beginning with very dark browns, black, gray and ending in reddish yellows and yellowish reds. There is little change in color between 800°C and 900°C. Note that the charts suggest that Hue changes the least, however, this is a result of representation of data within the charts and does not indicate an actual lack of change. Changes from 2.5 YR to 2.5YR/10 YR to 1 GLEY in any combination cannot be displayed linearly from zero to 10 in a meaningful way as they represent changes between red, yellow, and green/blue. Samples change rapidly between these colors within the first three stages of firing, from unfired to 600°C, at which point Hue becomes more consistent, staying within the Munsell YR card, moving from 10YR to 5YR. The Hue of raw clay from both sites has a slightly steadier trend line because it does not become darker in early stages of refiring. Colors shift from 10YR (CAKR) or 2.5Y (Ahteut) to 5YR and do not change after reaching 600°C.

Figure 5. Change in Hue throughout the refiring experiment for Cape Krusenstern archaeological and raw clay samples.

Figure 6. Change in Value throughout the refiring experiment for Cape Krusenstern archaeological and raw clay samples.

Figure 7. Change in Chroma throughout the refiring experiment for Cape Krusenstern archaeological and raw clay samples.

Figure 8. Change in Hue throughout the refiring experiment for Ahteut site archaeological and raw clay samples.

Figure 9. Change in Value throughout the refiring experiment for Ahteut site archaeological and raw clay samples.

Figure 10. Change in Chroma throughout the refiring experiment for Ahteut site archaeological and raw clay samples.

The trends for Value and Chroma are more easily seen than Hue. Both Cape Krusenstern and Ahteut archaeological samples have Values that tend to increase from a beginning range of two to five to between five and eight at the end of firing. The raw clay from Cape Krusenstern shows a less dramatic rise in Value, from three to six, that levels out at 500 °C. In contrast Ahteut clay Value hovers at about 6 throughout the firing process. The most dramatic change in archaeological samples is the Chroma measurement from Cape Krusenstern. These begin between one and two and end as high as eight, with the local raw clay sample following a very similar pattern. The Value measurement on Ahteut archaeological samples also increases as temperature increases. Ahteut archaeological sample Value measurements peak at four, while the clay sample Value shows a more dramatic increase that peaks at six.

Several other patterns are visible that are worth discussing in greater detail. Color change was observed in every sherd during the early stages of refiring beginning with the first refiring at 400 °C. All but five samples became visibly darker with a decrease in Hue, Value, and Chroma at 400 °C. For example S9, had an unfired cross section color of 2.5Y3/1, which became significantly darker, 1 GLEY2.5/N, at 400 °C (Figure 11, Figure 12, Figure 13). The remaining five sherds (S5, S7, and S14-S16) became lighter, moving from black to gray with at least one variable, Hue, Value, or Chroma increasing while the other variables remained stable. For example S14 had an unfired cross section color of 2.5Y2/1, which became lighter, 2.5Y5/1 when fired to 400 °C (Figure 14, Figure 15, Figure 16).

Figure 11. Sample #9 unfired.

Figure 12. Sample #9 at 400°C.

Figure 13. Cross section color measurements for Sample #9.

Figure 14. Sample #14 unfired.

Figure 15. Sample #14 at 400°C.

Figure 16. Cross section color measurements for Sample #14.

At 500°C two sherds, S3 and S8, experience little to no change in color, remaining dark gray or black, while the rest of the sherd began to lighten, increasing in at least the variables of Hue or Value with Chroma increasing the least. Within the refirings up to 600°C Value is the main color variable to change, increasingly rather steadily. Most sherds show some increase in Value and Chroma, while Hue tends to move from 10YR, to 7.5YR, or 7.5YR to 5YR with an overall trend towards yellowish-reds or pinks, by Munsell color descriptors.

The last observable pattern in the refiring data of the ceramic samples is in the stabilization of colors beginning around 700°C. Sherds, S7-S10 and S12 all stabilize in color at 700°C with Hue at either 7.5YR or 5YR and Value 7 or 8, and Chroma at 3 or 4. These samples do not change thereafter. The color measurements of sherds S4, S5, S13, S15, S17, S18 stabilize in roughly the same patterns at 800°C and do not change at 900°C. This pattern does not currently influence the estimation of initial firing temperatures, and may be a characteristic of the clays.

7 Discussion

This method of interpreting initial firing temperatures is based on the premise that color does not change until the original firing temperatures are exceeded. The color change observed in this experiment was consistent and incremental at nearly every stage of the refiring in each sherd. A pattern of consistent color change throughout the firing experiment indicates that either (1) firing temperatures were below the first refiring temperature or (2) the original firing atmosphere was different than the experimental refiring atmosphere causing color change to occur as the sherd becomes either oxidized or reduced. Consistent, incremental color change makes interpreting initial firing temperatures difficult if not impossible (Mitri and Davit 2004). Despite this, preliminary estimates of IFT are made and presented in the next section followed by

a discussion of the confounding factors such as firing atmosphere and organic content, and their role in color change, as well as suggestions for future research.

