RADIANT HEAT EFFECTS ON CERAMIC ARTIFACTS FROM THE AMERICAN SOUTHWEST: FROM EXPERIMENTAL RESULTS TO SITE TREATMENT GUIDELINES

By

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ABSTRACT

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Radiant Heat Effects on Ceramic Artifacts from the American Southwest: From Experimental Results to Site Treatment Guidelines

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Archaeological assemblages in the American Southwest are currently subjected to periodic wildfires and prescribed burns, and have been exposed to fires in the past. Ceramics are a key constituent of these assemblages, leading to questions regarding the effects of post-depositional heat exposure on pottery. Alterations of ceramic surface appearance and other attributes have been observed following wildfires, and such changes are significant because intact ceramics provide important temporal context and social information. Over the past 150 years, southwestern wildfires have shifted away from the historical high-frequency, low-severity regime; thus, cultural resources can be exposed to fires that are potentially more damaging than have occurred in the past. The range of fire environments and the duration and intensity of heating that result in damages to ceramic artifacts have not been previously systematically assessed. Results from laboratory tests conducted as part of the Joint Fire Science Program-funded ArcBurn project demonstrate that radiant heat fire environments, sustained dose, and ceramic category are important determinates for predicting the patterns of alteration. Results can be used to identify fire environments that cause loss of cultural information from artifact assemblages in order to develop management treatments and procedures to guide archaeological preservation in fire-prone landscapes.

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Chapter 1. Introduction

Over the centuries, ecological structures in the United States have been altered due to human action and climate change. One example of this is wildfires, which have become larger and more severe in recent decades across many regions, including the American Southwest (Allen 2001; Romme et al. 2009). Although wildfires can be beneficial for the rejuvenation of natural resources that are fire-adapted or fire-dependent, other resources, such as archaeological sites, are non-renewable and can be damaged or destroyed by wildfires or prescribed burns. This damage thus becomes an issue of permanent loss of cultural heritage in fire-prone landscapes.

The topic for this thesis was established by the research project entitled *Linking Field Based and Experimental Methods to Quantify, Predict and Manage Fire Effects on Cultural Resources*, hereafter referred to by its working title, ArcBurn. This project is led by principal investigator Dr. Rachel Loehman of the US Geological Survey, and is a collaborative project of archaeologists, fire ecologists, fire behavior specialists, and foresters from the US Forest Service, US Geological Survey, National Park Service, The Forest Guild, and southwestern tribes. ArcBurn is funded by the Joint Fire Science Program, a collaborative interagency organization in the Department of the Interior that funds scientific research on wildland fires and distributes results to help policymakers, fire managers and practitioners make sound decisions (http://www.firescience.gov/JFSP_about_us.cfm). The overarching goal of the ArcBurn project is to better understand effects of wildfires and prescribed burns on archaeological resources, using rigorous fire effects testing and analysis in wildfire and controlled laboratory settings. Project collaborators will then translate experimental results into guidelines to help forest and fire managers use the best available science to make decisions about how to protect cultural resources during fuel treatments, prescribed fire, wildfire suppression, and post-fire rehabilitation. The controlled laboratory experiments are conducted at the Missoula Fire Sciences Laboratory in Missoula, Montana on three artifact types found in the culture-rich north-central region of New Mexico: ceramics, obsidian, and welded tuff masonry blocks (architectural stone). These three artifact types are tested in three fire environments common to the region: smoldering (ground fire), flame (surface fire) and radiant heat (crown fire/slash pile burn).

There are many challenges to replicating fire environments in a lab and measuring their effects on materials, so prior to testing, Dr. Loehman assembled a team of consultants and co-principal investigators. Each expert was chosen based on their specialist knowledge of particular artifacts, fire behavior, engineering, material sciences or forestry: Bret Butler and Jim Reardon (USFS Missoula Fire Sciences Laboratory), Jennifer Dyer (USFS Six Rivers National Forest), Connie Constan (USFS Santa Fe National Forest), Jamie Civitello and Anastasia Steffen (Valles Caldera National Preserve), Rory Gauthier (National Park Service, Bandelier National Park), Alexander Evans (The Forest Guild), and Ronald Loehman (University of New Mexico). Many of these consultants work for northern New Mexico land management organizations and are invested in learning how wildfires and prescribed burns, which are common in the area, affect their local archaeological resources so that they can better manage the effects from severe fires.

This thesis focuses on one component of the experimental work conducted for the ArcBurn project: effects of radiant heat on ceramics, and potential loss of information that might result from exposure to crown fire or slash fire environments. I then demonstrate how this information can be used to develop treatment guidelines to reduce damages and loss of cultural information resulting from fire exposure. Throughout this document, terms specific to this study are employed, and their definitions can be found in Table 1.1.

Table 1.1. Terms used throughout this thesis (Fire-related definitions adapted from the National Wildfire Coordinating Group, http://www.nwcg.gov/pms/pubs/glossary/index.htm).

Term	**Definition**
Category	Sherds that share key decoration, slip, and paste attributes and are therefore considered equivalent for the purposes of this study; for example plain utility, textured utility, glaze paint, mineral paint, and carbon paint.
Crown Fire	A fire that advances to the tops of trees or shrubs more or less independent of a surface fire.
Damage	Alteration of an artifact's attributes that is severe enough to impact an archaeologist's ability to obtain information critical to the interpretation of culture history.
Digging Line	A line cleared of combustible materials created by fire crews, generally with hand tools. Intended to contain or control a fire.
Dose	The temperature and duration material culture is subject to in an experiment.
Dozer Line	A line cleared of combustible materials constructed by the front blade of a dozer, intended to contain or control a fire.
Effect	Alteration or change, but not severe enough to impact an archaeologist's ability to gain knowledge from the artifact's original attributes.
Experiment	Overarching design for systematically testing artifacts in a controlled laboratory setting.
Fuel	Any combustible material.
Fuel Load	The amount of fuel present expressed in weight of fuel per unit area. In this case, it is measured by the consumable fuel's dry weight.
Ground Fire	Fire that consumes the organic material beneath the surface fuel layer (smoldering).
Fire Intensity or Intensity	Heat released per unit of time; the primary unit is BTU (British thermal unit) per second per foot of fire front.
Management	Implementation of appropriate preservation tactics.
Post-Burn	Subsequent to heat-testing.
Pre-Burn	Prior to heat-testing.
Prescribed Burn	Any fire intentionally ignited by management actions in accordance with applicable laws, policies, and regulations to meet specific objectives.
Preservation Guide	A reference for resource managers to assist in making the best management decisions to minimize damages to cultural resources in a fire-prone environment.
Severity	Degree to which a site has been altered or disrupted by fire; loosely, a product of fire intensity, residence time and the nature of the archaeological site.
Sherd	Any pottery fragment – a piece of broken vessel or other earthenware item that was produced by Native Americans during the historic or prehistoric period.

Term	Definition
Slash	Tree or brush debris resulting from such natural events as wind, fire, or snow breakage; or such human activities as road construction, logging, pruning, thinning, or brush cutting. Slash includes logs, chunks, bark, branches, stumps, and broken understory trees or brush.
Surface Fire	Fire that burns loose organic debris on the surface, which includes dead branches, leaves, and low vegetation.

In this thesis, a prototype preservation guide is developed, which makes recommendations based only on the radiant heat effects to ceramics. This is not a complete or final product but is an initial step in development, to be finalized as a working document. Only after laboratory studies are completed and an extensive consultation with its intended audience and other experts is done, can the guide be developed into its final form as a tool to advise managers in their decisions. The audience for this guide includes archaeologists and fire managers, with the goal of bridging the two fields. The idea is to keep the guide efficient and simple so managers are motivated to use it in the field. As such, the main guide page of the prototype takes the form of a decision tree, which provides the opportunity for a quick assessment of fire danger levels near their sites.

Some reasons that archaeologists are interested in protecting artifacts from fire are: 1) Artifacts are important recorders of past history, culture, and land use; 2) Intact assemblages preserve our country's heritage for future generations; and 3) Archaeological sites on federal land are protected by law and designated managers must preserve them to the best of their abilities. Ceramics, for example, hold many clues about the past in the attributes they carry. As described in more detail in Chapter 2, decorations on the sherds, the technology of manufacture, and sherd density assist archaeologists in understanding the timeframes during which ceramics were produced, function, and trade patterns between groups.

In this study, the tested sherds were separated based on their decoration attributes, as this may be the most susceptible attribute in radiant heat. These categories are widely recognized as general classes of ceramics that can be found in ArcBurn's region of study. The five decorative ceramic categories are: textured utility, carbon paint, glaze paint, mineral paint, and plain utility (Figure 1.1).

Figure 1.1. Examples of ArcBurn ceramic categories

Besides the valuable information archeologists can glean from intact artifacts, the nation's cultural heritage is protected by law. A series of Federal laws (http://www.nps.gov/archeology/public/publicLaw.htm), with The National Historic Preservation Act of 1966 serving as arguably the crucial mandate, requires federal agencies to protect cultural resources on government lands. Archaeologists have been working alongside fire managers for decades, and have developed several tools to assist archaeologists and fire managers in protecting sites from fire-damage (Gassaway, personal communication 2015). Unfortunately, every region is different, not only from specific archaeological material, but fire regimes and fuel compositions as well. Due to this variability, it may not be possible to create a preservation guide that works universally, which is why attempting to make a regionally and material-specific guide might be the most beneficial and user-friendly approach, as initiated in this thesis. Since approximately 14% of northern New Mexico is public land, under which its rich culture-history is protected, and since it is a fire-prone environment, it is the ideal place to test a regionally and material-focused protection guide. There have been other experiments in which scientists have tested fire effects on artifacts (presented in the following subsection), but the ArcBurn project is the first study with the goal of collecting data specifically in hopes of developing a guide.

Starting in the 1980s, with the increasingly common occurrence of very large and severe fires, cultural resource managers began to more systematically turn their attention to the range of threats the archaeological record faced. Studies were conducted on how heat and flame environments might damage archaeological resources. These studies, and those that followed, paved the way for the research being conducted here. The following subsection details a few of the experimental designs which provide a foundation for the ArcBurn project.

Literature Review of Experimental Approaches to Fire Damage of Artifacts

A number of practitioners have conducted burn tests on ceramics (e.g., Bronitsky 1986; Bronitsky and Hamer 1986; Cogswell et al. 1996; Lentz et al. 1996; Pierce 2005; Rasmussen et al. 2012; Schiffer 1990; Schiffer et al. 1994; Sturdevant et al. 2009; Young and Stone 1990). In addition to the experimental work itself, land management agencies, especially the US Forest Service and Bureau of Land Management, have published several reports or given presentations on this topic as a reference guide for archaeologists and fire managers to help disseminate this research (Buenger 2003; Duke et al. 2003; Ruscavage-Barz 1999; Ryan 2010; Ryan et al. 2012). The following table (Table 1.2) is a summation from a literature review conducted on publications and reports pertaining to the results of ceramic artifact heat testing.

Table 1.2. Summary of experimental work pertaining to thermal effects on ceramics.

Study reference	Exposure temperature	Observed effect(s)
Bennett and Kunzmann (1985)	350°C	Paint loss/change
	400˚C-600˚C	Core pattern change
	400-1000˚C	Paint loss/change
	500˚C	Spalling
	500-600˚C	Slip color change
	600˚C	Cracking
	600-1000˚C	Oxidation

Study reference	Exposure temperature	Observed effect(s)
Buenger (2003)	600°C-1000°C	Paint loss/change Slip color change
Crandall and Ging (1955)	700˚C-750˚C	Fracture
Duke et al. (2003)	350˚C	Cracking Oxidation Slip color change Spalling Vitrification
Lissoway (1986)	350˚C	Paint loss/change
Rice (1987)	200˚C-500˚C	Oxidation
	400˚C-600˚C	Cracking
	900˚C-1200˚C	Vitrification
Ryan (2010)	350˚C	Paint loss/change
	750˚C-870˚C	Spalling
Ryan et al. (2012)	500˚C-900˚C	Oxidation
	573 ˚C-870˚C	Temper alteration
	750˚C-870˚C	Spalling
	900˚C-1100˚C	Vitrification
Rye (1981)	500°C	Oxidation
Schiffer et al. (1994)	>800˚C	Cracking
Shepard (1956)	800˚C	Oxidation

As Table 1.2 demonstrates, there has been extensive experimentation already conducted on effects of heat exposure to ceramics that set the stage for more research. However, there are gaps in knowledge that drive the ArcBurn project's design and methods. Key examples are the lack of prior information on the duration of heating that caused observed effects, and the lack of specification of how their studies apply to real-world fire environments.

For example, Bennett and Kunzmann (1985) authored one of the first reports of thermal experiments on cultural resources. They conducted experiments on quartz, obsidian, pottery sherds, stoneware, china, glass, bone, and enameled tinware. They did not thoroughly explain their methods of heating, but it is briefly noted that they placed various artifacts in a muffle furnace (similar to a kiln) at temperatures ranging from 200° to 800°C for periods of several hours. Although this work established a foundation for many later publications, it is difficult to know how their results correlate to real world conditions. Archaeological sites exposed to crown or surface fires experience a maximum of 90 seconds of radiant heat (Silvani and Morandini 2009). Thus, the environment Bennett and Kunzmann simulated might not be realistic, although they certainly identified a range of effects radiant heat may potentially cause.

In 2003, Brent Buenger wrote his dissertation on the topic of wildfire effects on artifacts and conducted two experiments. The first was to validate or contradict Bennett and Kunzmann's (1985) results in a muffle furnace and the second was a wind tunnel experiment, which would replicate an open flame surface fire environment. Buenger conducted thermal experiments at the Missoula Fire Science Laboratory on mammal bone, mussel shell, lithics (porcelinite, obsidian, chert, phosphoria, novaculite, silicified wood, and sandstone), pottery (prehistoric and historic), and historic glass artifacts. His tests in the wind tunnel were conducted on a burn table, on which the fuel bed (simulated ground surface loaded with fuel) was loaded with excelsior (wood shavings to assist in ignition) and ponderosa pine sticks in light, moderate, moderate-heavy and heavy loads. These fuels were then exposed to low and then high wind velocities. His ceramics results from these tests were, "no significant thermal damage in the form of thermal fracturing or spalling was observed for Southwestern black-on-white and corrugated pottery sherd specimens" (Buenger 2003:246). Buenger was much more detailed in reporting his methodology than his predecessors, but questions remain about his ceramic categories, replicability, and reporting. Buenger lumped the black-on-white, corrugated and gray ware into one prehistoric ceramic category and had only a sample size of 3 sherds per wind tunnel test. Last, Buenger acknowledged throughout his dissertation that other effects may occur to ceramics other than fracture and spalling, but fails to evaluate those other effects.

These two foundational studies, along with others, have been pivotal in the current understanding of how to protect cultural resources from wildland fires and prescribed burns. However, because of the limitation of these studies, the ArcBurn project tests seek to continue developing the understanding of fire effects to cultural resources. The purpose of more testing is to strengthen the current knowledge by reporting more detailed methods, providing more replication of each experiment, and by simulating several real-world fire environments.

In order to understand why improving protection of this archaeological record is important, it is crucial to establish the historic and prehistoric Native American occupation of the Jemez Mountains where the ArcBurn project is focused, and provide more background on both the ceramic artifacts and the fire history of the region. The following chapter provides background for each.

Chapter 2. Cultural and Environmental Background

Cultural and Artifact Background

Anthropologists divide Southwestern past peoples into three primary ancestral culture groups: Mogollon, Hohokom and Ancestral Puebloan (previously known as the Anasazi), each of which is considered to occupy a sub-region of the Southwest (Cordell 1997; Wormington 1947) (Figure 2.1). The Mogollon occupied the space from the southeast quarter of Arizona, to the southern half of New Mexico, to the north-central portion of northwest Mexico. The Hohokam resided in the central-southern portion of Arizona, and the Ancestral Puebloan occupied the space from southern Utah, to southwestern Colorado, to northern Arizona, to northern New Mexico. This thesis focuses on fire effects on the material culture of Ancestral Puebloans who lived in the Jemez Mountains in north-central New Mexico, as shown in the red box in Figure 2.1.

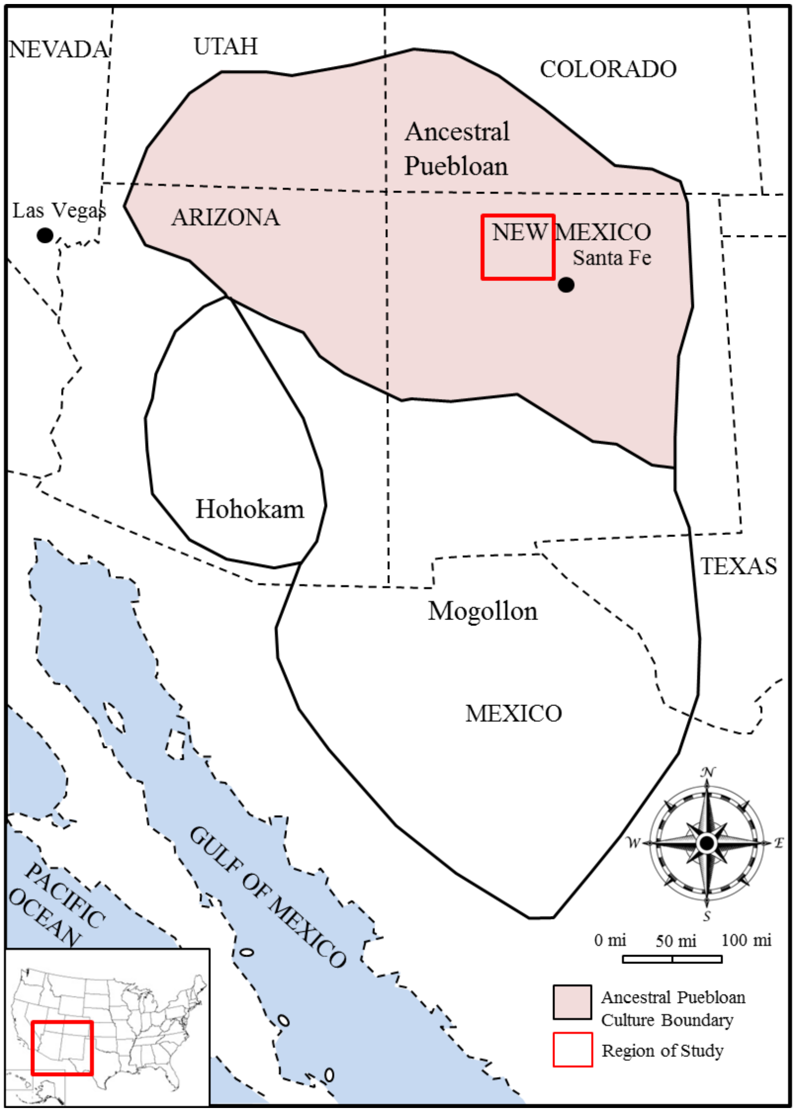


Figure 2.1. Map of Southwestern US outlining Hohokam, Mogollon and Ancestral Puebloan culture boundaries as well as the ArcBurn study area (adapted from Cordell 1997:24, Figure 1.7).

Archaeologists use attributes of ceramics, such as shape, paint style and color, corrugation style, etc. to define cultural boundaries on the landscape (Blinman 1993; Cordell 1994). Thus, to interpret cultural history experienced prior to written record, archaeologists look to oral history and the archaeological record, including ceramics, to tell the story.

Southwest tribes are known for their specialized knowledge of ceramic manufacturing and their iconic decorations (Dobyns 2002; Lyneis 1995). Their well-developed ceramic production varied considerably across the region and through time, which, along with other supporting data, have been central to determining cultural transitions in the southwest (Cordell 1994). Across the Ancestral Pueblo area, there are a number of different "branches" and numerous local developments. The following table describes the established basic chronology and development of the Ancestral Puebloan peoples, as well as the more detailed chronology for our study area, that of the Northern Rio Grande peoples.

Table 2.1. Pecos Classification of Ancestral Puebloan chronology as outlined by Ruscavage-Barz (1999:13-14) and Reyman (1993), and classification of Northern Rio Grande chronology as outlined by Wendorf and Reed (1955).