7.1 Estimations of Initial Firing Temperatures

As discussed above, there is no quantified or standardized amount of color change that signifies when the IFT has been exceeded. Rice (1987) uses “little to no change” and “marked change” to describe the level of color change observed. For this study the criteria used to establish IFT estimations were that both Value and Chroma, increased by at least two, for instance a measurement of 10YR2/1 increased to 10YR4/3. In most sherds Chroma increased slowly, often not changing in the first few phases of refiring. Value increased more steadily. Value and Chroma were chosen because in the earliest stages of refiring. Hue changed most erratically.

Based on this criteria IFT estimations for the entire sample indicate that 22% of sherds were fired between 400°C and 500°C, 44% were fired between 500°C and 600°C, 11% were fired between 600°C and 700°C, 5% were fired between 700°C and 800°C, and 17% were fired above 600°C but below either 700°C or 800°C (Table 2). Looking at the estimated IFT's of the samples from the Cape Krusenstern site complex and the Ahteut site separately indicates that there were overall differences in firing temperatures between the two sites.

Table 2. Sample number and estimated initial firing temperature.

Sample #	IFT Degrees Celsius
S1	600
S2	600
S3	600
S4	500
S5	600
S6	600
S7	600
S8	600
S9	700
S10	500
S11	500
S12	500
S13	700-800
S14	600
S15	800
S16	700
S17	700-800
S18	700-800

Table 3. Summary of IFT estimates

IFT °C	# of Samples	% Total	IFT °C	# of Samples	% CAKR	IFT °C	# of Samples	%Ahteut
400-500	4	22%	400-500	4	30%	400-500	0	0%
500-600	8	44%	500-600	7	54%	500-600	1	20%
600-700	2	11%	600-700	1	8%	600-700	1	20%
700-800	1	5%	700-800	0	0%	700-800	1	20%
600-800	3	17%	600-800	1	8%	600-800	2	40%
800-900	0	0%	800-900	0	0%	800-900	0	0%

Estimations of IFT's for the Cape Krusenstern samples indicate that 30% of sherds were fired between 400°C and 500°C, 54% were fired between 500°C and 600°C, and 8%:one sherd each, was fired between 600°C and 700°C and 600°C and 800°C. In total, 11 of the 13 sherds from this sample were fired below 600°C (

Table 3). The IFT's of 84% of the Cape Krusenstern samples are well within the low end of the attainable temperature range of an open fire (Rice 1987:156, Gosselain 1991:255, Tite 2008:219).

Estimations of IFT's for the Ahteut site samples indicate that 20% were fired between 500°C and 500°C and 600°C, 20% were fired between 600°C and 700°C, 20% were fired between 700°C and 800°C, and 40% were fired between 600°C and 800°C (

Table 3).

While the sample size is small, samples from the Ahteut site have higher IFT's than the samples from Cape Krusenstern. The results do support the hypothesis that the Ahteut site samples have higher IFT's than the Cape Krusenstern site complex, however it is difficult to draw comparisons and conclusions with small and unbalanced sample sizes. Statistical significance testing is not possible with such small sample sizes. A refiring experiment with a larger sample size from both sites is necessary to draw comparisons between the two sites. Additionally, more detailed site-specific fuel studies and analysis of hearth features are necessary to understand the relationship between firing temperatures and fuel availability at the sites.

Open fires generally reach maximum temperatures between 600°C and 900°C (Rye 1981:103-104, Rice 1987:156, Gosselain 1992:256, Tite 2008:220) with lowest maximum temperatures between 300°C and 560°C (Rye 1981:103-104, Gosselain 1992:256). Even when higher temperatures are reached in an open firing, peak temperatures are only maintained for a few minutes and decline rapidly (Rice 1987:157, Tite 2008:219). Gusts of wind can drop the temperature of an open fire by about 200°C (Rice 1987:156).

The extreme variability in temperature and atmosphere of open firings coupled with the small sample size here mean that IFT interpretations should, in general, be taken as rough estimations (Maggetti et al. 2010:506). Additionally, there are other variables, discussed below, that may affect refiring studies. Considering the interpretations presented here, that 66% of the samples were fired below 600°C, with an additional 11% fired below 700°C, these temperatures fall within the lower end of maximum temperatures that can be reached in open firings. The majority of the sherds with higher estimated IFTs do come from the interior Ahteut site, however the significance of this clustering cannot be determined at this point.

7.2 The Effect of Atmosphere and Organic Content on Estimating IFT's

Additional considerations in interpreting study results are factors such as original firing atmosphere and organic content. Consistent and incremental color change observed in the experiment may be the result of a refiring atmosphere that is not consistent with the original firing atmosphere. Firing atmosphere will constrain the colors of a fired vessel. A reducing atmosphere, where oxygen is not present, will cause ceramics become very dark brown, very dark gray, and black. In an oxidizing atmosphere where oxygen flows freely vessels will become lighter; taking on more red, pink, and orange colors as a result of the oxidization of iron compounds. In fact some potters use the manipulation of atmosphere in kiln firings to control the color of their ceramics (Mitri and Davit 2004:744).

Mitri and Davit (2004) conducted a refiring experiment to estimate IFT's similar to this study. That study differed in the use of a spectrophotometer to measure color change instead of the Munsell color charts, and in the use of both oxidizing and reducing atmospheres. In Mitri and Davit's (2004) experiment Samples with gray cores, interpreted as having been fired in a reducing atmosphere but refired in an oxidizing atmosphere, experience color change similar to that observed in this experiment. Color change occurred, with variables increasing after the lowest refiring temperature and then continuously observed throughout the refiring experiment. This provides no indication of initial firing temperature and eliminated the possibility of determining IFT through color change (Mitri and Davit 2004:743). This exact pattern however, only represents the color change seen on five sherds, Cape Krusenstern site complex sherds S5, S7, and the Ahteut site sherds S14-16. Because of this, estimated IFT's for those 5 sherds, presented above should be rejected.

The remaining 13 sherds, 11 from Cape Krusenstern site complex and two from the Ahteut site became darker losing Hue, Value, and Chroma when fired to 400°C. Color change from a gray to darker gray and black observed at temperatures lower than 700°C are caused by burning off of residual organic content making the estimation of initial firing temperatures difficult (Matson 1971: 66, Rice 1987:428). Organic material in a vessel is often due to the use of organic temper or residue accumulated throughout a vessels uselife, although it can originate in the clay itself. Organic temper and organic residue build up are both common in Arctic ceramics. Organic tempers such as feather, grass, dung, blood and fish eggs were commonly used along with mineral tempers Arctic ceramics. Oil and blood were applied to a vessel as a part of the manufacturing process and throughout a vessels uselife during repairs or in resealing the vessel (Anderson in review).

A majority of the sherds from both sites used in this experiment were tempered with organic materials. Only sherds S1 and S8 from the Cape Krusenstern site complex were tempered with mineral content alone. The remaining 13 sherds were tempered with feather or unknown organic material (

Table 4) (Anderson 2011). With the exception of S13, all sherds the Cape Krusenstern site complex that become darker losing Hue, Value, and Chroma, have estimated IFT's lower than 700°C. This temperature is low enough that organic content could be driving the color change seen at 400°C. Samples S17 and S18 from the Ahteut site are tempered with organic material and become darker at 400°C. These sherds have estimated IFT's of between 600°C and 800°C. This temperature range may still be low enough to be driving the color change seen at 400°C. Regardless of the estimated IFT's this color change seen at 400°C is most likely explained by the burning off of organic content.

Table 4. Summary refiring data including IFT, organic temper type, and color change at 400°C .

Sherd Number	IFT	Organic Temper	Color Change at 400°C
S1	600	None	Darker
S2	600	Unknown	Darker
S3	600	Unknown	Darker
S4	500	Unknown	Darker
S5	600	Unknown	Lighter
S6	600	Unknown	Darker
S7	600	N/A	Lighter
S8	600	None	Darker
S9	700	Feather	Darker
S10	500	Feather	Darker
S11	500	Feather	Darker
S12	500	Feather	Darker
S13	700-800	Unknown	Darker
S14	600	Unknown	Lighter
S15	800	Unknown	Lighter
S16	700	Feather	Lighter
S17	700-800	Unknown	Darker
S18	700-800	Unknown	Darker

Sherds S1, S5, S7, and S8 from Cape Krusenstern site complex do not fit this model at all. Organic temper was not identified in sherd S1 or S8 and both became darker, becoming completely black at 400°C. Although organic temper was not identified in the paste it is possible that organic material accumulated throughout the vessels uselife. Sherd S5 and S7 were tempered with unknown organic material and became lighter in color (gained Hue, Value, Chroma) when fired at 400°C. These sherds had estimated IFT's below 600°C. It is certainly possible that the IFT's presented here are wrong and that the IFT's were high enough to burn out organic content.

A comparison between the color change that occurred in the clay samples from both sites and the archaeological samples shows that sherds did not turn black upon the first stage of refiring as a function of the clay itself. The clay sample from Cape Krusenstern was recorded as 10YR3/1 unfired and 10YR5/1 when fired to 400°C, a slight but noticeable difference from the

Duelks

unfired color (**Error! Reference source not found.**Figure 17 and **Error! Reference source not found.**Figure 18). The clay sample from Ahteut experienced a more drastic change in color upon first firing. The Ahteut clay sample was recorded as 2.5Y6/1 unfired and 10YR5/3 at 400°C (**Error! Reference source not found.**Figure 19 and **Error! Reference source not found.**Figure 20). Although this data represents only a small sample of clay sources it does show that the trend of sherds becoming darker when refired at 400°C is not a function of the clay itself.

Figure 17. Unfired raw clay sample from the Cape Krusenstern site.

Figure 18. Raw clay sample from the Cape Krusenstern site at 400°C.

Figure 19. Unfired raw clay sample from the Ahteut site.

Figure 20. Raw clay sample from the Ahteut site at 400°C.