ANCESTRAL PUEBLOAN			**NORTHERN RIO GRANDE**		
Date	**Puebloan Culture Phase**	**Phase Description**	**Date**	**Northern Rio Grande Culture Phase**	**Phase Description**
A.D. 1600-present	Pueblo V (Historic)	Spanish military and Catholic church influences; Ancestral Puebloan groups revolted against Spanish; pueblos were downsized or abandoned in the early contact period; Puebloan population declined	A.D. 1600-present	Historic Period	Population declines from warfare and illness; Several tribes within the Puebloan people revolted against Spanish influences; Puebloan people fled from Spanish for survival, some of whom later returned to their ancestral land
A.D. 1300-1600	Pueblo IV	Larger pueblos; centrally located in plazas; black on white ceramics largely replaced by a number of different polychrome traditions; plain utility category partially replaced textured utilities	A.D. 1325-1600	Classic Period	Glaze paint and red slipped pottery introduced; beginning of mesa-top farming; large pueblos with several hundred rooms (multiple stories) with several plazas; masonry and adobe used for construction of pueblos; kivas present
A.D. 1100-	Pueblo III	Multi-story pueblos; elaborate	A.D. 1200-	Coalition	Several groups move into region;

ANCESTRAL PUEBLOAN			**NORTHERN RIO GRANDE**		
Date	**Puebloan Culture Phase**	**Phase Description**	**Date**	**Northern Rio Grande Culture Phase**	**Phase Description**
1300		black on white ceramics; abandonment of the four corners region at the end of the period	1325		small pueblos and field houses with agricultural features appear; masonry replaces adobe for pueblo construction; pottery decoration with organic pigments emerge
A.D. 900-1100	Pueblo II	Cliff granaries; emergence of corrugated ceramics	A.D. 600-1200	Developmental Period	Pottery technology introduced; increase in number of pueblos after A.D. 900
A.D. 700-900	Pueblo I	Surface-level rooms; emergence of early black on white pottery			
A.D. 400-700	Basketmaker III (Developmental Archaic)	More elaborate pit houses; upright storage cists; bow and arrow technology; trough metates; emergence of early pottery	B.P. 15,000-A.D. 600	Preceramic period	Begins with isolate artifacts; little activity, develops into sporadic temporary use (hunting, gathering, collecting) and use of an array of stone tools
A.D. 400	Basketmaker II (Archaic)	Small pit houses; storage cists, shallow grinding slabs; one-hand manos, corner and side-notched dart points; employment of agriculture			

The ceramics we find today are representative of vessels and dishes from which organics and liquids (often food) could be processed, cooked, served, or stored. Surface treatments, clay choices, and temper choices not only affected the vessel’s practical characteristics, such as impermeability to liquids and susceptibility to chipping, but also contain, especially for the surface treatments, social and ideological information as well (Schiffer and Skibo 1997). The following paragraphs provide a deeper understanding of how the sherds we find today were manufactured in the beginning of their systemic (i.e. use-life) context.

The production process of pottery has four stages: obtain raw materials, refine and blend raw materials, manufacture using operational methods, and distribution (Rye 1981; Sinopoli 1991). Obtaining raw materials can be accomplished through direct procurement, trading or purchasing. The basic raw materials of pottery are water, clay (paste) and temper which are mixed together at various ratios (depending on the vessel’s function and intended characteristics). Since clay is elastic, temper is added to clay in order to, “counteract the tendency of the pure clay to crack during the shrinkage that takes place in sun-drying and in firing” (Guthe 1925:21).

The preparation of the raw materials consists of cleaning out the coarser materials and plant remains. This can be done by sifting or drying the clay in the sun and breaking the unwanted matter out. The method of blending materials can vary, but the simplest way is to wet the clay until it becomes plastic and then sprinkle in non-plastic additives (temper).

Manufacturing varies heavily, but the simplest way to accomplish the task of vessel formation was by hand through kneading the clay and then pinch-forming, coiling, and/or using a mold (one or all of which may be employed for a single vessel) (Rye 1981). Once the vessel is formed, it is dried and then often, but not always, dipped or painted in a slip of fine clay. If the vessel is slipped, it must be dried again, and if it is to be further decorated, this is when the manufacturer would do so. Decoration takes many forms; it could be painted with simple pigment or glaze, or textured, which is created through incising, beating, scraping, trimming, shaving and punctuating (Graves 2001; Rye 1981).

When the vessel is again dry, it is fired. Firing subjects the vessel to sufficient heat for long enough to ensure that the clay minerals undergo several chemical and physical changes making the vessel body harder, less porous and stable (Rye 1981). The potter controls for the temperature and atmosphere of firing based on their individual product preferences, of which the temperatures can range from 500°C to 1000°C (Rye 1981; Shepard 1956). The atmosphere is typically oxidizing (predominance of oxygen) or reducing (predominance of carbon monoxide) depending on the atmosphere's openness to air fluctuation during the firing process (Rye 1981). Ancestral Pueblo potters are well-known for using reducing atmospheres to produce grey to white clay bodies, particularly in their painted ceramics (Rye 1981). During the firing process, a diagnostic attribute may appear if it was manufactured in a reducing environment: a carbon core. The core is the cross-section of a ceramic, which can be observed if the vessel is broken. The carbon core presents itself as a dark gray band and can have up to 19 patterns (Van Hoose 2006) (Table 3.1).

Since ceramics were manufactured in a fire or heated environment, they may resist or succumb to certain types of damages caused by wildfires or prescribed burns. For example, they may resist certain types of effects, such as cracking, fracturing, spalling, and core pattern change up to the temperature at which the clay was fired, but until testing, this is only a hypothesis.

As previously mentioned, ceramic attributes, and simply their presence, can provide key evidence of past lifeways. A few examples of evidence that can be used in site interpretation that could be influenced by fire are: frequency of ceramic presence, decorative design (or lack thereof), its temper and its clay. Touching on the first form of ceramic evidence, simply the presence or increase of ceramics could indicate occupation type and period. During the cultural phases shown in Table 2.1, the people of the Northern Rio Grande transitioned in time from seasonal use of the landscape to become more sedentary (Cordell 1994). Sedentism can be observed in the archaeological record, not only through the increase of reliance on agriculture and more elaborate structures, but through pottery use. Cordell notes that, "ceramic containers, because they are both heavy and fragile, are not useful items for highly mobile groups, especially those without pack animals" (1994:55). With this logic, we can infer that an increase of ceramics observed in the archaeological record reflects increased sedentism, and/or possibly a growing population. While a wildfire does not inherently remove artifacts from the surface, it does remove surface fuels, under which ceramics were covered. When artifacts are no longer covered, they are more visibly exposed to passers-by, which could lead to their illegal removal. If these ceramics were looted as a secondary effect of burning, then the interpretative quality of these artifacts' frequency becomes skewed.

Ceramic designs can be used to infer trade patterns among peoples within the region. The Northern Rio Grande peoples manufactured much of their own pottery, but once trade networks were established with surrounding (and even distant) groups, ceramics of other decoration styles were observed (Adams and Duff 2004). Among other artifacts, ceramics are some of the most indicative signs of trade networks in the Southwest. With each group's iconic decorative patterns, raw material choices, and manufacturing techniques, archaeologists can deduce a rough location of manufacture, which is again a main line of evidence in establishing culture areas. If decoration is affected or damaged from wildfires or prescribed burns, its ability to shed insight on past trade networks and culture areas weakens.

Intact ceramics can also be tested with lab equipment to better understand the sherd's date of manufacture and source for the clay. For example, it is possible to conduct thermoluminescence dating on temper that is comprised of certain crystalline material, as done by Farias et al. (2009). Since temper is mixed in with the clay, the date of the ceramic's manufacture is sealed in the paste until the temper itself is exposed to light or heat again (essentially, until the pot is broken and the temper is exposed). With this, if archaeologists would like to collect a manufacture date, they may do so by conducting thermoluminescence analysis on the sherd's unexposed temper. Other types of lab analyses used for ceramics studies are: X-Ray Florescence (XRF), neutron activation (INAA), and Inductively coupled plasma mass spectrometry (ICP-MS) for determining trace element composition. These technologies have the ability to scan the clay paste for elemental traces, the combination of which may be unique to its clay source. These forms of analyses can determine ceramics from common origins, helping identify manufacturing groups, and even lead archaeologists back to where the clay raw material was collected if the chemical composition is unique.

Contemporary wildfires are becoming more severe, and according to archaeological post-burn survey reports, loss of ceramic information such as looting and loss of decoration are apparent (Hangan et al. 2008; Reed and Bremer 2011). It is currently unclear whether the severe heat of contemporary wildfires can alter the dating ability of thermoluminescence, or the elemental trace detection with XRF, INAA and ICP-MS techniques, the determination of which is beyond the scope of the current study. However, if all of these analytical methods can be altered by severe fire, then the ability to interpret the archeological record will be permanently skewed or lost as severe wildfires continue to consume the forests of the Jemez Mountains. The fire history of the Jemez Mountains is detailed in the following subsection for a better idea of what the archaeological record has already experienced.

Fire history, fire ecology, and fire behavior

Three elements are needed to sustain fire: an ignition source (heat), fuel, and oxygen (Figure 2.2). Factors such as topography, weather, and fuel properties (amount and arrangement) control these elements and subsequently how fire behaves as it moves across the landscape. In a wildfire, these components interact in a succession of burning stages: pre-heating, combustion, and smoldering (Ryan et al. 2012:15-16). First, fuels are pre-heated along a wildfire's perimeter, which dries and warms them, in turn preparing them for combustion. The fuels then ignite, causing flame. Once the flame front dies, it begins the smoldering stage, otherwise known as the "glowing phase" (Ryan et al. 2012:17). The continuation of this pre-heating, combusting and smoldering process depends on ecological, seasonal, weather, topographical and climatic factors. Once one of these factors is altered by environmental change or human manipulation, fire regimes can dramatically change as well.

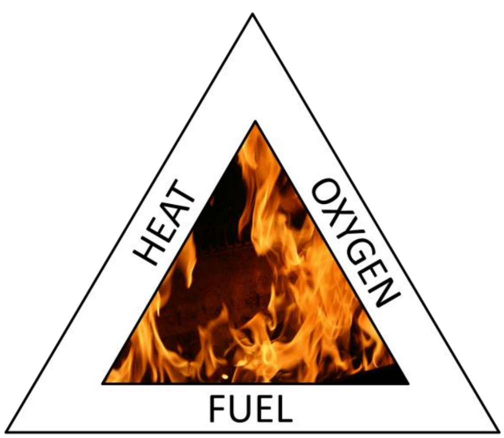


Figure 2.2. Fire triangle

In New Mexico, an example of unintentional fuel composition change came with the building of the railroad in 1880 (Allen 2001). With improved passenger and freight transportation came more utilization of the land in New Mexico, including sheep grazing, which in itself was an accidental form of fire suppression. Grasses tend to keep the flame front moving from one source of dry woody fuels to another by acting as a continuous fuel bed across a large area. Grazing can cause an indirect form of suppression by removing this continuous fuel, the consequence of which is that the woody fuels build up in the forest as they are less frequently being removed by fire (Swetnam and Betancourt 1990). In dry seasons, a lightning strike can ignite these high fuel loads and cause a much larger and more severe fire.

The forests of north-central New Mexico are primarily comprised of ponderosa pine, which intermingles with other species. At higher elevations, ponderosa pine is replaced by white and douglas firs along with aspen (Allen, n.d.; Touchan et al. 1996). Due to the prevalence of ponderosa pine forests in the research area, it is this species' fire regime that was used for the basis of this study. An examination of fire regime history of the ponderosa pine and mixed conifer forests within our study area was conducted by Thomas Swetnam of the Laboratory of Tree-Ring Research at the University of Arizona, outlined in the following paragraphs.

Regional fire histories can be developed using two sources: Forest Service fire documents and tree fire-scar records (Swetnam and Betancourt 1990). The US Forest Service was established in 1905, and ever since has collected data on the annual number and locations of fires (Swetnam and Betancourt 1990). The second source for fire history records is the physical record of fire scars left behind on trees that were damaged but not killed. This record can be dated using dendrochronology, and this tree-ring record can preserve a history of fire scars for hundreds, and sometimes thousands of years, depending on the tree's life expectancy. These data are collected through evaluating tree cores (core of tree trunk, from exterior to the center, demonstrating the ring count, and subsequently dry and wet seasons or drought years) and tree cookies (cross section of tree trunk showing the ring count, fire scars, dry and wet seasons and drought years, using entire circumference), or a partial tree cookie (approximately half of a tree trunk cross section). Not all trees are scarred during fire episodes, but when enough cookies are collected from each sampled forest that the likelihood of several of the sampled trees having been scarred is high.

The fire scar data Swetnam evaluated from Frijoles Canyon ranged from A.D.1709-1905, and he established that during this time, fires typically burned every 7.3 years with a standard deviation of 5.5 years; the maximum interval in that time was a fire-free period of 23 years (1990). It is hypothesized that during this time Native Americans in the region influenced the local fire regimes largely through impacts on the environment (Vale 2002). For example, prehistoric people in the Southwest utilized, and subsequently altered attributes of the landscape for agricultural purposes, which means they may have affected the vegetation (Briggs et al. 2006). Prehistoric peoples were not only altering the fuel composition, but also purposefully burned for many reasons including the stimulation or promotion of certain vegetation (Vale 2002). These agricultural features and purposeful burning altered local fire regimes. However, the full impact of Native American activities on the prehistoric landscape and how those influenced the historic and present day state of the landscape is unknown.

According to fire scar data Swetnam collected for the last three centuries, there were two abnormally long fire-free periods: 1830s-1840s and the late 1800s. The first is attributed to climatic factors, specifically a wet environment (as indicated by the larger tree rings from that decade). Swetnam states that this was the wettest decade in the last 200 years (Swetnam and Betancourt 1990). The second period of fire absence was the late 1800s, which he suggests may have been due to the start of sheep grazing in the 1820s (Swetnam and Betancourt 1990). Again, the causal chain is that because sheep graze on grasses, the fuel that carries fire from one woody source to another, fires that may start from lightning or human activity likely wouldn't carry as readily. The buildup of woody fuels resulting from fire exclusion increases the potential for more intense fire than was typical during this environment's prehistoric and early historic periods.

The history of fires of northern New Mexico documented by the Forest Service began with lower frequency due to grazing and suppression, but an increase in fire severity due to fuel build-up (Ryan et al. 2012; Swetnam and Betancourt 1990). Specifically, within the Jemez Mountains, I will highlight some of the more recent fires with high severity: the Dome fire of 1996, the Oso Complex of 2000, the Cerro Grande of 2000, the Las Conchas of 2011, and the Thompson Ridge fire of 2013 (Figure 2.2). This fire data was downloaded from the Monitoring Trends in Burn Severity website, a long-term project monitoring wildfires in the United States. The Dome fire of 1996 burned a total of 15,782 acres of land, the severity of which 2,696 acres were considered moderate and 349 acres were considered high, which means approximately 2% of the entire fire was considered high severity (MTBS 2015b). The Oso Complex of 2000 consumed 5,297 acres, 1,405 of which were considered moderate severity while 1,829 acres were considered high severity, making approximately 35% of the total fire high severity (MTBS 2015d). The Cerro Grand fire of 2000 consumed much more than the Oso Complex, reaching a total of 44,280 acres burned. The amount classified as moderate severity was 8,129 acres, while there were 14,504 acres considered high severity, amounting to approximately 33% of the consumed land having been exposed to high severity fire (MTBS 2015a). The Las Conchas fire of 2011 consumed a total of 150,877 acres. Of the total consumed, 25,920 acres were considered moderately severe and 30,499 were considered high severity (approximately 20%) (MTBS 2015c). Lastly, the

Thompson Ridge fire of 2013 burned a total of 21,080 acres, of which 4,354 were considered moderate severity and 2,029 were considered high (approximately 10%) (MTBS 2015e).

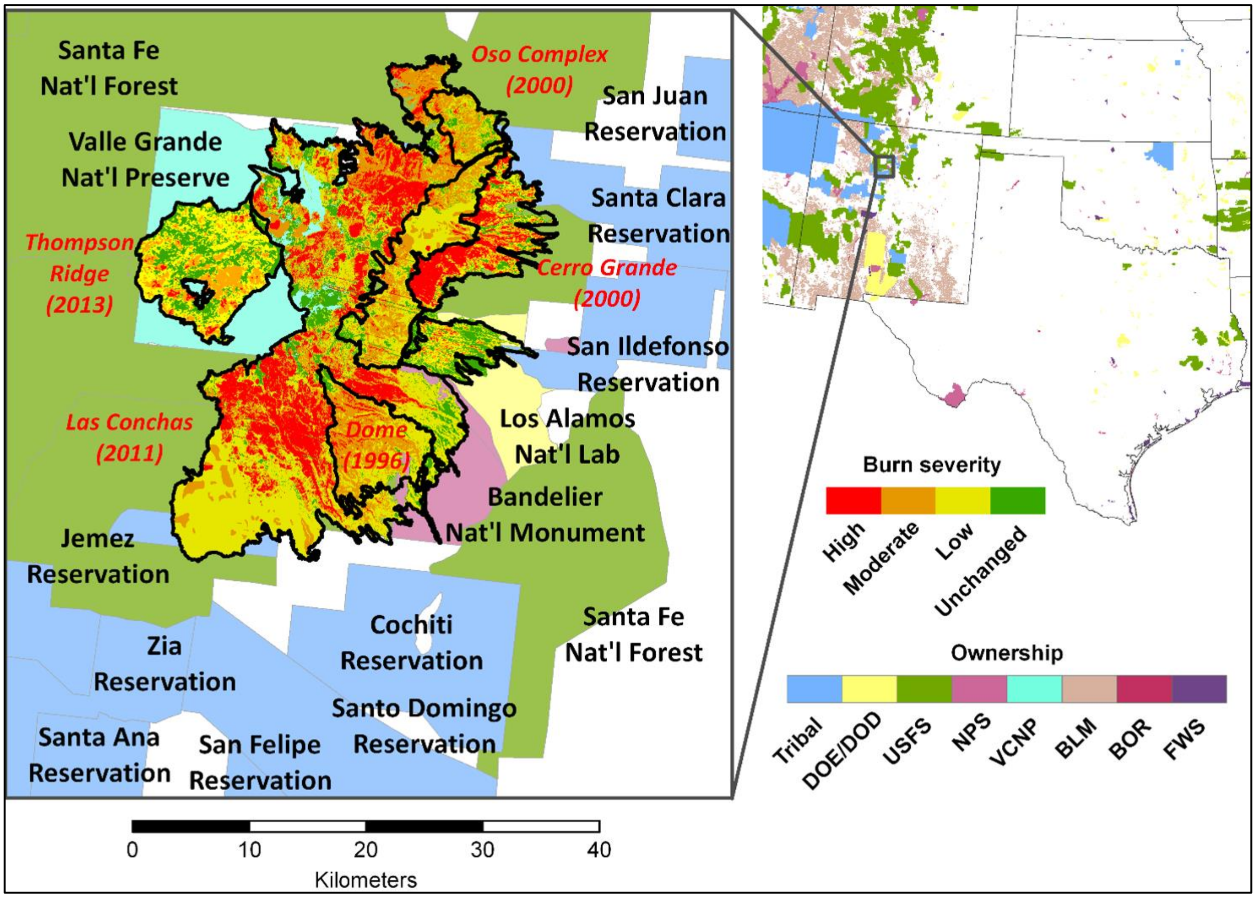


Figure 2.3. Map of fire severity in the Jemez Mountains of north-central New Mexico (map courtesy of Rachel Loehman, 2015).

Figure 2.3 displays how much area high severity contemporary fires consumed in the study area in the last two decades. Fire severity is based on plant mortality, which means high severity fires kill the most plants (including trees) of the possible levels on the ordinal scale of fire severity (Keeley 2009). When trees are killed from a severe fire, they would no longer leave a fire scar record, which means the fires of the past that left fire scars would not be considered high severity, as demonstrated with the abundance of trees that survived prehistoric and historic fires. With this figure in mind, we can deduce that contemporary wildfires are very different, specifically more severe, than in the past. If these severe fires continue, whether due to fire suppression, grazing or climate change, it is possible that the entirety of north-central New Mexico could eventually be exposed to severe fire in the near future.

At this point, it is difficult for archaeologists to predict what the potential for damage is for a site in fire events at this scale. It is unknown whether sites can tolerate low to moderate burn severity, or if they can become damaged from all of the spectrums of fire severity. This question will be addressed in the conclusions of this study, but first the materials and methods are detailed in the following chapter.