Figure 21. Color change data for Cape Krusenstern raw clay sample.

Figure 22. Color Change data for the Ahteut site raw clay sample.

It is necessary to account for the presence of organic temper remaining in sherds prior to refiring, as it will help in interpreting color change. However, using the estimated IFT's as a proxy to support the statement that organic temper is driving the color change at 400°C creates a circular reasoning, rendering the argument invalid. A refiring atmosphere that differs from the original firing atmosphere of a vessel will create consistent color change throughout the refiring experiment may obscure IFT's or make them impossible to determine (Matson 1971: 66, Rice 1987:428). Further research is needed to evaluate the validity of these initial firing temperatures.

7.3 Future Research

Additional research including alternative methods will be necessary to estimate IFT of arctic ceramics. A furnace capable of a reducing or highly variable atmosphere, similar to that of an open firing, will be necessary for refiring sherds that we can now confirm were fired in reducing atmosphere. Beyond that, more high-tech and so, more costly methods of analysis may be needed. Some recent research conducted to estimate IFT's include the use of portable spectrophotometer to measure color change, reducing the subjectivity of measurements made by a human observer (Mitri 1998:46, Mitri and Davit 2004). The spectrophotometer is also capable of more precise color measurements than a human observer with a Munsell chart.

A study conducted by Rasmussem et al. (2012) determined firing temperatures of South American ceramics by measuring magnetic susceptibility of refired sherds. An incremental refiring regimen similar to that used in this study but in temperature increments of 30°C was used. This method was successful in estimating IFT's between 400°C and 1000°C. When testing the method on fired clay samples of known IFT, the method produced results accurate within 40°C of actual IFT (Rasmussem et al. 2011:1708).

A third method for estimating IFT's of low fired ceramics is measuring thermal expansion of refired sherds. This method is based on the assumption that (1) refired samples will expand as the refiring temperature increases towards its IFT and (2) that the sherd will contract when the IFT is exceeded due to shrinkage that occurs with the resumption of sintering (Zhu et al. 2014:563). The thermal expansion method has been used in the earlier research of Tite and Roberts, but has been refined by Zhu et al. (2014). In this study the traditional method of measuring expansion and contraction with a dilatometer during the refiring is used and the results are checked through multiple measurements and the use of X-ray diffraction (XRD) to identify minerals present following refiring. Checking results with XRD works particularly well with low-fired ceramics, as it is able to identify the quantity of quartz present. High levels of quartz will remain after firing if IFT's were low. Zhu et al.'s (2014) experimental procedure was successful in identifying IFT's of sherds fired between 450°C and 550°C.

Like most archaeological ceramics from Northwest Alaska, the samples used in the study have the physical characteristics of low-fired pottery. They are thick, coarse, and sometimes crumbly with dark colors that although likely caused from a reducing atmosphere may also indicate the presence of organic material still present in the vessel body. Given these factors and the inaccuracy of estimating IFT through color measurements with the naked eye, the methods of Rasmussem et al. (2011) or Zhu et al. (2014) would be the ideal method for estimating IFT's of sherds from this Northwest Alaska.

8 Conclusion

This research was designed to estimate the initial firing temperatures of Northwest Alaskan pottery within a broader context of understanding pottery production process, fuel use, and the implications of differential access to fuel resources on Northwest Alaskan hunter-

gatherer lifeways. Samples were selected from two sites, the Cape Krusenstern site complex and the Ahteut site. The two sites were chosen for their extensive use of pottery, overlapping occupation periods, and for the comparison of firing temperatures between sites with differential access to fuel.

Estimations of initial firing temperatures presented here are tentative results that require further testing. Initial results indicate that 77% of the samples IFT's were below 700°C, well within the lower end of temperatures that characterize low fired pottery. Issues of firing atmosphere and the presence of organic materials in the paste, however, require further testing before the IFT's can be firmly established. Despite the complications involved in interpreting IFT's this experiment did provide new information regarding Northwest Alaskan ceramics. The consistent color change throughout the refiring experiment confirms that sherds were fired in a reducing atmosphere and it is likely that the sherds that became darker at the first stage of refiring had some amount of organic content present.

Additional studies that emulate open fire atmospheres are needed to determine if the organic content is driving the color change seen after the first firing. It may also be necessary to determine whether the residual organic content present in the sherds was leftover from the manufacturing process, acquired during the use life, or post depositionally. The application of alternate methods of identifying initial firing temperatures such as thermal expansion, XRD, or spectrophotometers may more produce more accurate results. The validity of results can be tested if used in combination with each other,.

Additionally, larger sample sizes will be required to accurately address questions regarding access to fuel, firing temperatures and the overall production process. The identification of firing features and additional fuel studies within sites will help to answer

Duelks

questions about the effect of fuel types on firing temperatures of Alaskan vessels. Beyond reconstructing the production process of Northwest Alaskan ceramics, understanding initial firing temperatures will provide important information regarding environmental constraints of the production process and methods used to overcome them, as well as adding to the understanding of fuel use and management.

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Duelks

Appendices

Duelks

Munsell color measurements for complete dataset.

Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chrom	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chrom	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
CAKR 13617c	1	Unfired	2.5 Y		5	1	Unfired	10 YR		3	1.5	Unfired	2.5 Y		4	1
CAKR 13617c	1	400°C	1 GLEY		3	1	400°C	2.5 YR		3	1	400°C	1 GLEY		2.5	1
CAKR 13617c	1	500°C	1 GLEY		3	1	500°C	10 YR		6	2	500°C	10 YR		6.5	1.5
CAKR 13617c	1	600°C	10 YR		7	3	600°C	10 YR		7	3	600°C	10 YR		7	3
CAKR 13617c	1	700°C	7.5 YR		7	3	700°C	7.5 YR		7	4	700°C	7.5 YR		7	4
CAKR 13617c	1	800°C	7.5 YR		7	4	800°C	7.5 YR		7	4	800°C	7.5 YR		7	4
CAKR 13617c	1	900°C	7.5 YR		7	4	900°C	7.5 YR		7	6	900°C	5 YR		8	4
Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chrom	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chrom	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
CAKR 14514d	2	Unfired	1 GLEY		3	1	Unfired	10 YR		3	2	Unfired	1 GLEY		4	1
CAKR 14514d	2	400°C	1 GLEY		3	1	400°C	2.5 Y		3	1	400°C	1 GLEY		2.5	1
CAKR 14514d	2	500°C	10 YR		6	1	500°C	10 YR		6	2	500°C	10 YR		5	2
CAKR 14514d	2	600°C	10 YR		7	4	600°C	10 YR		7	3	600°C	10 YR		7	4
CAKR 14514d	2	700°C	7.5 YR		7	4	700°C	7.5 YR		7	4	700°C	7.5 YR		7	4
CAKR 14514d	2	800°C	7.5 YR		8	4	800°C	7.5 YR		8	4	800°C	7.5 YR		8	4
CAKR 14514d	2	900°C	5 YR		7	6	900°C	5 YR		7	6	900°C	5 YR		7	6
Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chrom	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chrom	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
CAKR 14001	3	Unfired	2.5 Y		5	1	Unfired	2.5 Y		5	1	Unfired	2.5 Y		2.5	1
CAKR 14001	3	400°C	2.5 Y		3.5	1.5	400°C	2.5 Y		3	1	400°C	2.5 Y		4	1
CAKR 14001	3	500°C	10 YR		5.5	2	500°C	10 YR		5	1	500°C	10 YR		6	1
CAKR 14001	3	600°C	10 YR		6	3	600°C	10 YR		6	2	600°C	10 YR		6	2
CAKR 14001	3	700°C	10 YR		6	3	700°C	10 YR		7	2	700°C	10 YR		7	2
CAKR 14001	3	800°C	7.5 YR		7	6	800°C	7.5 YR		7	4	800°C	7.5 YR		7	4
CAKR 14001	3	900°C	5 YR		7	6	900°C	5 YR		7	4	900°C	5 YR		7	4
Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chrom	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chrom	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
CAKR 13148	4	Unfired	10 YR		3	1	Unfired	10 YR		3	1.5	Unfired	10 YR		2	1
CAKR 13148	4	400°C	10 YR		4	1	400°C	10 YR		5	3	400°C	10 YR		3	1
CAKR 13148	4	500°C	7.5 YR		5.5	4	500°C	7.5 YR		6	4	500°C	7.5 YR		6	4
CAKR 13148	4	600°C	7.5 YR		6	5	600°C	7.5 YR		6	5	600°C	7.5 YR		6	5
CAKR 13148	4	700°C	7.5 YR		6	5	700°C	7.5 YR		6	5	700°C	7.5 YR		6	5
CAKR 13148	4	800°C	5 YR		6	6	800°C	5 YR		7	8	800°C	5 YR		7	8
CAKR 13148	4	900°C	5 YR		7	4	900°C	5 YR		6	8	900°C	5 YR		6	8