Chapter 3. Materials and Methods

Radiant Heat Test

As developed in the preceding chapters, this thesis reports on the data collected from radiant heat tests conducted on Southwest ceramics. The ceramics used for this study are unprovenienced artifacts, referred to as, “guilt collections,” that were deaccessioned from the accessory collections at the Maxwell Museum of Anthropology at the University of New Mexico. The deaccessioning process was conducted by Jamie Civitello, Connie Constan, Jennifer Dyer, and Dave Phillips. The classification and the pre-and post-burn analysis were undertaken by ArcBurn’s ceramics expert, Dr. Connie Constan. The experiment was designed by Jim Reardon and Dr. Loehman, and the tests were conducted by lab technicians Rebekah Kneifel and Sarah Flanary.

The typical effects seen in post-burn surveys were provided by Constan (personal communication 2014). The thermal effects targeted in the radiant heat tests are: blackening, core pattern change, crazing, cracking, fracture, hardness change, oxidation, paint/slip/surface color loss or change, size change, spalling, temper change, and vitrification. The definition of each can be found in the table below.

Table 3.1. Definitions of thermal effects to ceramics.

Effect	**Definition**	**Reference(s)**
Blackening	The darkening of the ceramic surface due to exposure to heat or smoke (similar to fire clouding), or the presence of a reducing atmosphere.	Constan, personal communication 2014 Rice 1987:478
Core pattern change	Each ceramic core profile has a "core pattern" defined as the contrasting of oxidized and reduced portions of the sherd profile, which ranges from one solid color throughout the core to multiple stripes of two or more colors (like tree rings). There are 19 possible core patterns (labeled A-S), according to Van Hoose (2006). These patterns, which may inform archaeologists about manufacturing and use history of ceramics, could possibly be altered by heat exposure.	Van Hoose 2006:147 Rice 1987:474
Crazing	The presence of fine, non-linear or latticed cracks on the surface of a specimen.	Buenger 2003:261 Rice 1987:474
Cracking	Cracking is when the ceramic surface or profile develops shallow crevices. Cracking is more significant than crazing and may penetrate beyond the slip into the paste of the sherd.	Constan, personal communication 2014 Buenger 2003:27
Fracture	The breaking of a specimen into multiple pieces, and/or the presence of fractures or fissures that penetrate deeply into a specimen.	Buenger 2003:261
Hardness change	Hardness is the resistance of the surface to deformation. It is based on the Mohs Hardness Scale, which is a standard scale numbered from 1 to 10. Ceramics may experience a change in hardness when experiencing prolonged exposure to heat.	Rice 1987:474
Oxidation of pigment used for surface treatment	Alterations can include a change in color from the original pigment (black to red), or the combustion of the pigment entirely. Oxidation is the clay's molecular reaction to oxygen and heat, which is manifested in color alteration.	Buenger 2003:261 Rice 1987:479
Paint, slip, or surface color change or loss	Any observable color change of a specimen from original pre-fire color.	Buenger 2003:261
Size change	The dimensions of the sherd, including	Constan, personal

Effect	Definition	Reference(s)
	length, width, thickness, or weight, that change due to a plethora of factors that are instigated by thermal exposure.	communication 2014
Spalling	The exfoliation of a portion of the original surface of a specimen due to differential heating and pressure release.	Buenger 2003:261
Temper alteration	Temper is the non-plastic inclusions within the clay which can be comprised of geologic materials or organics. These materials have the capacity to chemically, molecularly or surficially alter during a heat event	Constan, personal communication 2014 Rice 1987:483
Vitrification/Melting	Melting and fusion of glassy minerals within clay during high-temperature firing of pottery (above 1000°C), resulting in loss of porosity; the process in which a substance melts and turns to glass.	Ryan et al. 2012:221 Rice 1987:484

Many of these effects have been observed in previous field and laboratory experiments, but it has not yet been demonstrated whether all effects can be observed in all fire environments, or if some effects are specific only to certain types of fire (radiant heat, flame exposure, or smoldering) and certain categories of ceramics.

Pre-burn measurements were chosen based on the potential changes with thermal exposure in the lab. The measurements were completed by Constan prior to sending the sherds to the Fire Lab. Constan's measurements included in the pre-burn analysis were: thickness (cm; caliper), length (cm; caliper), width (cm; caliper), hardness (Mohs hardness scale), core color (Munsell color chart), interior and exterior surface color (Munsell color chart), and interior and exterior paint color (Munsell color chart), core pattern, and observations on what kind of damage was present prior to testing, such as cracks or spalls.

Once Constan had completed the pre-analysis and the sherds arrived at the Fire Lab, their bags were labeled with the information required by our experimental design: artifact number, a blank space for date of the test, kiln temperature, duration of heating, and lab technician initials.

Artifact tags were included in each bag and contained the same information, as well as the thermocouple numbers attached to that individual artifact. Then, the lab technicians prepared the sherds for testing, which began with drilling two holes in each sherd. These holes serve the purpose of attaching thermocouples during the experiment in order to read the artifact temperature. One hole penetrated through the sherd in order to place the thermocouple's bead at the heat-exposed surface of the artifact. The second hole was drilled to approximately 1mm (give or take 0.2mm) from the heat-exposed surface. This hole accommodated a thermocouple temperature reading just below the heated surface of the artifact. Ultimately, three thermocouples were placed with each artifact, the third positioned in the sand beneath the sherd. The system of three thermocouples generated data to better understand heat transfer in ceramic artifacts.

Depending on the sherd's hardness and temper composition, drilling was difficult. A few sherds broke during the drilling process and several had up to three holes. For those that broke, the largest piece was tested. In order to reduce the number of sherds that required replacement, the ArcBurn team eventually decided to stop drilling the sherds that were breaking most freqeuently: plain utility and textured utility. For this reason, a few plain and textured utility sherds have holes for thermocouples, but most do not. For those that had three holes, the third hole that would not host a thermocouple was filled with fine-ground ceramic powder during the test. This powder was manufactured by crushing and grinding other "guilt collection" sherds into a fine powder.

Ceramics were then weighed (g), their interior and exterior surfaces were scanned on a Xerox DocuMate 700 flatbed scanner (600 DPI), and a broken edge, showing color and core pattern was photographed with a Pentax K5 SR camera with a Tamron macro lens in a light box. The light box was manufactured of wood, white poster paper, four lights with white tissue as light-diffusers and a camera stand (Figure 3.1). When taking a photo of a sherd's core, the sherd would be pedestalled on mounting craft putty in order to keep it stable and standing. The camera would be stabilized on the camera stand, and using the macro lens the technician would focus on the small portion of the sherd's edge that Constan removed in order to get a clear view of the sherd's core.

Figure 3.1. Photo light box

During pre-burn processing, physical and electronic copies of catalogs were kept, including a photo log, an artifact catalog, and a measurements catalog. Altogether, the kiln test consisted of 24 sherds per category (glaze paint, carbon paint, mineral paint, plain utility and textured utility): in total, 120 sherds.

We designed a factorial experiment with four doses of times and temperatures. The two different temperatures chosen were 600°C (1112ºF) and 900°C (1652ºF), and two different durations: 60 seconds and 90 seconds. Six sherds per category were tested in each dose. These temperatures and times were based on the radiant heat environment characteristic of crown fires (Butler et al. 2004; Hartford and Frandsen 1992; Silvani and Morandini 2009). Details on the assignment of artifacts to tests can be found in Appendix A.

Each test consisted of either three painted sherds (1 glaze paint, 1 carbon paint, and 1 mineral paint) or two utility sherds (1 plain utility and 1 textured utility). The categories were separated in the tests primarily due to the small size of the sand bed and limited thermocouples (bed size and thermocouples detailed below) (Figure 3.2). For painted categories, the more heavily decorated side faced up, exposing the decoration to the radiant heat. The utility categories were situated on the bed so the external surface was upward facing.

Figure 3.2. Arrangement of painted sherds (on left) and utility sherds (on right).

The kiln used in these tests was an Olympic Raku Kiln that is known for its top hat design with electric heating coils embedded in the lid. The lid is arranged on a pulley system so it can easily be lifted and lowered. In order to reduce variable heating from airflow, the lid was propped on the firing surface by firebricks, which secured the heat outlet by sealing the perimeter with the exception of a space just large enough to insert and remove the sand bed (Figure 3.3).

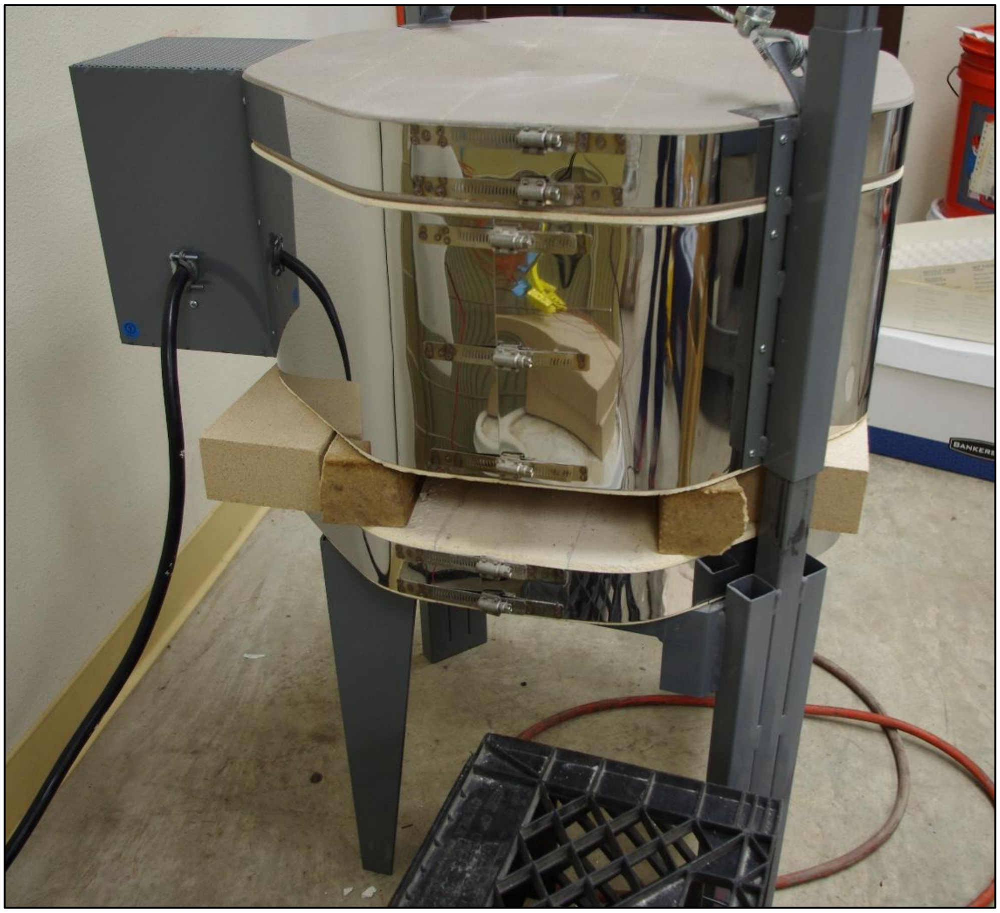


Figure 3.3. Kiln with firebricks and slot for inserting and removing sand bed.

The sherds were placed in a sand bed which is 16.5cm x 25.5cm x 5cm in size with 2.5cm thick walls and base. The bed is constructed from Cotronics Corporation Ceramic Boards, which are manufactured from refractory fibers that provide thermal shock resistance. The bed was filled to a depth of 2.5cm of Lane Mountain fine quartz sand. Prior to testing, thermocouples were threaded through the pre-designated back-end of the sand bed. Two metal bars were threaded perpendicularly through the middle of the sand bed beneath the sand in order to hold the thermocouples down.

Thermocouples of Type K were used in this experiment. These are comprised of a positive leg (nickel chromium) and a negative leg (nickel aluminum). Thermocouples are manufactured by soldering the two wires into a very small bead, the mechanism by which temperatures between 90°C and 1260°C can be read. On the opposite end, the positive and negative legs are then wired to a multiple-input data-logger. In the kiln test, a total of 10 thermocouples were used. The lab technicians were consistent with the placement of each thermocouple on either the surface of the artifact, 1mm beneath the artifact's surface, or beneath the sand under the artifact. Last, a lone thermocouple was used as the atmospheric temperature reader throughout the tests and resided in open air near the back of the sand bed (Figure 3.4).

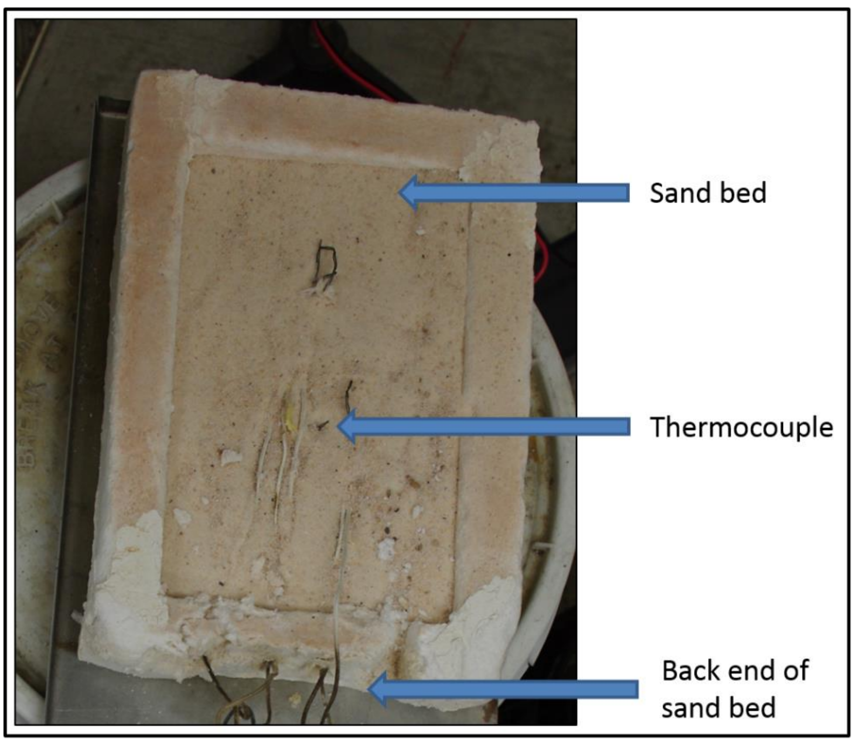


Figure 3.4. Sand bed and thermocouples

Once the sherds were arranged in the sand and the thermocouples were attached, the lab technicians tested the thermocouples and data-logger to make sure they were properly reading temperatures. The data were displayed on a computer in a program called Loggernet and saved as a text file for use in Excel (equipment setup displayed in Figure 3.5). When the thermocouples were properly working and the kiln was preheated to its pre-designated temperature (either 600°C or 900°C), the sand bed was inserted into the kiln.

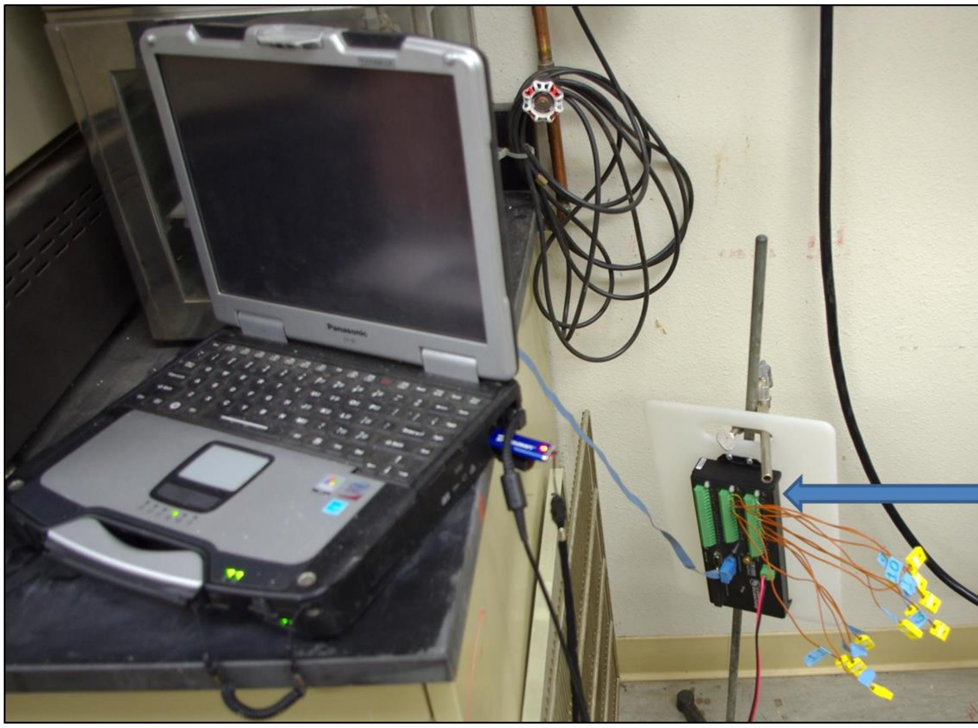


Figure 3.5. Data logger setup

Prior to inserting the sand bed, the lab technician would enter Loggernet and begin collecting temperature data once per second. Beginning data collection prior to inserting the sand bed in the kiln later allowed the technician to evaluate the rate of heating from room temperature to the kiln's target "atmospheric" temperature. As the sand bed was inserted, a stopwatch was started and used to time the event so the lab technician would remove the sand bed at the pre-designated duration (either 60 seconds or 90 seconds). Once the test was complete, the lab technician removed the sand bed from the kiln, stopped data collection in Loggernet and immediately removed the ceramics from the warm sand to a staging area where they cooled for 15 minutes. Between tests, the lab technicians would save the data, labeled with the test number, on an external hard drive. Then, the hot sand from the last test was dumped into a metal tray which was set aside to cool and was replaced by room temperature sand. When the artifacts were cooled, they were placed back into their associated artifact bags.

Post-burn processing included: weight (g), interior and exterior scans, and photographs of the ceramic's core (profile). Once the post-burn processing was complete, the sherds were carefully packed into two boxes and sent for analysis with an associated letter describing the treatments that occurred to each artifact. The post-burn analysis conducted by Connie Constan was similar to pre-burn analysis, consisting of the following measurements: thickness (cm), length (cm), width (cm), hardness (Mohs hardness scale), core color (Munsell color chart), interior and exterior surface color (Munsell color chart), and interior and exterior paint color (Munsell color chart). Constan also noted obvious effects related to color change, residue, obscured decoration, cracking and crazing, spalling and exfoliation, melting and vitrification, and presence of ash. Finally, I conducted visual analysis on each artifact to evaluate radiant heat effects. Visual analysis consisted of comparing a before and after photo of each sherd's interior surface, exterior surface, and core profile. If a visible change occurred, it would be considered an effect, but if a change occurred to the extent by which it altered an attribute or attributes so badly that it may hinder an archaeologist from proper analysis, it was considered damage. Taking the images was standardized by using the scanner instead of a light box. The only inconsistency in using the scanner for before and after pictures was shadows, based on how the sherd was sitting on the flat bed. These shadows affected lighting slightly, but not enough to bias the determination the presence or absence of radiant heat effects.

Preservation Guide

The results from the radiant heat tests were used to develop parameters for the proposed preservation guide. The first stage of developing the guide was to establish which radiant heat effects constitute damage (as defined in Table 1.1).

The second stage of developing the preservation guide was to determine the audience who would use it and understand their needs. The audience was realized to be archaeologists who work closely with fire managers and the fire managers working with archaeologists. Subsequently, it became apparent that both fields would need definitions of each other's terminology that would be used in mitigating ceramics from radiant heat damage. Therefore, terms such as slash (and broadcast slash), crown, tree stand, digging line, thinning, dozer line, and prescribed burn needed to be defined for archaeologists. Fire managers likely would need definitions for archaeological terms such as sherd, and the effects that archaeologists are looking for: surface color change, slip color change, and paint color change. Once these terms were defined, I created a decision-making flow chart employing these terms.

The flow chart starts with the first logical evaluation that needs to be done on site: assessment. The assessment stage is important for determining whether action is necessary. For example, if tight tree crown spacing and/or the presence of ladder fuels could facilitate crown fires, or a slash pile present on the site might produce a damaging level of radiant heat if burned, fuels treatments may be warranted to protect archaeological resources from damages.