Duelks

Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chror	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chror	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
CAKR 14026b	5	Unfired	10	YR	2	1	Unfired	10	YR	6	2	Unfired	10	YR	5	2
CAKR 14026b	5	400°C	10	YR	4	2	400°C	10	YR	3	1	400°C	10	YR	3	1
CAKR 14026b	5	500°C	7.5	YR	6	4	500°C	7.5	YR	6	3	500°C	7.5	YR	6	2
CAKR 14026b	5	600°C	7.5	YR	6	6	600°C	7.5	YR	6	4	600°C	7.5	YR	6	4
CAKR 14026b	5	700°C	7.5	YR	6	6	700°C	7.5	YR	7	4	700°C	7.5	YR	7	4
CAKR 14026b	5	800°C	5	YR	7	8	800°C	5	YR	7	6	800°C	5	YR	7	7
CAKR 14026b	5	900°C	5	YR	7	8	900°C	5	YR	7	6	900°C	5	YR	7	6
Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chror	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chror	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
CAKR 14455c	6	Unfired	10	YR	4	1	Unfired	10	YR	3	2	Unfired	10	YR	4	2
CAKR 14455c	6	400°C	1	GLE Y	3	1	400°C	2.5	Y	3	3	400°C	1	GLE Y	2.5	1
CAKR 14455c	6	500°C	7.5	YR	6	2	500°C	7.5	YR	6	1	500°C	7.5	YR	6	2
CAKR 14455c	6	600°C	7.5	YR	6	4	600°C	7.5	YR	6	4	600°C	7.5	YR	6	4
CAKR 14455c	6	700°C	7.5	YR	6	4	700°C	7.5	YR	6	4	700°C	7.5	YR	6	4
CAKR 14455c	6	800°C	7.5	YR	7	6	800°C	7.5	YR	7	4	800°C	7.5	YR	7	6
CAKR 14455c	6	900°C	7.5	YR	7	4	900°C	5	YR	7	6	900°C	7.5	YR	7	4
Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chror	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chror	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
CAKR 14503c	7	Unfired	10	YR	4	1	Unfired	2.5	Y	2.5	1	Unfired	2.5	Y	2.5	1
CAKR 14503c	7	400°C	10	YR	5	3	400°C	10	YR	5	2	400°C	10	YR	3	1
CAKR 14503c	7	500°C	7.5	YR	6	4	500°C	7.5	YR	6	3	500°C	10	YR	5.5	2
CAKR 14503c	7	600°C	7.5	YR	6.5	4	600°C	7.5	YR	6	4	600°C	7.5	YR	6	4
CAKR 14503c	7	700°C	7.5	YR	6	4	700°C	7.5	YR	6.5	4	700°C	2.5	YR	5	6
CAKR 14503c	7	800°C	5	YR	6	6	800°C	5	YR	6	6	800°C	2.5	YR	5	6
CAKR 14503c	7	900°C	5	YR	5	6	900°C	5	YR	6	6	900°C	5	YR	5	6
Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chror	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chror	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
CAKR 14515e	8	Unfired	10	YR	2.5	1.5	Unfired	10	YR	2.5	2.5	Unfired	10	YR	2	1
CAKR 14515e	8	400°C	1	GLE Y	4	1	400°C	1	GLE Y	3	1	400°C	2.5	Y	3	1
CAKR 14515e	8	500°C	1	GLE Y	3	1	500°C	1	GLE Y	3	1	500°C	1	GLE Y	3	1
CAKR 14515e	8	600°C	7.5	YR	7	3	600°C	7.5	YR	7	2.5	600°C	7.5	YR	7	2.5
CAKR 14515e	8	700°C	7.5	YR	7	4	700°C	7.5	YR	7	4	700°C	7.5	YR	7	4
CAKR 14515e	8	800°C	7.5	YR	7	4	800°C	7.5	YR	7	4	800°C	7.5	YR	7	4
CAKR 14515e	8	900°C	7.5	YR	7	4	900°C	7.5	YR	7	4	900°C	7.5	YR	7	4

Duelks

Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chror	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chror	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
CAKR 14821	9	Unfired	2.5	Y	3	1	Unfired	10	YR	3	1	Unfired	2.5	Y	3	1
CAKR 14821	9	400°C	1	GLEY	2.5	1	400°C	1	GLEY	3	1	400°C	1	GLEY	2.5	1
CAKR 14821	9	500°C	10	YR	5	1	500°C	10	YR	6	1	500°C	10	YR	5	2
CAKR 14822	9	600°C	7.5	YR	5.5	2	600°C	7.5	YR	6	1.5	600°C	7.5	YR	6	1.5
CAKR 14823	9	700°C	7.5	YR	7	4	700°C	7.5	YR	7	4	700°C	7.5	YR	7	4
CAKR 14824	9	800°C	7.5	YR	7	4	800°C	7.5	YR	7	4	800°C	7.5	YR	7	4
CAKR 14825	9	900°C	7.5	YR	7	4	900°C	7.5	YR	7	4	900°C	7.5	YR	7	4
Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chror	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chror	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
CAKR 14683	10	Unfired	10	YR	3	1	Unfired	10	YR	3	1.5	Unfired	10	YR	3	1
CAKR 14683	10	400°C	1	GLEY	4	1	400°C	10	YR	3	1	400°C	10	YR	2	1
CAKR 14683	10	500°C	7.5	YR	6	6	500°C	10	YR	6	4	500°C	7.5	YR	6	6
CAKR 14683	10	600°C	7.5	YR	6	4	600°C	7.5	YR	6	4	600°C	7.5	YR	6	4
CAKR 14683	10	700°C	5	YR	6	4	700°C	5	YR	6	4	700°C	5	YR	6	4
CAKR 14683	10	800°C	5	YR	6	3	800°C	5	YR	6	4	800°C	5	YR	6	4
CAKR 14683	10	900°C	5	YR	5	3	900°C	5	YR	6	4	900°C	5	YR	6	4
Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chror	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chror	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
CAKR 15147	11	Unfired	10	YR	4	2	Unfired	10	YR	3	1	Unfired	10	YR	3	1
CAKR 15147	11	400°C	1	GLEY	2.5	1	400°C	1	GLEY	2.5	1	400°C	1	GLEY	2.5	1
CAKR 15147	11	500°C	7.5	YR	5	1	500°C	7.5	YR	5	4	500°C	7.5	YR	5	5
CAKR 15147	11	600°C	7.5	YR	6	4	600°C	7.5	YR	6	4	600°C	2.5	YR	5	6
CAKR 15147	11	700°C	7.5	YR	6	4	700°C	2.5	YR	5	6	700°C	2.5	YR	5	6
CAKR 15147	11	800°C	5	YR	6	4	800°C	5	YR	6	6	800°C	2.5	YR	6	8
CAKR 15147	11	900°C	5	YR	5	3	900°C	5	YR	6	4	900°C	2.5	YR	6	4
Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chror	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chror	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
CAKR 14879	12	Unfired	10	YR	6	2	Unfired	10	YR	3	2	Unfired	10	YR	2	1
CAKR 14879	12	400°C	1	GLEY	3	1	400°C	10	YR	2.5	1	400°C	10	YR	2	1
CAKR 14879	12	500°C	7.5	YR	5	4	500°C	7.5	YR	5	3	500°C	7.5	YR	5	3
CAKR 14879	12	600°C	7.5	YR	5	4	600°C	7.5	YR	5	3	600°C	2.5	YR	5	4
CAKR 14879	12	700°C	5	YR	6	4	700°C	5	YR	6	4	700°C	5	YR	6	4
CAKR 14879	12	800°C	5	YR	6	4	800°C	5	YR	6	4	800°C	5	YR	6	4
CAKR 14879	12	900°C	5	YR	6	4	900°C	5	YR	6	4	900°C	5	YR	6	4

Duelks

Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chror	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chror	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
CAKR 14343II	13	Unfired	2.5	Y	2.5	1	Unfired	2.5	Y	3	1	Unfired	2.5	Y	3	1
CAKR 14343II	13	400°C	1	GLE	2.5	1	400°C	2.5	Y	2	1	400°C	2.5	Y	3	1
CAKR 14343II	13	500°C	10	YR	5	1	500°C	10	YR	6	2	500°C	10	YR	6	1
CAKR 14343II	13	600°C	10	YR	7	2	600°C	10	YR	7	3	600°C	10	YR	7	2
CAKR 14343II	13	700°C	10	YR	7	3	700°C	10	YR	8	2	700°C	10	YR	8	2
CAKR 14343II	13	800°C	7.5	YR	8	3	800°C	7.5	YR	8	3	800°C	7.5	YR	8	3
CAKR 14343II	13	900°C	10	YR	8	3	900°C	7.5	YR	8	3	900°C	7.5	YR	8	3
Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chror	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chror	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
SLA 013	14	Unfired	2.5	Y	5.5	2	Unfired	2.5	Y	3	1	Unfired	2.5	Y	2	1
SLA 013	14	400°C	10	YR	6	3	400°C	10	YR	7	2	400°C	2.5	YR	5	1
SLA 013	14	500°C	7.5	YR	7	4	500°C	10	YR	7.5	2	500°C	2.5	YR	6	1
SLA 013	14	600°C	7.5	YR	7	4	600°C	7.5	YR	7	3	600°C	7.5	YR	7	2.5
SLA 013	14	700°C	7.5	YR	7	4	700°C	10	YR	7.5	3	700°C	10	YR	7.5	3
SLA 013	14	800°C	7.5	YR	7	4	800°C	7.5	YR	8	3	800°C	7.5	YR	7.5	3.5
SLA 013	14	900°C	5	YR	7	6	900°C	7.5	YR	8	3	900°C	7.5	YR	8	3
Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chror	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chror	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
SLA 012	15	Unfired	10	YR	3	1	Unfired	10	YR	6	3	Unfired	10	YR	4.5	1
SLA 012	15	400°C	10	YR	6	3	400°C	10	YR	6	2	400°C	10	YR	3.5	1
SLA 012	15	500°C	10	YR	6	2	500°C	10	YR	7	4	500°C	10	YR	3.5	1
SLA 012	15	600°C	10	YR	7	2	600°C	10	YR	7	4	600°C	10	YR	4.5	1
SLA 012	15	700°C	10	YR	7	2.5	700°C	7.5	YR	7	2.5	700°C	10	YR	7	1
SLA 012	15	800°C	10	YR	7	2	800°C	7.5	YR	8	4	800°C	7.5	YR	7	4
SLA 012	15	900°C	7.5	YR	7	4	900°C	7.5	YR	8	4	900°C	7.5	YR	8	4
Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chror	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chror	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
SLA 018	16	Unfired	10	YR	6	3	Unfired	10	YR	5	1	Unfired	10	YR	2	1
SLA 018	16	400°C	10	YR	5.5	3	400°C	10	R	4	1	400°C	10	YR	4	1
SLA 018	16	500°C	7.5	YR	6	4	500°C	10	YR	5	1	500°C	10	YR	6	2
SLA 018	16	600°C	7.5	YR	6	5	600°C	7.5	YR	7	2.5	600°C	7.5	YR	7	2
SLA 018	16	700°C	7.5	YR	7	4	700°C	7.5	YR	7	4	700°C	7.5	YR	7	4
SLA 018	16	800°C	7.5	YR	7	4	800°C	7.5	YR	7	4	800°C	5	YR	7	4
SLA 018	16	900°C	5	YR	6	6	900°C	7.5	YR	8	4	900°C	7.5	YR	8	4

Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chrom	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chrom	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
SLA 120	17	Unfired	10 YR		4.5	2	Unfired	10 YR		4	2	Unfired	10 YR		3	2
SLA 120	17	400°C	10 YR		3	1	400°C	10 YR		3	1	400°C	2.5 YR		3	1
SLA 120	17	500°C	10 YR		6.5	2	500°C	10 YR		6	1	500°C	10 YR		5	1
SLA 120	17	600°C	10 YR		7	3	600°C	10 YR		7	2	600°C	10 YR		7	2
SLA 120	17	700°C	10 YR		8	2	700°C	10 YR		8	2	700°C	10 YR		8	2
SLA 120	17	800°C	7.5 YR		8	3	800°C	7.5 YR		8	2	800°C	7.5 YR		8	2
SLA 120	17	900°C	7.5 YR		8	3	900°C	7.5 YR		8	3	900°C	7.5 YR		8	3
Catalog #	Sample #	Temp.	Ext. Hue	Ext. Hue C	Ext. Value	Ext. Chrom	Temp.	Int. Hue	Int. Hue C	Int. Value	Int. Chrom	Temp.	CS Hue	CS Hue Cc	CS Value	CS Chrom.
SLA 121	18	Unfired	2.5 YR		2	1	Unfired	10 YR		5	2	Unfired	10 YR		5	2
SLA 121	18	400°C	10 YR		3	1	400°C	10 YR		3	1	400°C	10 YR		2.5	1
SLA 121	18	500°C	10 YR		7	3	500°C	10 YR		6	2	500°C	10 YR		6	2
SLA 121	18	600°C	7.5 YR		8	2	600°C	10 YR		8	2	600°C	10 YR		8	2
SLA 121	18	700°C	10 YR		8	2	700°C	10 YR		8	2	700°C	10 YR		8	2
SLA 121	18	800°C	7.5 YR		8	3	800°C	7.5 YR		8	3	800°C	7.5 YR		8	3
SLA 121	18	900°C	7.5 YR		8	3	900°C	7.5 YR		8	3	900°C	7.5 YR		8	3

Figure A1. Sample 1 Exterior

Figure A2. Sample 1 Interior

Figure A3. Sample 1 Cross Section

Duelks

Figure A4. Sample 2 Exterior

Figure A5. Sample 2 Interior

Figure A6. Sample 2 Cross Section

Figure A7. Sample 3 Exterior

Figure A8. Sample 3 Interior

Figure A9. Sample 3 Cross Section

Figure A10. Sample 4 Exterior

Figure A11. Sample 4 Interior

Figure A12. Sample 4 Cross Section

Figure A13. Sample 5 Exterior

Figure A14. Sample 5 Interior

Figure A15. Sample 5 Cross Section

Figure A16. Sample 6 Exterior

Figure A17. Sample 6 Interior

Figure A18. Sample 6 Cross Section

Figure A19. Sample 7 Exterior

Figure A20. Sample 7 Interior

Figure A21. Sample 7 Cross Section

Figure A22. Sample 8 Exterior

Figure A23. Sample 8 Interior

Figure A24. Sample 8 Cross Section

Duelks

Figure A25. Sample 9 Exterior

Figure A26. Sample 9 Interior

Figure A27. Sample 9 Cross Section

Figure A28. Sample 10 Exterior

Figure A29. Sample 10 Interior

Figure A30. Sample 10 Cross Section

Figure A31. Sample 11 Exterior

Figure A32. Sample 11 Interior

Figure A33. Sample 11 Cross section

Duelks

Figure A34. Sample 12 Exterior

Figure A35. Sample 12 Interior

Figure A36. Sample 12 Cross Section

Duelks

Figure A37. Sample 13 Exterior

Figure A38. Sample 13 Interior

Figure A39. Sample 13 Cross Section

Duelks

Figure A40. Sample 14 Exterior

Figure A41. Sample 14 Interior

Figure A42. Sample 14 Cross Section

Duelks

Figure A43. Sample 15 Exterior

Figure A44. Sample 15 Interior

Figure A45. Sample 15 Cross Section

Figure A46. Sample 16 Exterior

Figure A47. Sample 16 Interior

Figure A48. Sample 16 Cross Section

Figure A49. Sample 17 Exterior

Figure A50. Sample 17 Interior

Figure A51. Sample 17 Cross Section

Figure A52. Sample 18 Exterior

Figure A53. Sample 18 Interior

Figure A54. Sample 18 Cross Section