The flow chart is the central portion of the guide because it carries the manager through the logical questions necessary for leading them to a recommendation. The prototype developed for this thesis is not yet ready for use by land managers. Nevertheless, it provides a concrete step from which ArcBurn can move forward on consultation with fire managers and archaeologists while continuing to measure other factors of wild fire exposure on a greater range of artifacts.

Chapter 4. Results

I conducted low-power visual analysis (i.e. effects that can be seen with the naked eye or a low-powered hand lens and requires no measurement). The visual analysis was done using before and after scans of the interior and exterior surfaces of each artifact (for methods, see chapter 3). Visual analysis mimics the types of observations archaeologists may make in the field to assess fire effects, thus these visual analysis results provide an on-par assessment to that of the target audience of the proposed guide. The following subsections will describe how each ceramic category visually reacts to different radiant doses.

Textured Utility: 600°C x 60 sec

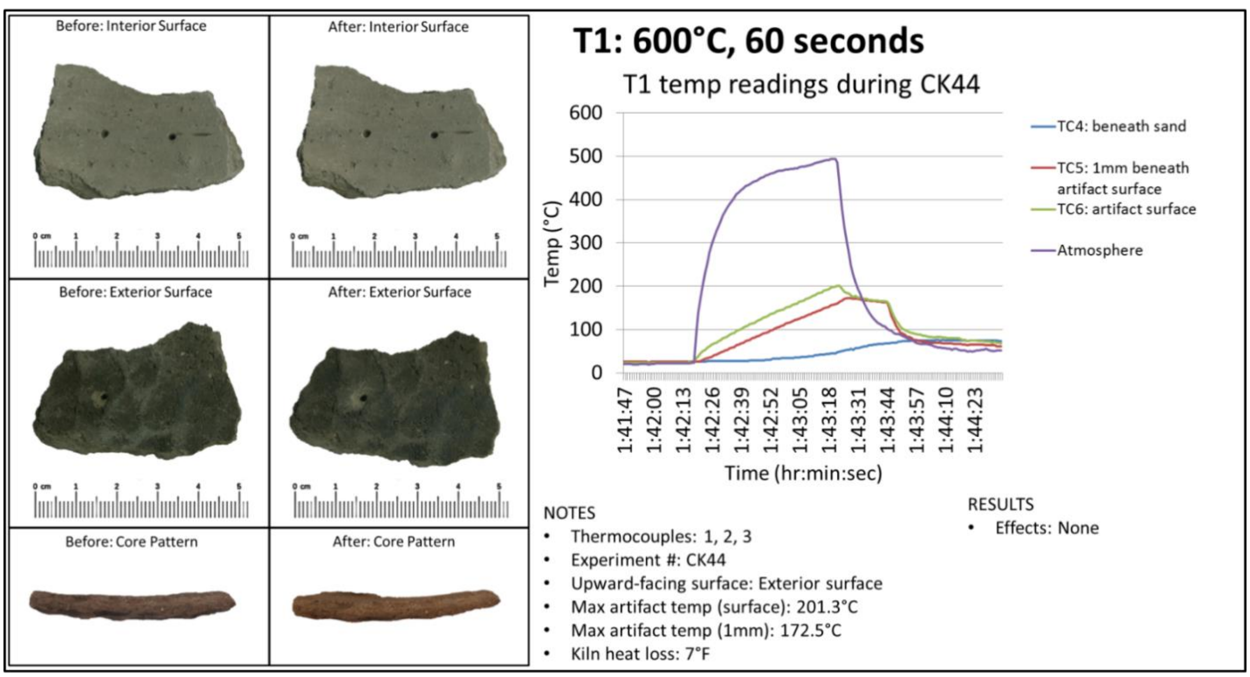


Figure 4.1. Textured utility 600°C x 60 sec typical effects

Textured utility ceramics remained largely unchanged from the low radiant heat dose of 600°C x 60 seconds; only one of the six sherds displayed slip color change. The slip color change was seen on both the interior and exterior surfaces of the artifact. This sherd was different from most of the other textured utility sherds in its category in that it had a pale yellow-colored slip, which was much lighter in color than the sherd's paste. Most of the other textured utility sherds tested had an absence of slip altogether, which made the surfaces (interior and exterior) close to their paste color. This sherd may have been more prone to color change than the rest, which is why it was the only sherd affected in the lowest heat dose.

As seen in the temperature graph above (Figure 4.1), the maximum artifact temperature reached was approximately 200°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 185°C, and it reached its maximum temperature approximately 5 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures slightly plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 80°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the textured utility sherds, thus it does not match the temperature readings exactly to the other five, but is representative of temperature trends when the sherds are exposed to radiant heat.

The textured utility ceramics showed no other change in the low heat and short duration environment. The very slight discoloration to the one artifact does not reduce the ability to extract cultural information, and thus will not be considered damage.

Textured Utility: 600°C x 90 sec

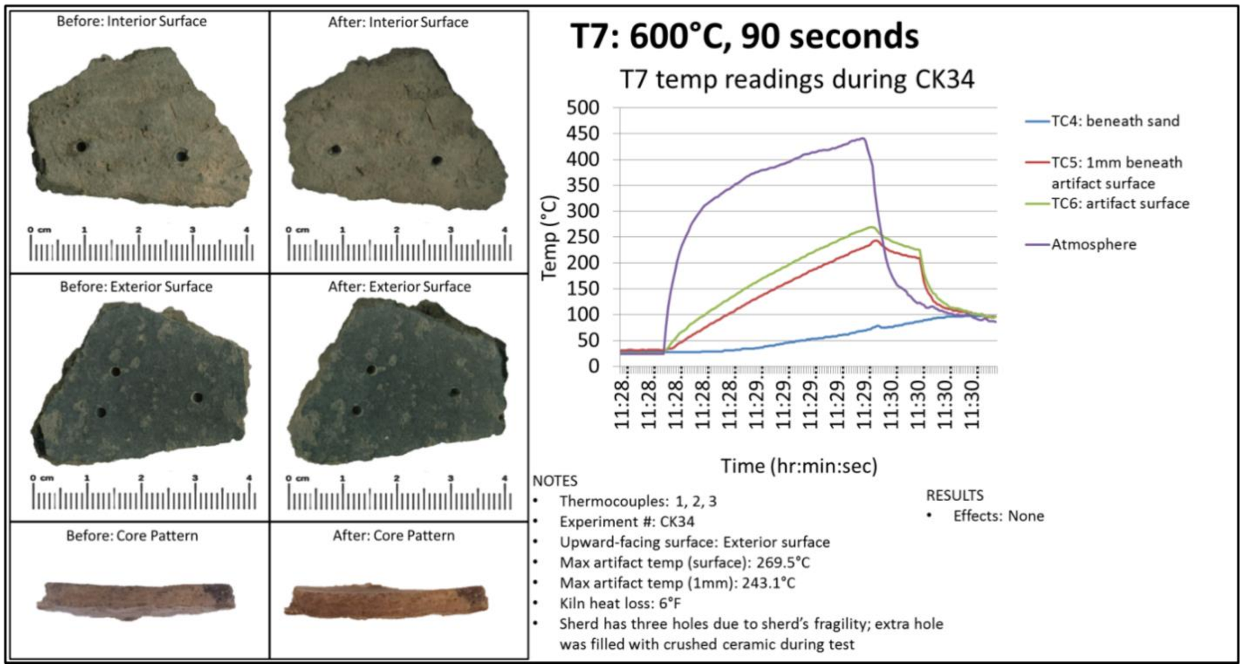


Figure 4.2. Textured utility 600°C x 90 sec typical effects

Of the six textured utility ceramics exposed to this slightly longer duration (90 seconds) at the same heat setting (600°C), only two showed signs of surface color change. Both of the affected sherds darkened slightly on their exterior surfaces (the upward facing surface that was most exposed to the radiant heat).

As seen in the temperature graph above (Figure 4.2), the maximum artifact temperature reached was approximately 260°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 245°C, and it reached its maximum temperature less than 5 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures slightly plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 100°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the textured utility sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated.

Textured utility ceramics in the low heat and longer duration environment showed no other changes. The very slight discoloration to the two sherds does not reduce the archaeologist's ability to extract cultural information, and thus will not be considered damage.

Textured Utility: 900°C x 60 sec

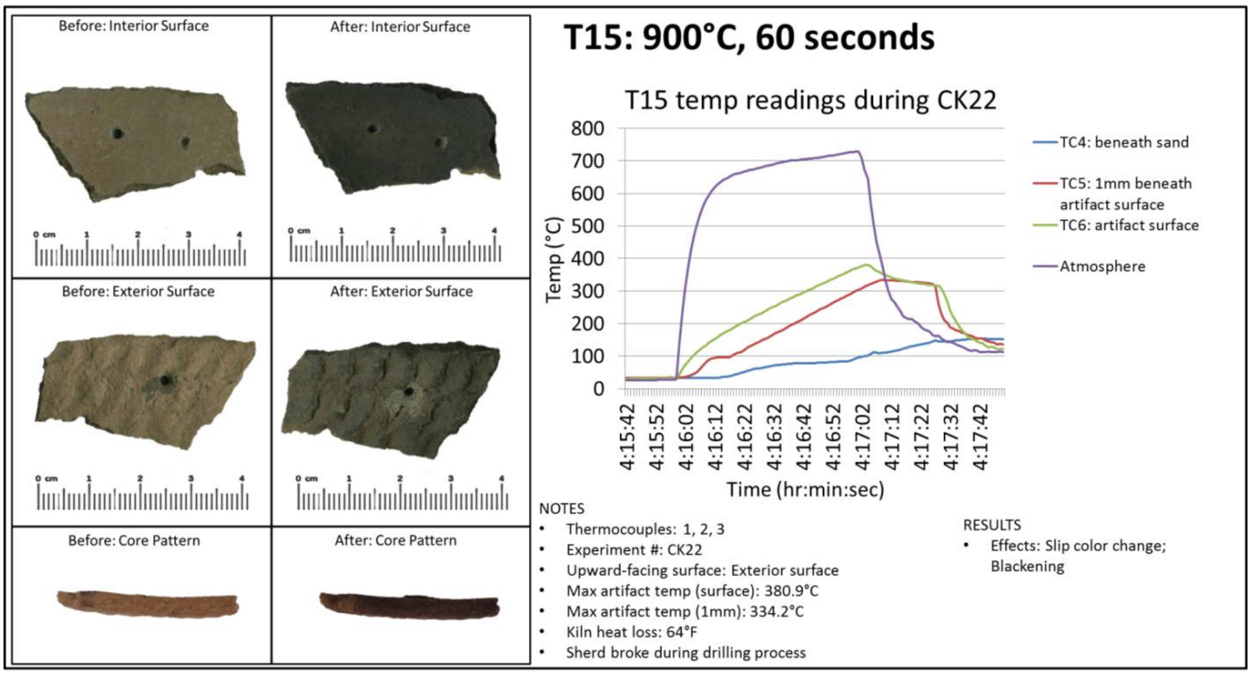


Figure 4.3. Textured utility 900°C x 60 sec typical effects

The textured utility ceramics in the 900°C x 60 second environment all displayed surface color change. Two of the six sherds showed severe enough color change to produce blackening. Five of these six sherds showed surface color change on both surfaces, the interior and exterior, while the last one had surface color change only on the interior surface, which was downward-facing during each test.

As seen in the temperature graph above (Figure 4.3), the maximum artifact temperature reached was approximately 390°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 320°C, and it reached its maximum temperature approximately 5 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures slightly plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 135°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the textured utility sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated.

Textured utility ceramics in the high heat and shorter duration environment showed no other changes. The discoloration is severe enough to affect how an archaeologist might interpret the artifact. This level of discoloration constitutes irreversible damage.

Textured Utility: 900°C x 90 sec

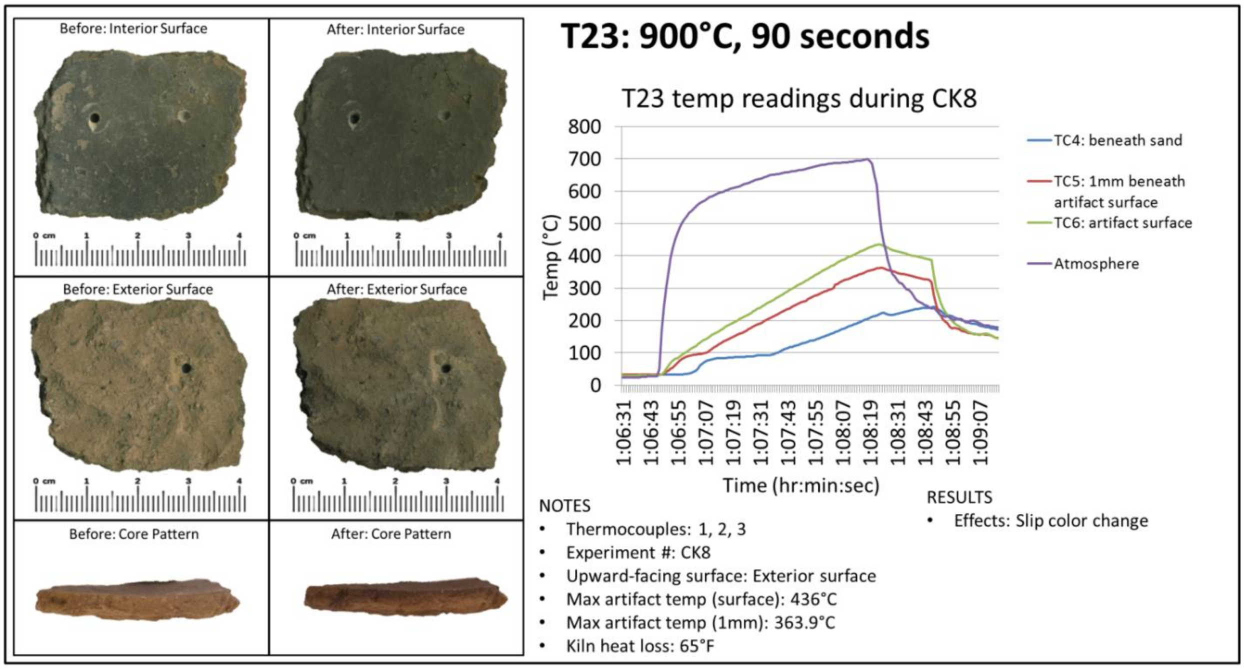


Figure 4.4. Textured utility 900°C x 90 sec typical effects

All six textured utility sherds exposed to the 900°C x 90 seconds dose experienced surface color change, two of which were severe enough to produce blackening. Unlike the last test, five of these six sherds showed surface color change on the interior only and one showed change on the interior and exterior.

As seen in the temperature graph above (Figure 4.4), the maximum artifact temperature reached was approximately 420°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 370°C, and it reached its maximum temperature approximately 5 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures slightly plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 80°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the textured utility sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated.

The textured utility ceramics in the high heat and longer duration environment showed no other changes. However, the discoloration is severe enough to affect how an archaeologist might interpret the artifact. This level of discoloration constitutes irreversible damage.

Carbon Paint: 600°C x 60 sec

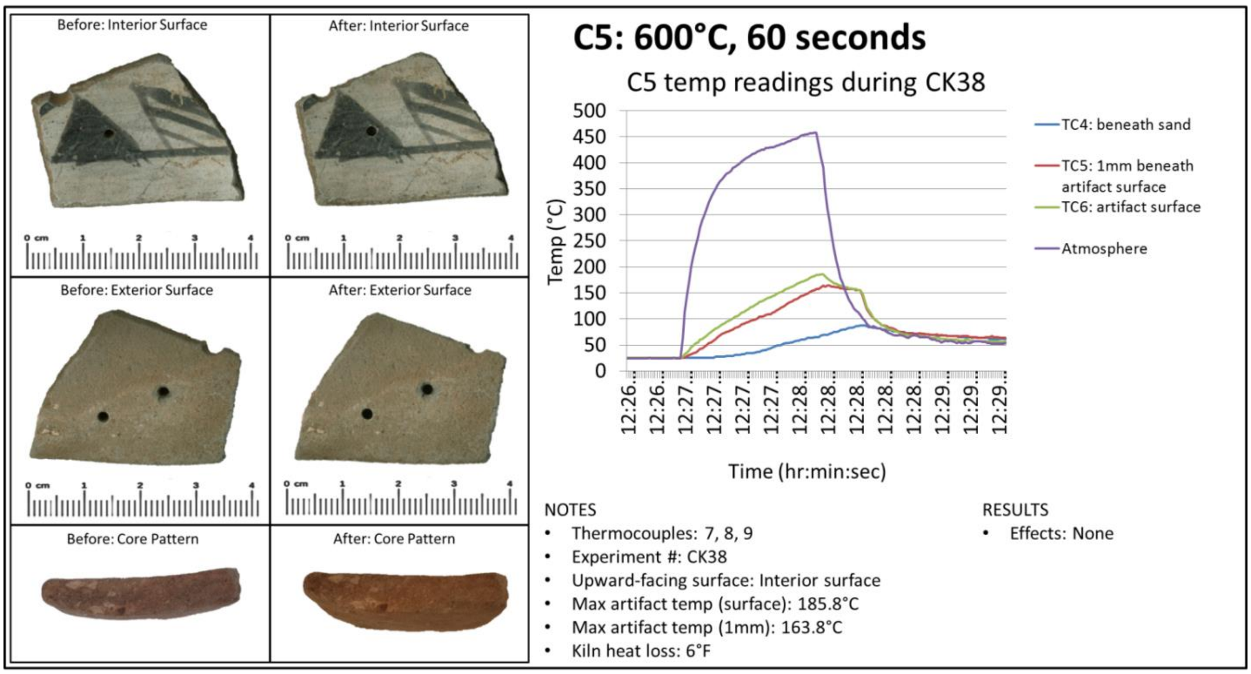


Figure 4.5. Carbon paint 600°C x 60 sec typical effects

Only one of six carbon paint sherds experienced slip color change in heat dose 600°C x 60 seconds. This change was so slight that it did not affect the contrast between the dark gray paint and the (post-burn) light cream-colored slip. The affected surface was the interior, which was facing up during the kiln test, exposing it to the radiant heat. No other changes were observed.

As seen in the temperature graph above (Figure 4.5), the maximum artifact temperature reached was approximately 175°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd’s exposed surface was 155°C, and it reached its maximum temperature less than 5 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures slightly plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 60°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the carbon paint sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated.

The very slight discoloration to these artifacts does not reduce the ability to extract cultural information, and thus is not considered significant enough to be labeled as damage.

Carbon Paint: 600°C x 90 sec

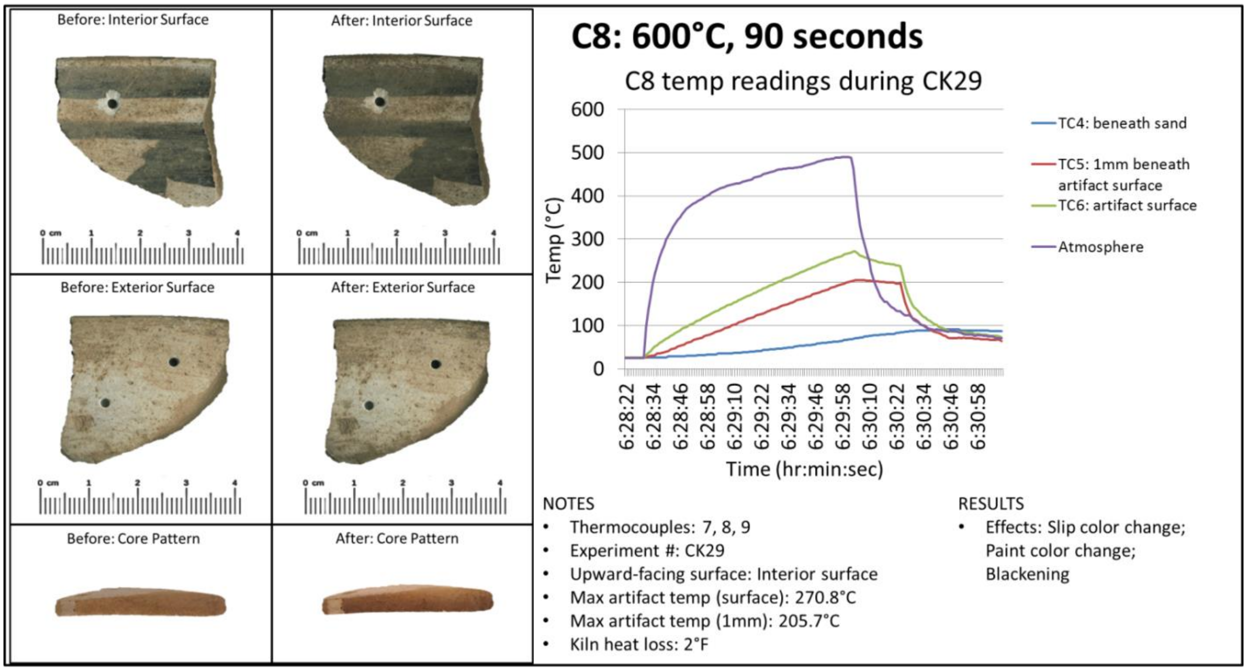


Figure 4.6. Carbon paint 600°C x 90 sec typical effects

All six carbon paint ceramics in the 600°C x 90 seconds dose experienced slip color change, two of which were severe enough to produce blackening. The same two sherds that blackened also displayed paint color change. All six sherds were affected on the upward-facing surface (five of the upward faces were interior surfaces and one was an exterior surface), which was most exposed to the radiant heat from the kiln.

As seen in the temperature graph above (Figure 4.6), the maximum artifact temperature reached was approximately 280°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 200°C, and it reached its maximum temperature less than 5 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures slightly plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 90°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the carbon paint sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated.

Carbon paint ceramics in the low heat and longer duration environment showed no other change. Unfortunately, discoloration was severe enough to potentially affect how an archaeologist might interpret the artifact. This level of discoloration constitutes irreversible damage.

Carbon Paint: 900°C x 60 sec

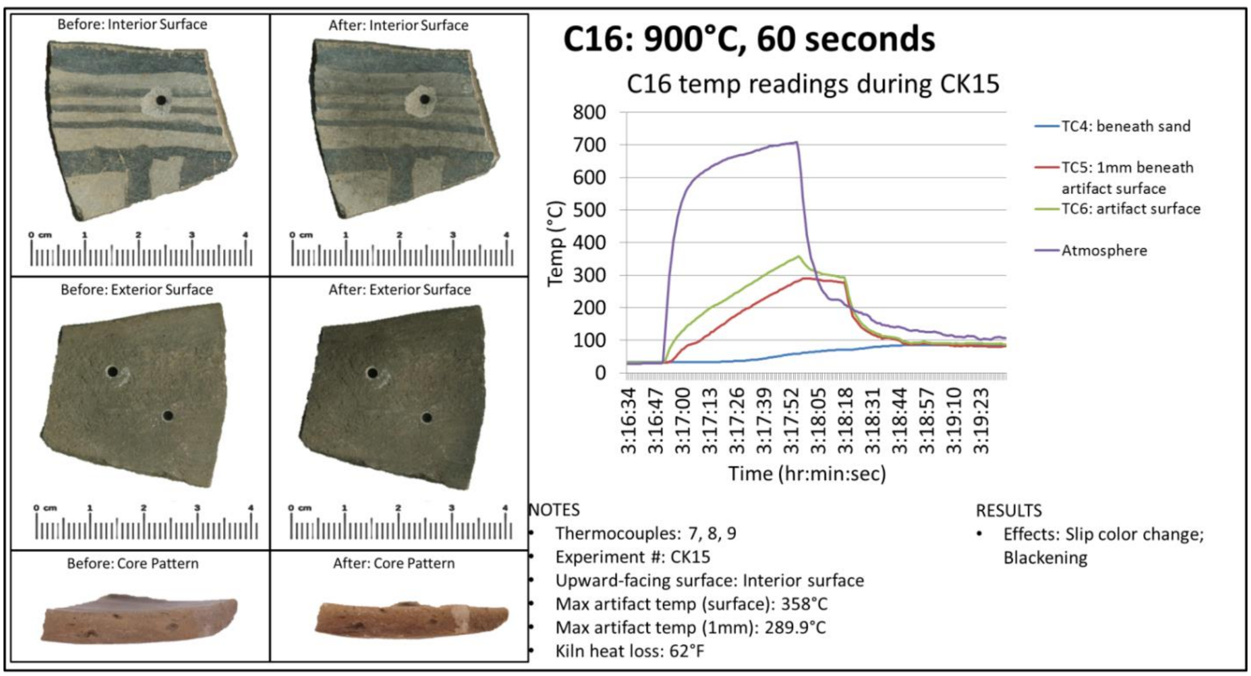


Figure 4.7. Carbon paint 900°C x 60 sec typical effects

Again, all six carbon paint sherds showed signs of slip color change and paint color change, three of which can be classified as blackening in in the 900°C x 60 second dose. One of the sherds that was blackened from slip color change also displayed paint color change. Five of the sherds were affected on both surfaces and one was only affected on its exterior surface, which was facing down in the sand bed during the kiln test.

As seen in the temperature graph above (Figure 4.7), the maximum artifact temperature reached was approximately 350°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 200°C, and it reached its maximum temperature approximately 5 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures slightly plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 110°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the carbon paint sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated.

The discoloration to carbon paint ceramics caused by high heat and a short duration is severe enough to affect how an archaeologist might interpret the artifact. No other changes were observed, but the level of discoloration constitutes irreversible damage.

Carbon Paint: 900°C x 90 sec

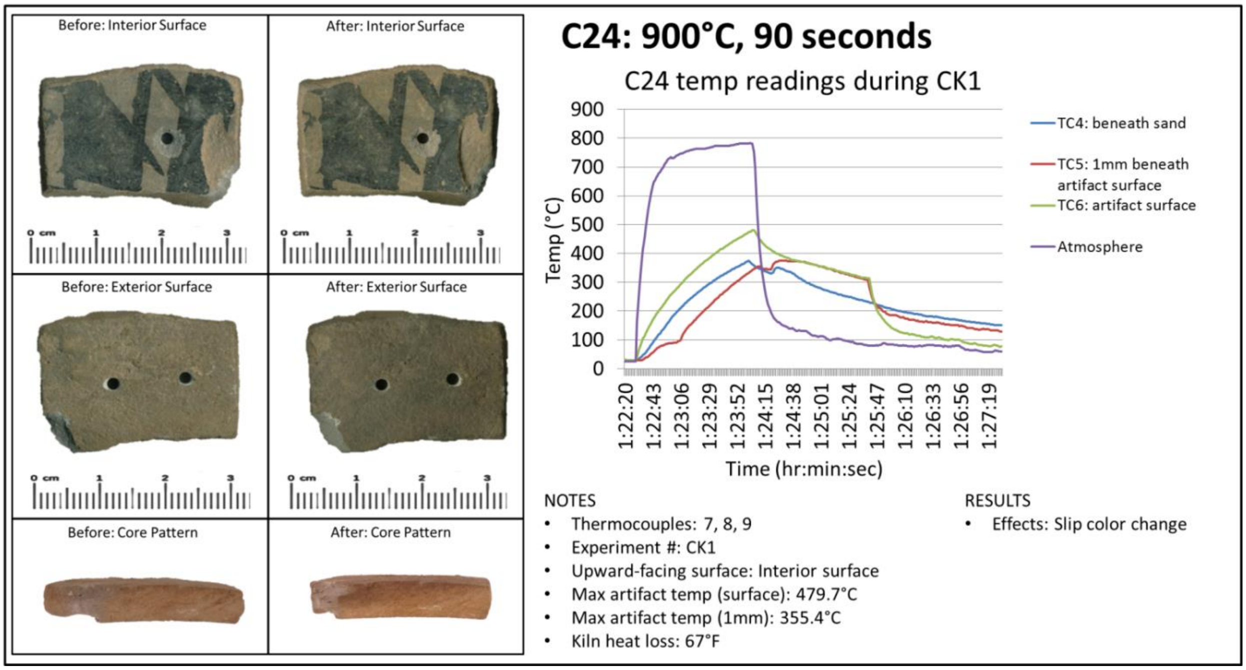


Figure 4.8. Carbon paint 900°C x 90 sec typical effects

Four of the six carbon paint ceramics in the 900°C x 90 seconds dose experienced slip color change. Of the four that experienced slip color change, one was blackened. Three of the artifacts showed slip color change on both surfaces, while one was affected on the interior surface, which was facing down during the kiln test.

As seen in the temperature graph above (Figure 4.8), the maximum artifact temperature reached was approximately 495°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 390°C, and it reached its maximum temperature approximately 15 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures slowly declined and later plateaued around 105°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of carbon paint sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated.

Discoloration to carbon paint ceramics was severe enough from the high heat and longer duration to affect how an archaeologist might interpret the artifact. No other changes were observed, but the level of discoloration constitutes irreversible damage.

Mineral Paint: 600°C x 60 sec

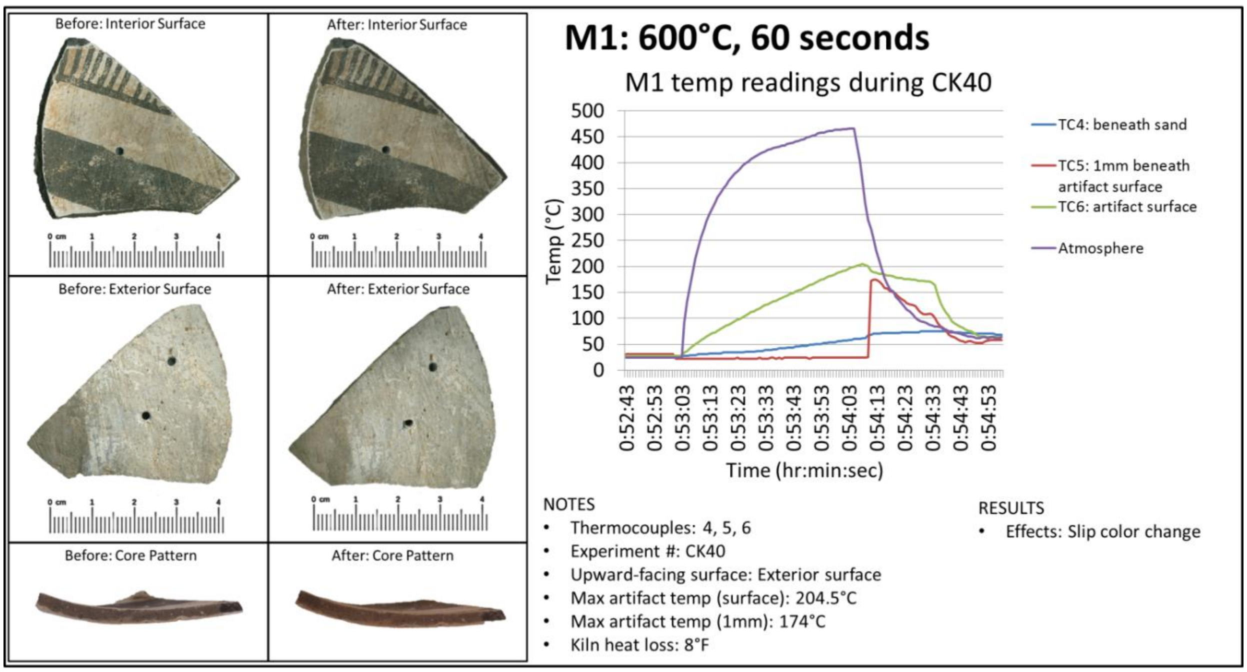


Figure 4.9. Mineral paint 600°C x 60 sec typical effects

The mineral paint ceramics experienced more negative effects from the low radiant heat dose of 600°C x 60 seconds than any other ceramic category. Of the six mineral paint sherds that were tested in this heat environment, four experienced slip color change. Two of the artifacts showed slip color change to both their interior and exterior surfaces, while the other two showed slip change on their interior surfaces, both of which were facing upward during the kiln test, exposing it to the radiant heat.

As seen in the temperature graph above (Figure 4.9), the maximum artifact temperature reached was approximately 200°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 175°C, and it reached its maximum temperature approximately 5 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The surface temperature slightly plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 50°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the mineral paint sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated.

Mineral paint ceramics in the low heat and short duration environment showed no other changes. Then again, discoloration was severe enough to potentially affect how an archaeologist might interpret the artifact. This level of discoloration constitutes irreversible damage.

Mineral Paint: 600°C x 90 sec

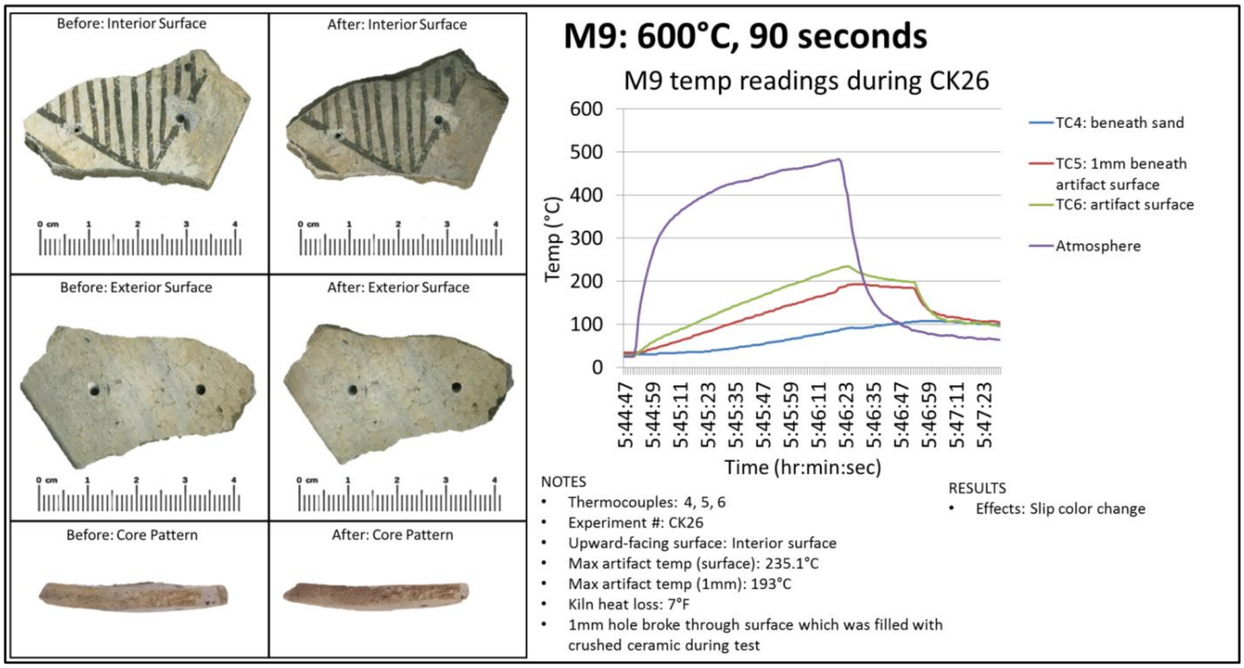


Figure 4.10. Mineral paint 600°C x 90 sec typical effects

In the 600°C x 90 seconds dose, slip color change was observed on all six of the mineral paint sherds. Three of the artifacts showed slip color change to both their interior and exterior surfaces. Two showed slip change on their exterior surfaces, one of which was facing upward and the other facing downward in the kiln test. The last artifact showed slip change on its interior surface which was facing upward in the kiln.

As seen in the temperature graph above (Figure 4.10), the maximum artifact temperature reached was approximately 225°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 200°C, and it reached its maximum temperature approximately 5 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures slightly plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 100°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the mineral paint sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated.

Mineral paint ceramics in the low heat and longer duration environment showed no other changes. However, discoloration was severe enough to potentially affect how an archaeologist might interpret the artifact. This level of discoloration constitutes irreversible damage.

Mineral Paint: 900°C x 60 sec

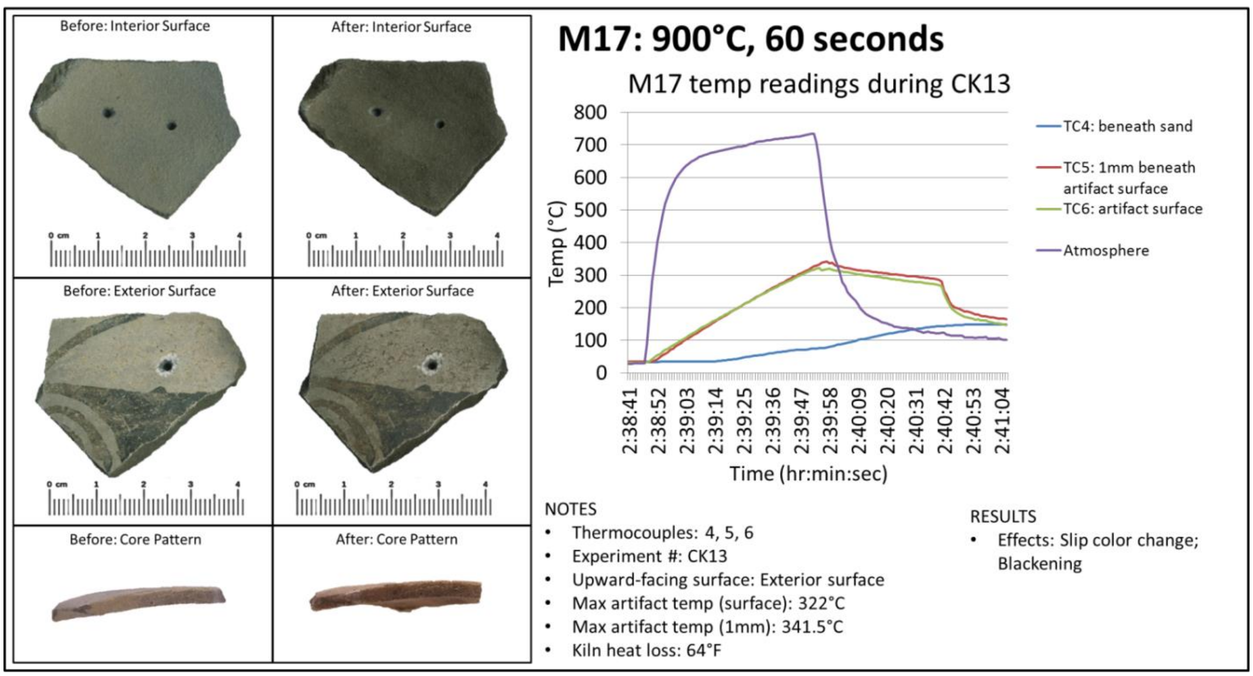


Figure 4.11. Mineral paint 900°C x 60 sec typical effects

In the 900°C x 60 second dose, all six of the mineral paint sherds showed slip color change and blackening. All of the artifacts showed slip color change to both their interior and exterior surfaces. Paint color change was also observed on two of the samples, one of which occurred only on the interior surface, the only surface with paint, and the other paint change occurred on both surfaces.

As seen in the temperature graph above (Figure 4.11), the maximum artifact temperature reached was approximately 320°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 330°C, and it reached its maximum temperature approximately 5 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 150°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the mineral paint sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated.

Discoloration to mineral paint ceramics was severe enough from the high heat and shorter duration to affect how an archaeologist might interpret the artifact. No other changes were observed, but the level of discoloration constitutes irreversible damage.

Mineral Paint: 900°C x 90 sec

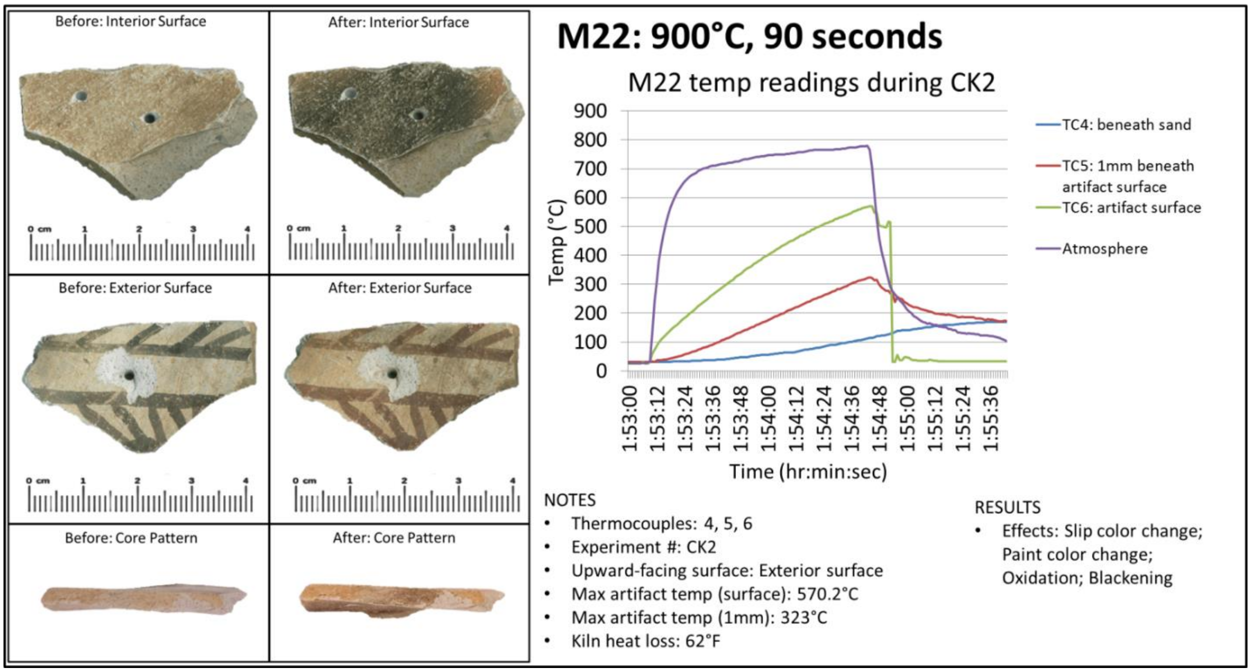


Figure 4.12. Mineral paint 900°C x 90 sec typical effects

All six of the mineral paint sherds tested in the 900°C x 90 second test displayed slip color change on both surfaces, five of which also displayed blackening. Of the five that experienced both slip change and blackening, paint color change and oxidation were also observed on four.

As seen in the temperature graph above (Figure 4.12), the maximum artifact temperature reached was approximately 590°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 310°C, and it reached its maximum temperature approximately 5 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The surface temperature thermocouple appears to have malfunctioned, indicated by the immediate decrease in temperature when it was removed from the kiln. The temperature slowly declined and then plateaued around 190°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the mineral paint sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated.

The discoloration to mineral paint ceramics caused by high heat and a longer duration is severe enough to affect how an archaeologist might interpret the artifact. No other changes were observed, but the level of discoloration constitutes irreversible damage.

Plain Utility: 600°C x 60 sec

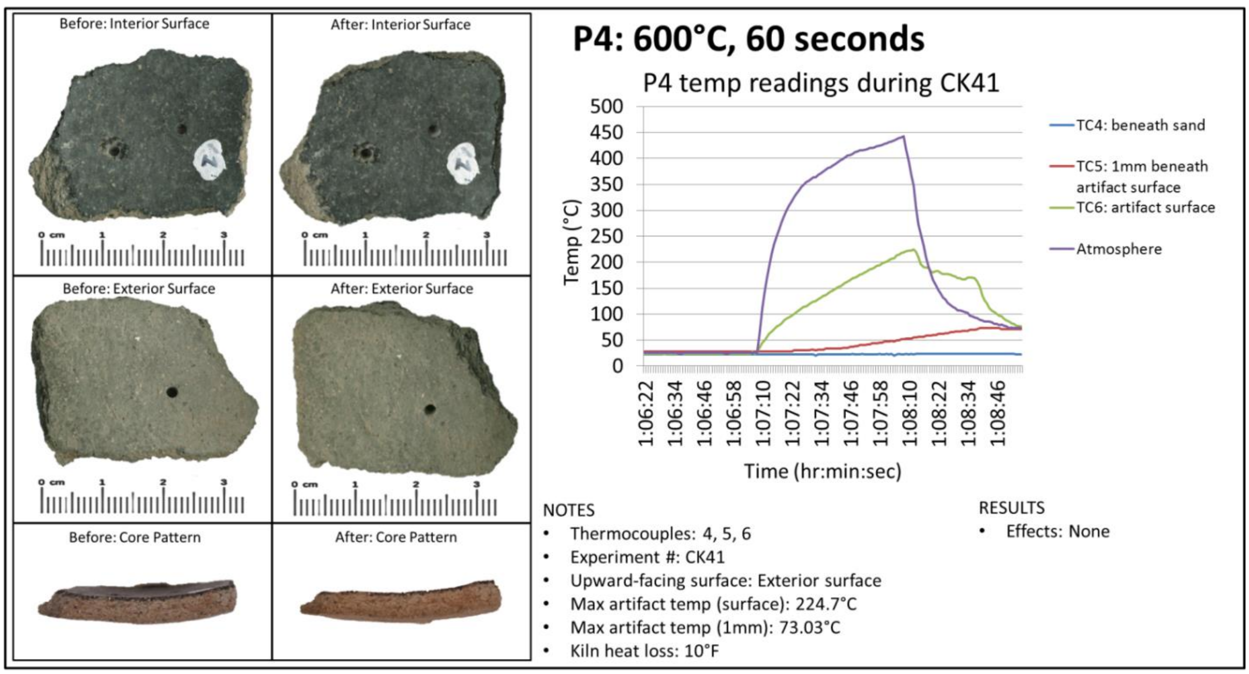


Figure 4.13. Plain utility 600°C x 60 sec typical effects

The six plain utility sherds tested in the 600°C x 60 second dose did not display any negative effects. Plain utility does not experience any damage during the event of low heat, short duration episodes.

As seen in the temperature graph above (Figure 4.13), the maximum artifact temperature reached was approximately 225°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 600°C, and it reached its maximum temperature approximately 30 seconds after the surface temperature reached its maximum and the sand bed was pulled from the kiln. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperature slowly declined and then plateaued around 75°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the plain utility sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated. Due to the lack of damage, this environment is not considered damaging.

Plain Utility: 600°C x 90 sec

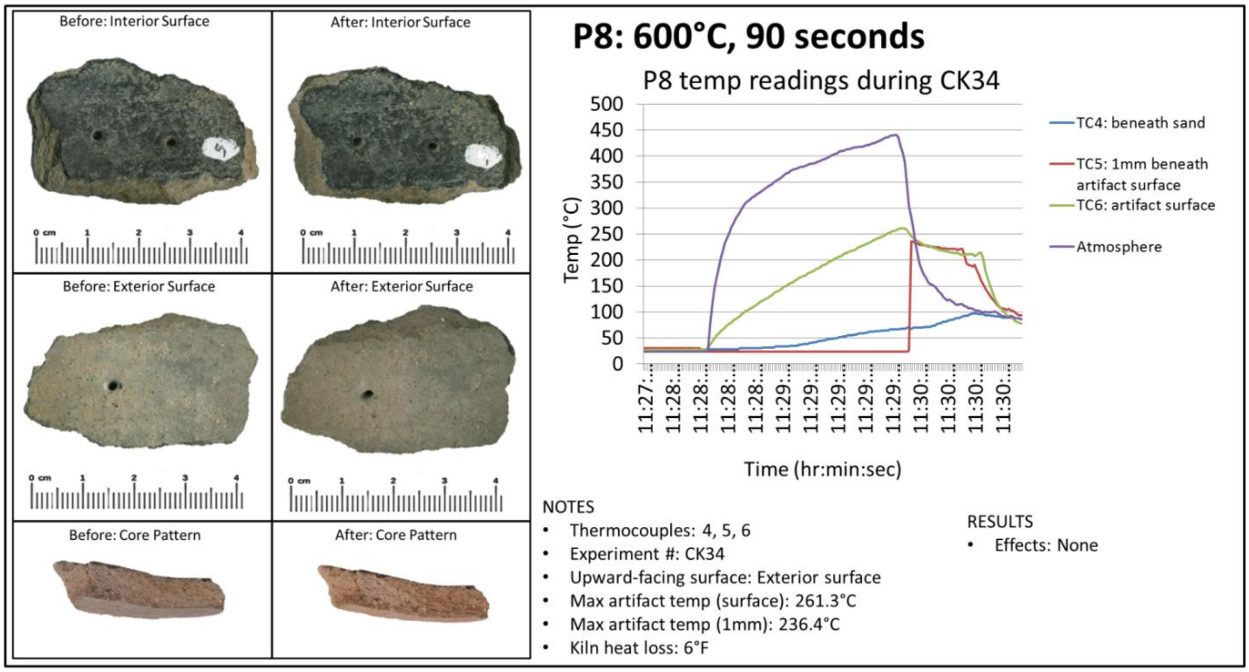


Figure 4.14. Plain utility 600°C x 90 sec typical effects

The six plain utility sherds tested in the 600°C x 90 second dose did not display any negative effects. Plain utility does not experience any damage from low heat, longer duration episodes.

As seen in the temperature graph above (Figure 4.14), the maximum artifact temperature reached was approximately 255°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd’s exposed surface was 245°C, and it reached its maximum temperature less than 5 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperature slowly declined and then plateaued around 100°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the plain utility sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated. Due to the lack of effects, this environment is not considered damaging.

Plain Utility: 900°C x 60 sec

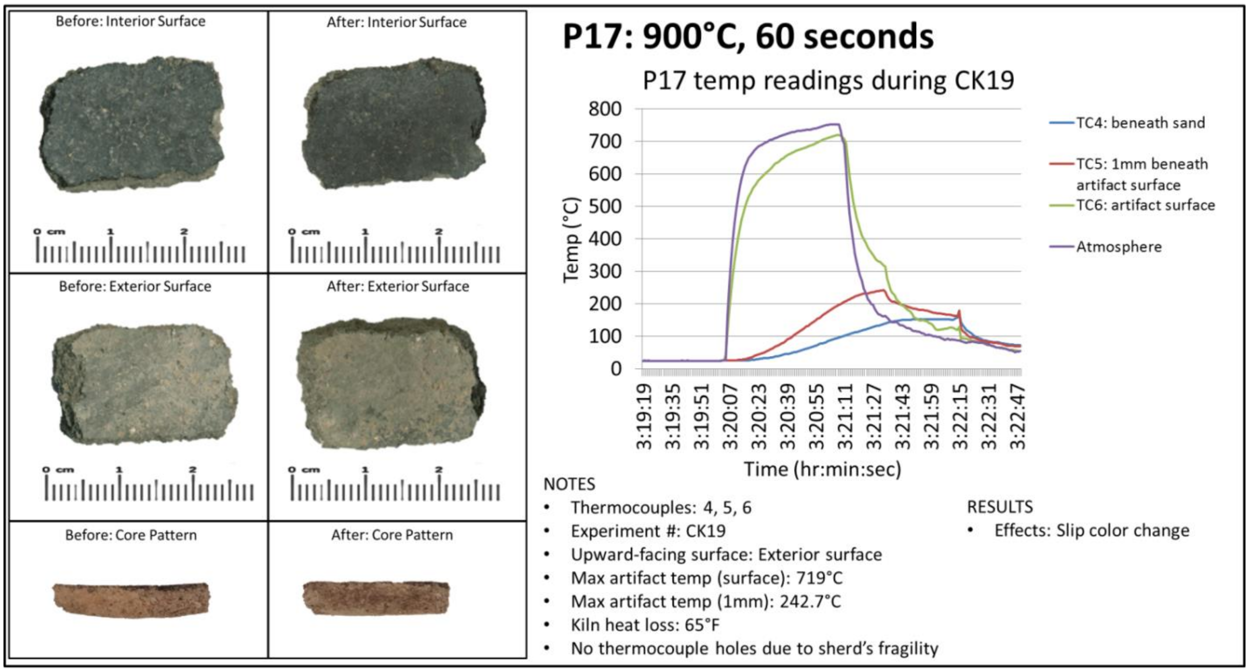


Figure 4.15. Plain utility 900°C x 60 sec typical effects

All six plain utility sherds tested in the 900°C x 60 second dose experienced surface color change. Two sherds experienced color change on both surfaces, two experienced change on the exterior surface which was facing upward, and two experienced change on the interior surface which was facing downward.

As seen in the temperature graph above (Figure 4.15), the maximum artifact temperature reached was approximately 705°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). It is important to note that this particular sherd does not have drilled holes, so the thermocouple bead sat at the top of the artifact and the higher temperature reading is likely due to the fact that the thermocouple was unsheathed. The maximum temperature recorded beneath the artifact was 230°C, and it reached its maximum temperature approximately 20 seconds after the surface temperature reached its maximum. Again, there was not a 1mm beneath the surface hole drilled in this sherd. In this case, the bead sat on the downward-facing surface and this is likely the reason it is such a low temperature. The temperature slowly declined and then plateaued around 80°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the plain utility sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heat. No other damages were observed, and although each sherd experienced discoloration, these effects were so slight that it is not considered damage.

Plain Utility: 900°C x 90 sec

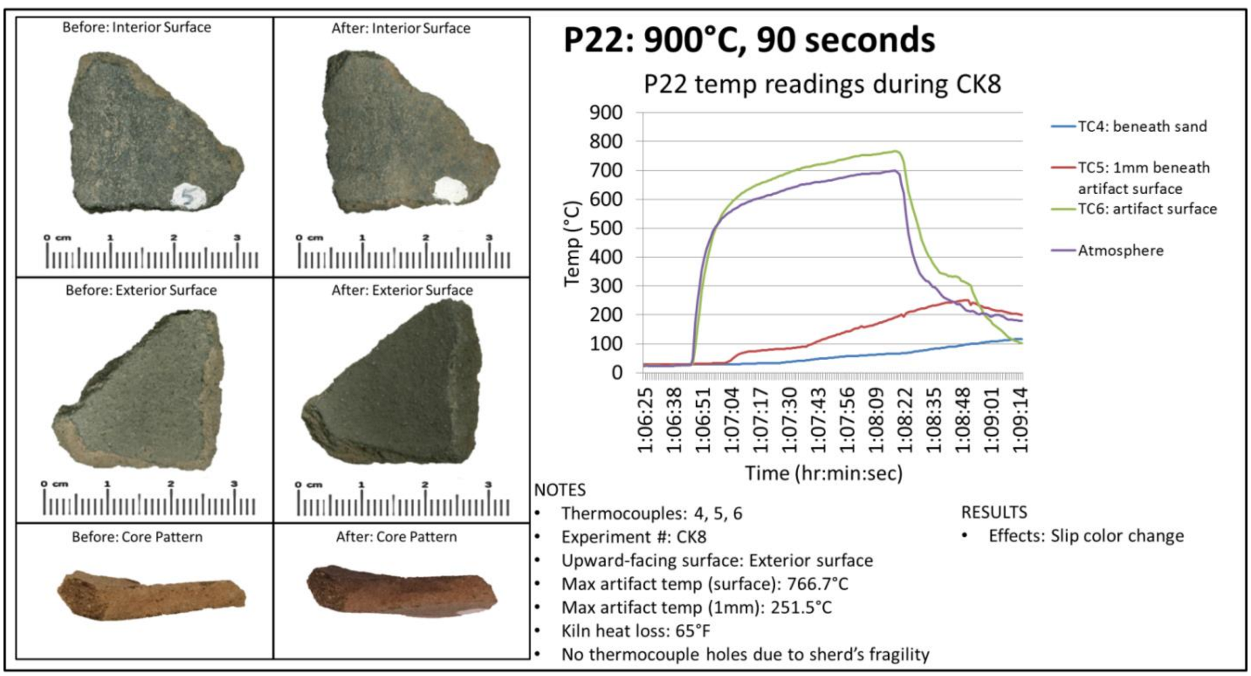


Figure 4.16. Plain utility 900°C x 90 sec typical effects

The six plain utility sherds tested in the 900°C x 90 second environment all experienced surface color change. Two sherds experienced change on both surfaces, one experienced change on the exterior surface which was facing upward, and three experienced change on the interior surface which was facing downward.

As seen in the temperature graph above (Figure 4.16), the maximum artifact temperature reached was approximately 280°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). It is important to note that this particular sherd does not have drilled holes, so the thermocouple bead sat at the top of the artifact and the higher temperature reading is likely due to the fact that thermocouple bead was unsheathed. The maximum temperature recorded beneath the artifact was 200°C, and it reached its maximum temperature less than 5 seconds after the surface temperature reached its maximum. Again, there was not a 1mm beneath the surface hole drilled in this sherd. In this case, the bead sat on the downward-facing surface and this is likely the reason it is such a low temperature. The temperatures slowly decreased and then plateaued around 90°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the plain utility sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heat.

The discoloration to plain utility ceramics caused by high heat and a longer duration is severe enough to affect how an archaeologist might interpret the artifact. No other changes were observed, but the level of discoloration constitutes irreversible damage.

Glaze Paint: 600°C x 60 sec

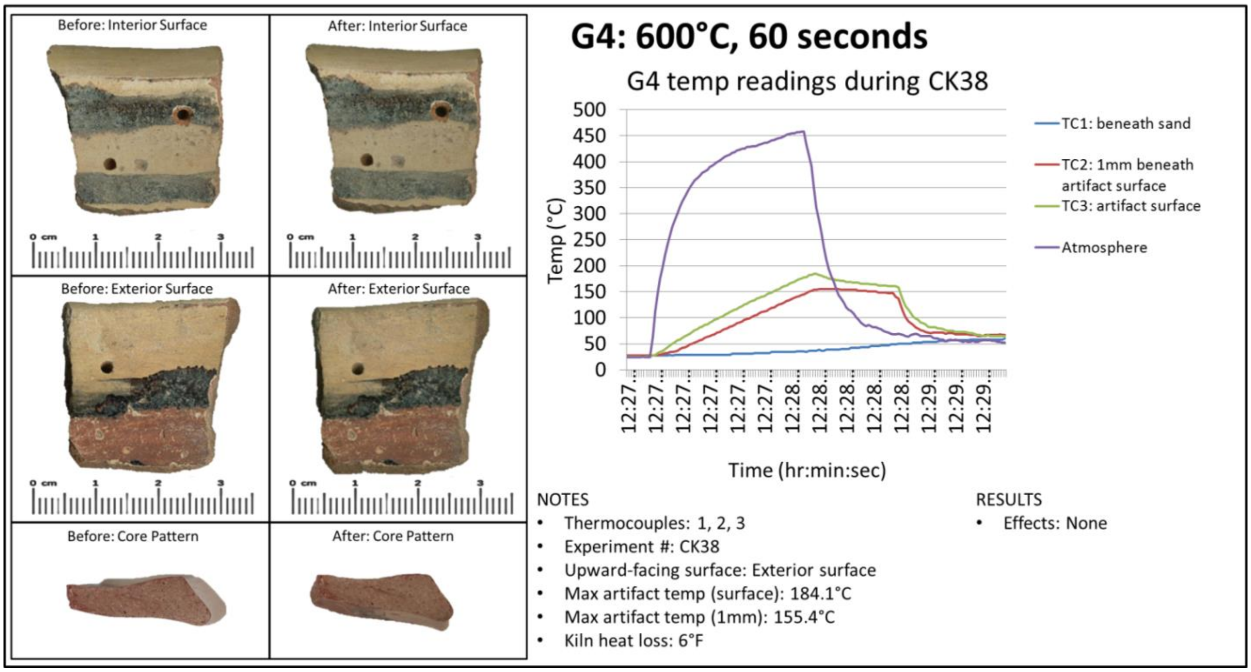


Figure 4.17. Glaze paint 600°C x 60 sec typical effects

None of the six glaze paint sherds tested in the 600°C x 60 second environment displayed any radiant heat effects. As seen in the temperature graph above (Figure 4.17), the maximum artifact temperature reached was approximately 190°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 150°C, and it reached its maximum temperature around the same time as the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 50°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the glazed paint sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated. Due to the lack of effects, this low heat, short duration environment is not considered damaging.

Glaze Paint: 600°C x 90sec

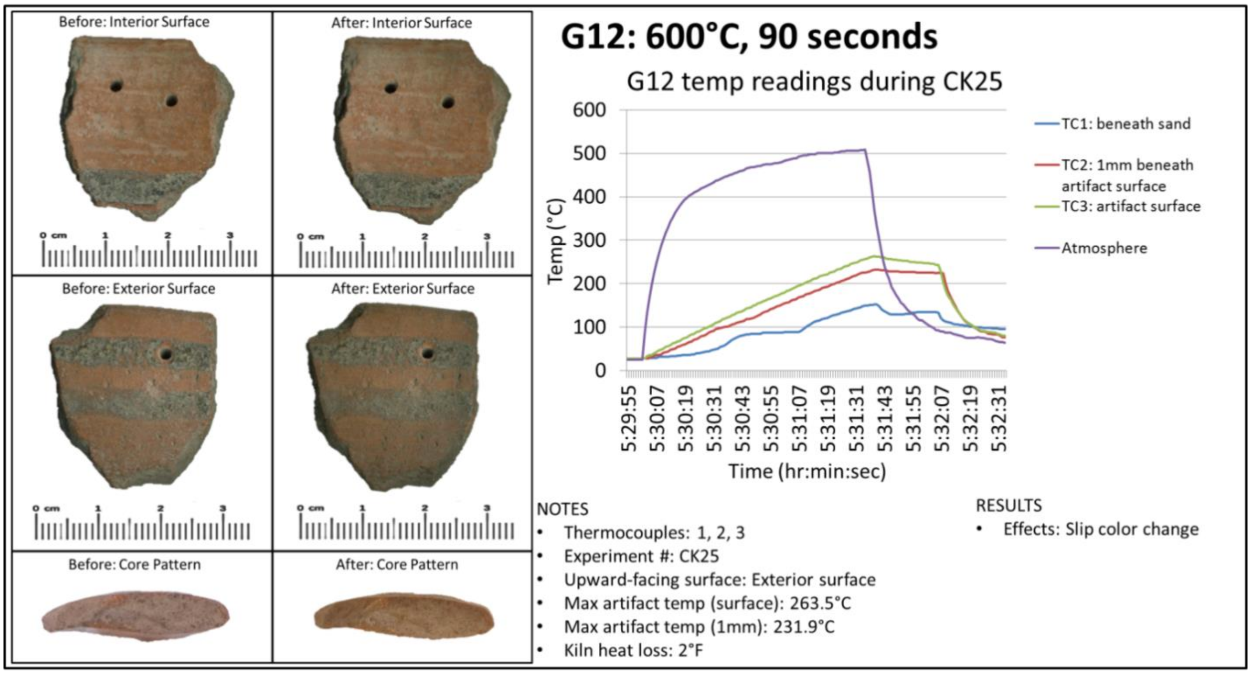


Figure 4.18. Glaze paint 600°C x 90 sec typical effects

In the 600°C x 90 second dose, four of the six glaze paint ceramics showed slip color change. Three of the artifacts displayed change on their exterior surfaces, which were facing upward in the kiln and the other showed change on both surfaces. No other effects were observed to glaze paint ceramics in the low heat for a longer duration.

As seen in the temperature graph above (Figure 4.18), the maximum artifact temperature reached was approximately 250°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 230°C, and it reached its maximum temperature around the same time as the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 100°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the glazed paint sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated. Although slip color change was observed on more than half of the samples, the change was so light throughout that this environment should not be considered damaging.

Glaze Paint: 900°C x 60 sec

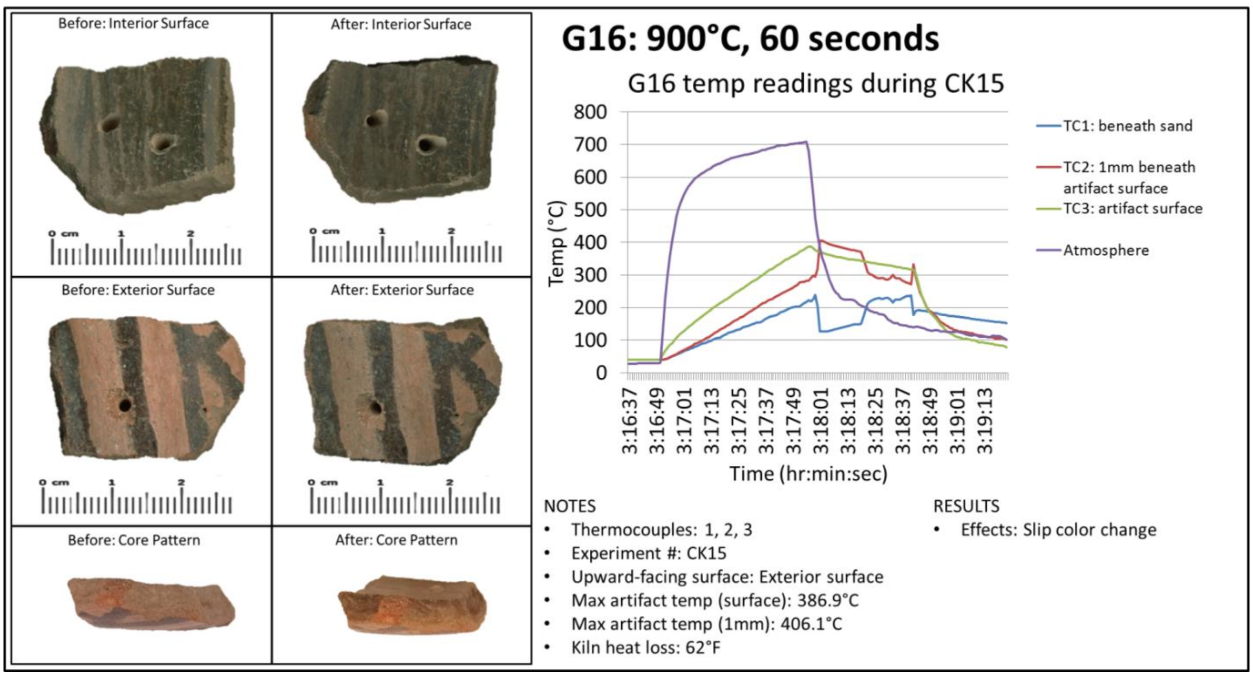


Figure 4.19. Glaze paint 900°C x 60 sec typical effects

Of the six glaze paint sherds that were exposed to 900°C x 60 seconds, all six experienced slip color change, two of which were severe enough to blacken. Three of the sherds showed change on both surfaces, while the other three showed change on only the interior surfaces that were facing downward in the kiln. The discoloration to glaze paint ceramics caused by high heat and a short duration is severe enough to affect how an archaeologist might interpret the artifact.

As seen in the temperature graph above (4.19), the maximum artifact temperature reached was approximately 395°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). The maximum temperature recorded 1mm beneath the sherd's exposed surface was 400°C, and it reached its maximum temperature approximately 5 seconds after the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 150°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The temperature fluxuation in the graph is abnormal, so there were likely a few glitches in these temperature readings. Also, the graph above only represents one of the glazed paint sherds, thus it does not match the temperature readings exactly to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated. No other changes were observed, but the level of discoloration constitutes irreversible damage.

Glaze Paint: 900°C x 90 sec

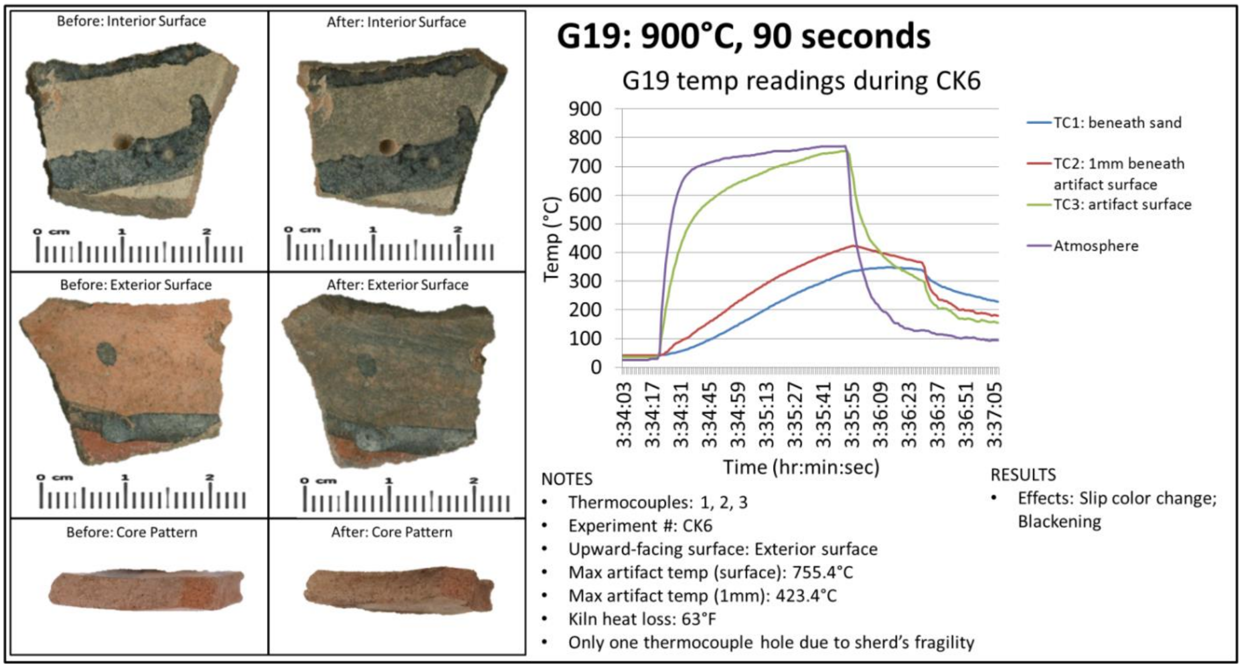


Figure 4.20. Glaze paint 900°C x 90 sec typical effects

Four of the six glaze paint sherds displayed change during the 900°C x 90 second dose. The four sherds showed slip color change, of which three were blackened. One of the blackened and slip changed sherds also had paint color change. The discoloration to glaze paint ceramics caused by high heat and a longer duration is severe enough to affect how an archaeologist might interpret the artifact.

As seen in the temperature graph above (Figure 4.20), the maximum artifact temperature reached was approximately 750°C, which was recorded at the sherd surface exposed to radiant heat (exterior surface). It is important to note that this particular sherd does not have a hole drilled all the way through, so the thermocouple bead sat at the top of the artifact and the higher temperature reading is likely due to the fact that the thermocouple was unsheathed. The maximum temperature recorded 1mm beneath the sherd's exposed surface was 410°C, and it reached its maximum temperature around the same time as the surface temperature reached its maximum. They reached their maximum as they were pulled from the kiln, which indicates that the sherd would have continued to heat if left in the kiln longer. The temperatures plateaued immediately after being removed from heat, but then rapidly declined in temperature and plateaued again around 180°C, even though the lab room temperature was approximately 20°C (as seen on the graph prior to heating). The graph above only represents one of the glazed paint sherds, thus it does not match the temperature readings precisely to the other five, but is representative of the trend of temperatures to which the sherds are exposed and to which they heated. No other changes were observed, but the level of discoloration constitutes irreversible damage.

Table 4.1. Summary table of radiant heat effects

*Min= mineral; Glz= glaze; Carb= carbon; Text= textured; Pln= plain; SlCC= slip color change; Bl= blackening; PCC= paint color change; SuCC= surface color change; Fractions= #affected/#tested

	600°C					**900°C**				
	Min Paint	**Glz Paint**	**Carb Paint**	**Text Utility**	**Pln Utility**	**Min Paint**	**Glz Paint**	**Carb Paint**	**Text Utility**	**Pln Utility**
60 sec	SlCC (4/6)	None	SlCC (1/6)	SlCC (1/6)	None	SlCC (6/6); Bl (6/6); PCC (2/6)	SlCC (6/6); Bl (2/6)	SlCC (6/6); Bl (3/6); PCC (1/6)	SuCC (6/6); Bl (2/6)	SuCC (6/6)
90 sec	SlCC (6/6)	SlCC (4/6)	SlCC (6/6); Bl (2/6); PCC (2/6)	SuCC (2/6)	None	SlCC (6/6); Bl (5/6); PCC (4/6); Ox (4/6)	SlCC (6/6; Bl (3/6); PCC (1/6)	SlCC (4/6); Bl (1/6)	SuCC (6/6); Bl (2/6)	SuCC (6/6)

Table 4.1 provides a summary of the visual observations of change that occurred after the experiment. Constan's analysis, which, as of May 2015 is in draft form, provides a more quantitative assessment on how the ceramics discussed above reacted to radiant heat (personal

communication, 2015). Readers concerned with a detailed understanding of Constan's analysis should consult the pending final report; what follows is a brief synopsis aimed at the overall goals of this thesis. For most sherds, there was no observed change in temper or weight before and after heating (Table 4.2). For example, only seven of 120 sherds showed temper change, and approximately 20% of the sherds became harder, while 18% became softer, according to Moh's scale before and after measurements (Table 4.3). When examining core pattern, Constan noticed that approximately 34% of the samples exhibited change, which was observed across ceramic categories and in most doses with the exception of plain utility at 600°C for 90 seconds and carbon paint at 900°C for 60 seconds (Table 4.4). No cracking, fracturing, or vitrification was observed. The effect that appeared to have had a correlation with the test variables (ceramic category, duration, and temperature) was paint, slip and surface color change. Color change increased with heat doses, and Constan notes that approximately 47% of sherds exposed to 600°C exhibited color change, while 80% of those exposed to 900°C exhibited color change. Of course, the strength of these effects might change with a larger sample size.

Table 4.2. Weight (g) change table developed by Constan (personal communication, 2015)

Ceramics Category	**600ºC**	**900ºC**
Carbon Paint	0.22	0.16
Glaze Paint	0.02	0.04
Mineral Paint	0.04	0.08
Plain Utility	0.02	0.10
Textured Utility	0.02	0.14
Grand Total	0.06	0.10

Table 4.3. Hardness change, measured by Constan (personal communication, 2015)

Became Softer	**Same Hardness**	**Became Harder**	**Total**
24	74	22	N= 120

Table 4.4. Core pattern change, measured by Constan (personal communication, 2015)

Core Pattern Stayed the Same	Core Pattern Change	Total
79	41	N= 120

Constan's analysis is complimentary to the visual analysis described in this chapter. While Constan observed and measured changes that an archaeological technician could not see though visual analysis, like hardness and weight, they appear to be consistent across ceramic category or heat dose. The more detailed analysis done by Constan verified the likelihood that the primary visible effect of radiant heat on ceramics is color change, and that these are observations archaeologists can make simply using a hand lens, suggesting that we should base any recommendations for a mitigation guide on potential paint, slip and/or surface color change.

Chapter 5. Conclusions

Summary and Preservation Guide Development

In the Jemez Mountains of the American Southwest, archaeological sites have long been exposed to frequent, low-severity wildfires, but in the last several decades the fire systems have shifted to less frequent and more severe fires. If the trend toward increased severity of wildfires continues, the likelihood for cultural resource damage will increase. For this reason, archaeologists and land managers are looking for a way to protect archaeological resources from fire damage.

Determining damage is important to archaeologists because cultural resources are non-renewable and when damage occurs, it is irreversible. Previous studies have provided useful information on how artifacts are damaged, but the results have been inconsistent (Table 1.2), and methods have been incompletely reported. To fill this gap, a team of specialists has been assembled in order to conduct a thorough study. Once the study is complete, the team will apply those results to the problem by developing a preservation guide for fire managers and archaeologists.

This thesis project involves the initial steps of this larger study, specifically an experiment with ceramic artifacts in a kiln to test radiant heat, with the results reported in Chapter 4. Based on the experimental results, damage caused by a specific temperature and duration is dependent on the ceramic category exposed to that fire environment. For example, textured utility, plain utility, carbon paint and glaze paints withstood the 600ºC for 60 seconds radiant heat environment, but the mineral paints showed enough effects to be determined damage. In fact, mineral paints experienced negative effects in all four radiant heat environments, and all were considered damaging. Due to these results, mineral paints appears to be the least resilient category of ceramic to radiant heat environments and should not be exposed to radiant heat under any fuel load.

Carbon paint ceramics appear to be the second most sensitive category to radiant heat. They are seriously damaged starting at the 600ºC x 90 second duration environment and continue to show damage into the 900ºC for 60 seconds environment. Oddly, in the most severe heat and duration (900ºC for 90 seconds), they showed very few effects. This inconsistency in carbon paint damage was not expected, and the only way to better understand carbon paint ceramic damage in radiant heat would be to conduct more tests to insure that the pattern is replicable, and then have a chemist analyze the mechanism behind the change. Unfortunately, this is not possible at this stage of the research. Since archaeologists prefer not to allow damage to artifacts, the determination of which environment to start mitigating heat should be at 600ºC at 90 seconds, since damage was present.

The next two ceramic categories, both of which appeared to be somewhat resilient to radiant heat, were textured utility and glaze paint. These two experienced very minor effects in the 600ºC environments, which were not severe enough to constitute damage, but they were more drastically affected in the 900ºC environments.

The plain utility ceramics displayed very minor effects in the 900ºC environments, but not drastic enough to constitute damage. Thus, none of the doses were severe enough to be considered damaging for plain utility. In this situation, the recommendation would be that there is no need to intervene for a site whose ceramic assemblage is entirely comprised of plain utility.

Table 5.1. Determination of which kiln environments are damaging to ceramic categories

Ceramic Category	**Kiln Temperature (ºC) x Duration (seconds)**	**Did this dose cause an effect?**	**If so, were the effects severe enough to be considered damage?**
Textured Utility	600 x 60	Yes	No
	600 x 90	Yes	No
	900 x 60	Yes	Yes
	900 x 90	Yes	Yes
Carbon Paint	600 x 60	Yes	No
	600 x 90	Yes	Yes
	900 x 60	Yes	Yes
	900 x 90	Yes	No
Mineral Paint	600 x 60	Yes	Yes
	600 x 90	Yes	Yes
	900 x 60	Yes	Yes
	900 x 90	Yes	Yes
Plain Utility	600 x 60	No	No
	600 x 90	No	No
	900 x 60	Yes	No
	900 x 90	Yes	No
Glaze Paint	600 x 60	No	No
	600 x 90	Yes	No
	900 x 60	Yes	No
	900 x 90	Yes	No

Given these results, the problem with making recommendations to archaeologists and fire managers who would be using the mitigation tool developed from these conclusions is that typically assemblages contain multiple ceramic categories, and as summarized Table 5.1, the ceramic categories have different capacities for withstanding radiant heat. In order to turn this information into a guide that managers can use to make good and rapid judgments, we need to consider how to protect ceramic resources as a collective group rather than how to protect them as individual categories. The questions to address are: do we recommend that all ceramic assemblages be protected from fuel loads that emit 600º for 60 seconds, our lowest experimental dose, since at least one category displayed damage in said dose? Or, do we take the typical start of damage to the ceramics in our study and recommend that fuel loads reaching levels that translate to 900º for 60 seconds be treated? These recommendations should be based on what archaeologists find important when they analyze sites based on surface artifact characteristics. Although consultation with forest and cultural resource managers is ongoing, my preliminary recommendation, based on the results, the interests of archaeologists, and the interests of fire managers needing to manage fuel loads efficiently, is that fire events that emit 600ºC for 90 seconds or more should be prevented (either through prescribed burning to reduce fuel loads and potential dose, or by moving/removing fuels) in order to preserve archaeological resources from fire damage.

We can now refer back to the question in Chapter 2 on whether low, moderate or severe fires would cause effects and/or damage. In this study, the 600°C doses were typical of moderate intensity fires, while the 900°C doses were chosen to reflect severe intensity fires. If this holds true in real fire environments, then we can say that ceramics experience radiant heat effects, and sometimes damage, in moderate wildfires. In severe wildfires, ceramics would display frequent damage. Again, the variables in fire intensity are very complex, which is why recommendations based on this preliminary correlation of the experimental data with real-world situations in the Jemez Mountains region will require review by the Arcburn Project team of specialists.

Thus, the set point for action will be further developed as the project continues to collect data and consults with archaeologists who manage forested environments. How this recommendation might be applied to real-world situations is displayed in Figures 5.1-5.8, a prototype preservation guide, which focuses on providing practical recommendations in the form of a decision tree (Figure 5.4). Clearly, the prototype preservation guide is not ready to be applied as it stands in this thesis, which is why it does not contain any actual measures, and instead uses vague language as a proxy. However, it helps map a direction that the ArcBurn team can go to protect ceramics from radiant heat in real-world situations. It was created with the help of consultants: Alexander Evans, Rachel Loehman, Jim Reardon, Faith Ann Heinsch, Megan Friggens, Connie Constan and Bret Butler. Each of these individuals specializes in a field that is directly related to portions of this guide.

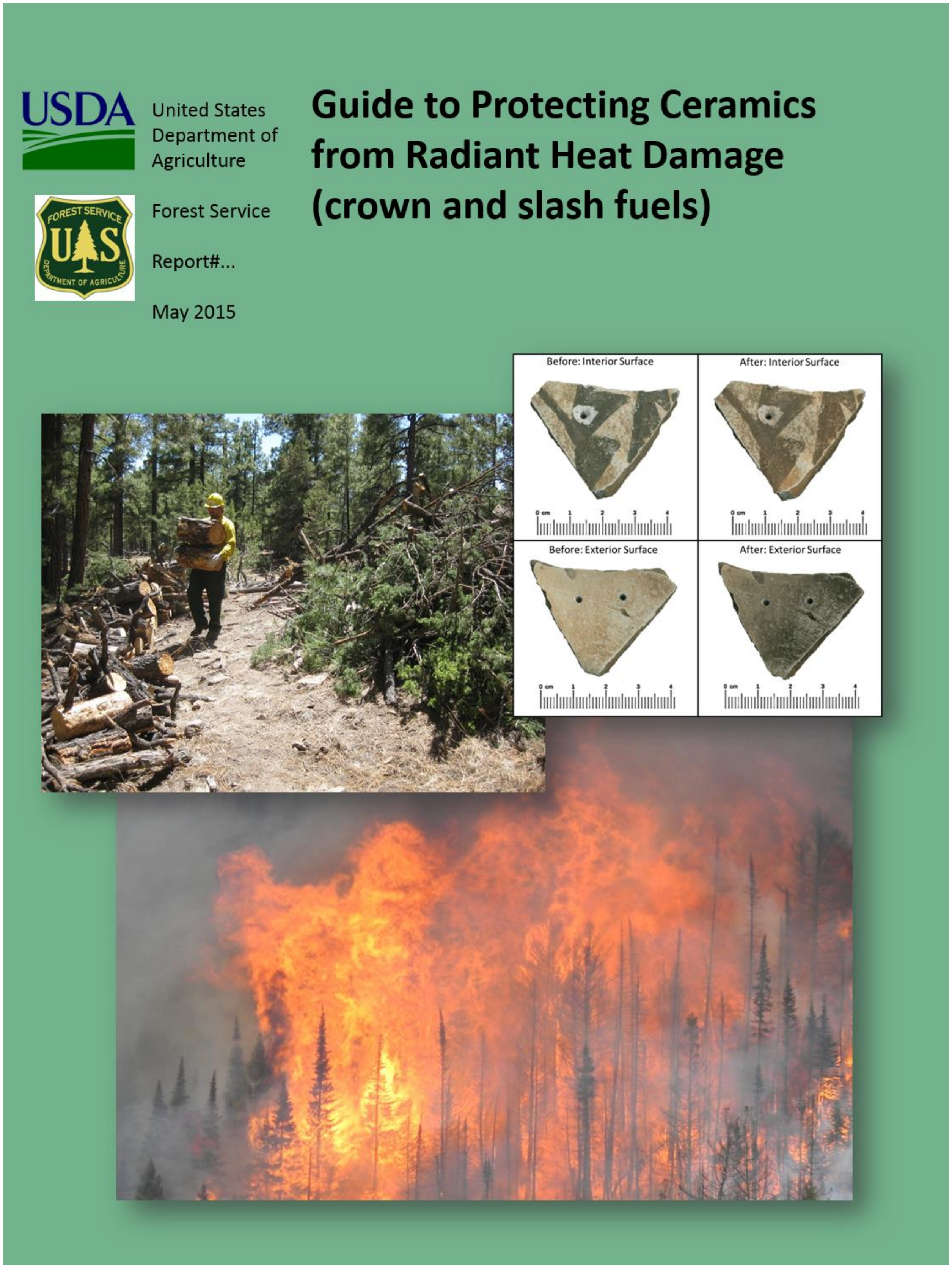


Figure 5.1. Prototype preservation guide cover page

Fire Impacts to Cultural Resources

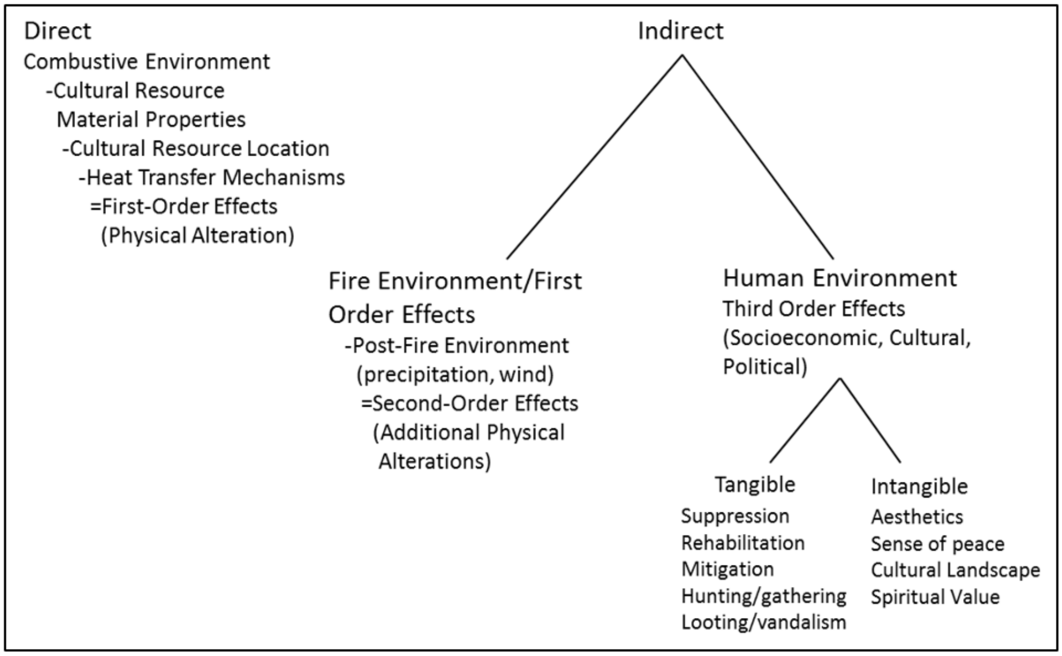


Figure 1. Fire Impacts to Cultural Resources taken from Ryan et al. (2012:12), redrawn for clarity.

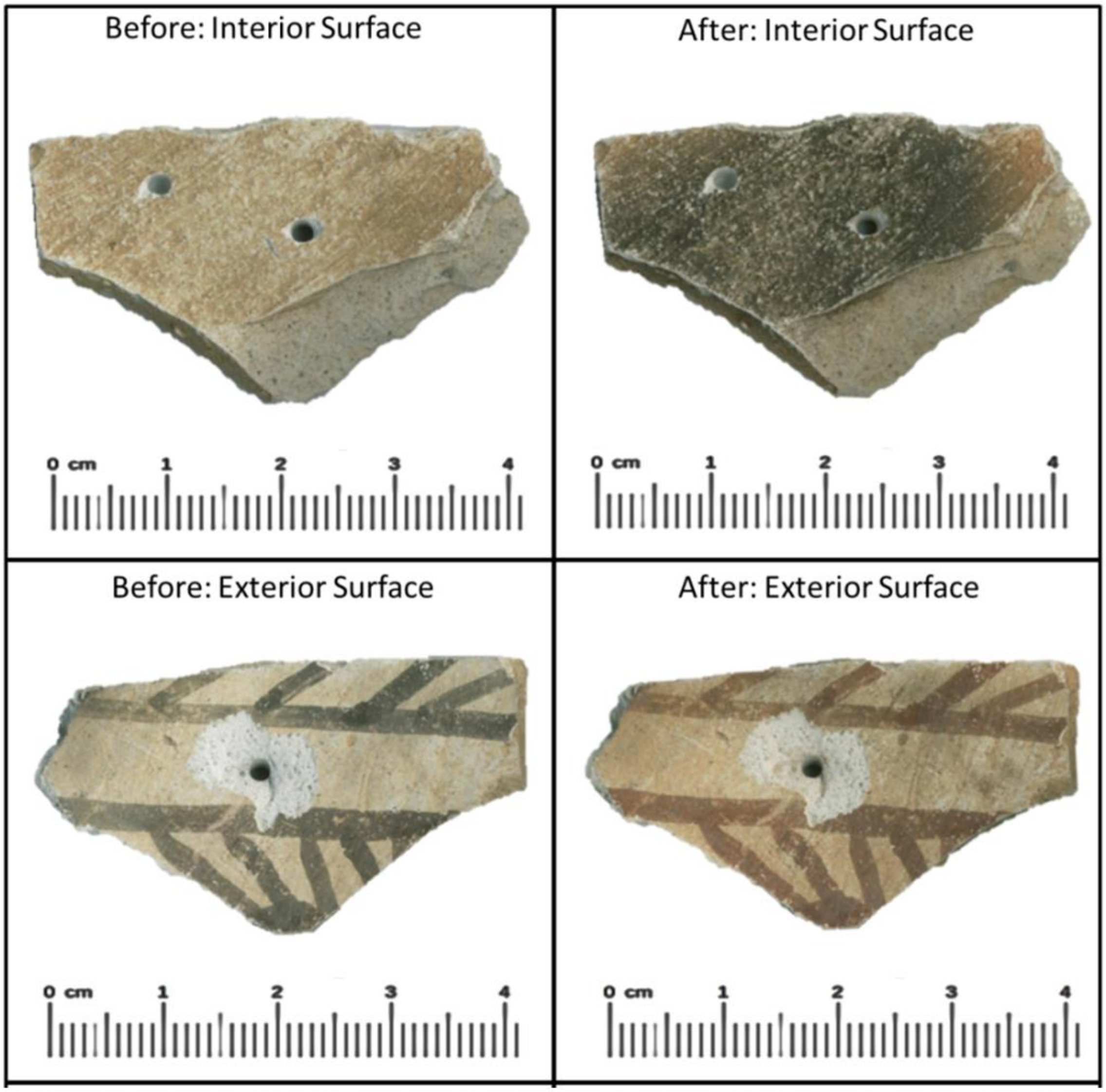
Table 1. Kiln experimental results; radiant heat effects to ceramics

Temp °C	**Time (sec)**	**Effect(s) observed/# of times**	**Damaging environment?**
600	60	Slip color change on 6/30 samples	No
600	90	Surface color change on 8/60 samples Slip color change on 10/60 samples Blackening on 2/60 samples Paint color change on 2/60 samples	Yes
900	60	Surface color change on 18/60 samples Slip color change on 12/60 samples Blackening on 5/60 samples Paint color change on 3/60 samples	Yes
900	90	Surface color change on 12/60 samples Slip color change on 13/60 samples Blackening on 10/60 samples Paint color change on 4/60 samples Oxidation on 4/60 samples	Yes

1

Figure 5.2. Prototype preservation guide page 1

Examples of Radiant Heat Effects to Ceramics



*This image is of a mineral paint sherd that experienced slip color change in the form of blackening (top right) and oxidation (bottom right) as well as paint color change in the form of oxidation (bottom right). This sherd was exposed to 900°C for 90 seconds.

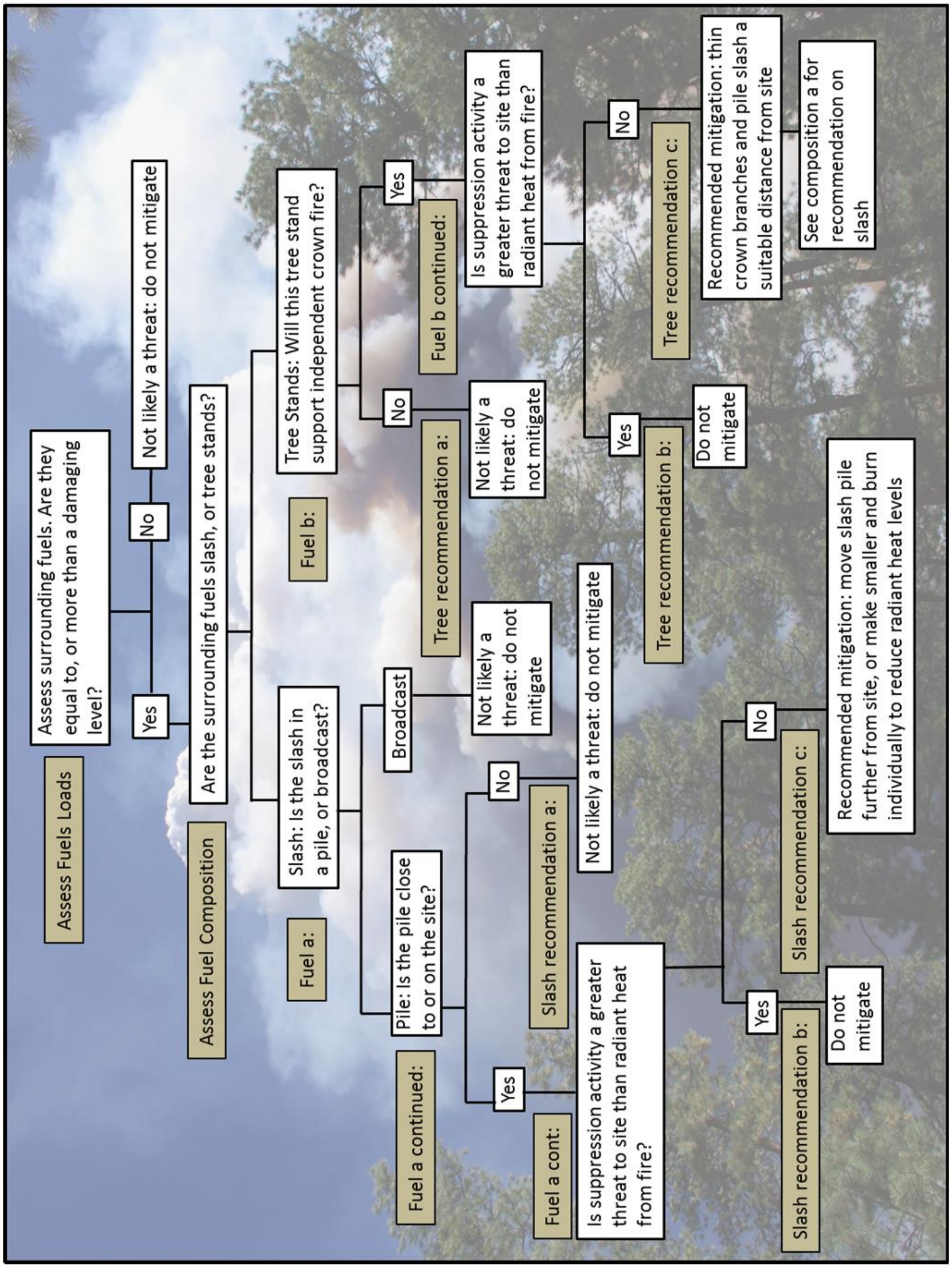
Surface color change: when an unslipped surface (typically seen in utility sherds) is altered to either a different color or different shade of the same color. This change may be observed in environments that produce 600°C for 90 seconds or more.

Slip Color Change: when the slip colorant is altered either to a different color or a darker version of the same color. This change may be observed in environments that produce 600°C for 60 seconds or more.

Paint Color Change: when the paint colorant is altered either to a different color or a darker version of the same color. This change may be observed in environments that produce 600°C for 90 seconds or more.

2

Figure 5.3. Prototype preservation guide page 2



Mitigation-assistance flow-chart. Background photo credit: Rachel Loehman

3

Figure 5.4. Prototype preservation guide page 3

Examples of Flow Chart Compositions and Recommendations

Fuel Compositions

Slash: "The accumulation of limbs, tops, and miscellaneous residue left by forest management activities, such as thinning, pruning, and timber harvesting." (Larimer County n.d.)

Tree Stand: "A group of standing trees is referred to as a stand. One stand will usually have characteristics that will distinguish it from other stands. Differences could be species, average diameter, density and location." (Iowa DNR n.d.)

Photo credit: Bret Butler

Photo credit: Rachel Loehman

Fuel a

Slash Pile: see example slash pile photo above. A pile is when slash is stacked.

Broadcast slash: When the slash is evenly distributed throughout the burn area to be burned effectively. (Larimer County n.d.)

Fuel b

Tree stand that will not support crown fire: see example tree stand above. This is a low density stand which would not support a crown fire. Although, the determination of whether a crown fire will be supported by a crown density should ultimately be evaluated by a professional fire manager.

Tree stand that will support crown fire: This is a high density stand which would support a crown fire. The determination of whether a crown fire will be supported by a crown density should ultimately be evaluated by a professional fire manager.

Crown: "the part of a tree or woody plant bearing live branches and foliage." (Society of American Foresters n.d.)

Broadcast slash

Photo credit: Faith Ann Heinsch

Dense crown

Photo credit: Rachel Loehman

4

Figure 5.5. Prototype preservation guide page 4

Examples of Flow Chart Comps and Recs Continued…

Fuel a continued

If the slash pile is within X ft. of, or on top of the site, the radiant heat levels can be damaging to ceramics. This is why, if it is not piled close to or on the site, the first recommendation (Slash recommendation a) is to not mitigate. Although, if the pile is close to the site, further investigation should be considered. Human suppression activities (in this case, moving or distributing fuels) are potentially more damaging to the ceramics. If so, the pile should not be moved. On the following page are examples of suppression activities, all of which may be damaging to an archaeological site. It is up to the archaeologist to determine whether a fire manager's recommended treatment would be more or less damaging than radiant heat levels.

Fuel b continued

If a tree stand is able to support independent crown fire, the radiant heat from crown fire can be damaging to ceramics. This is why, if the tree density is low and cannot support a crown fire, the first recommendation (Tree recommendation a) is to not mitigate. Although, if the stand is able to support independent crown fire, further investigation should be considered. Suppression activities (in this case, thinning and piling branches) are potentially more damaging to the ceramics than radiant heat. If so, the branches should be left on the tree to burn. If the branches are thinned, the manager must also consider whether to pile the slash or broadcast, in which case they should refer back to Composition a. On the following page are examples of suppression activities, all of which may be damaging to an archaeological site. It is up to the archaeologist to determine whether a fire manager's recommended treatment would be more or less damaging than radiant heat levels.

Suppression Activities

Digging line: fire crews dig a line between a fire and the location by which fire managers would like to stop the fire. This line would not completely stop a fire, but the goal is to slow it down.

Photo credit: Rory Gauthier

5

Figure 5.6. Prototype preservation guide page 5

Examples of Flow Chart Comps and Recs Continued…

Suppression Activities

Thinning: Cutting down and removing a portion of the trees in a forest (Maine Forestry 2007)

Photo credit: Rory Gauthier

Photo credit: John Galvan

Prescribed Burning: The, “deliberate use of fire to help manage a forest.” (Natural Resources Conservation Service 1999)

Photo credit: Jason Forthofer

6

Figure 5.7. Prototype preservation guide page 6

Examples of Flow Chart Comps and Recs Continued…

Suppression Activities

Dozer line: Similar to hand-digging by fire crews, a dozer is used to dig a line between a fire and the location by which fire managers would like to stop the fire. This line would not completely stop a fire, but the goal is to slow it down.

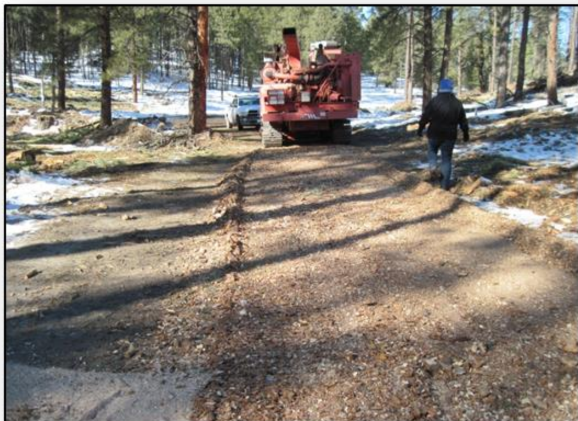


Photo credit: Ana Steffen and Jen Dyer

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7

Figure 5.8. Prototype preservation guide page 7

Future Work

This study has focused on macroscale damage, and incorporating other kinds of effects that others have considered, would be useful to further explore. For example, Buenger (2003:172) discovered that ceramics exposed to fire may be altered chemically, which we did not measure. Archaeologists rely on dating methods like thermoluminesence to indicate how old an artifact dates, which is valuable cultural information (Dunnell and Feathers 1995). Thermoluminsecence dating is done by measuring the radiation dose, which builds since the last time the crystalline materials in the ceramics have been exposed to light or heat (Dunnell and Feathers 1995). Thus, determining whether a ceramic artifact has been burned in a recent fire is very contextually important for how the archaeologist should date it. While it hasn't been researched, the integrity of other trace chemical and microbotantical analytical methods conducted on ceramics might suffer as well. For example, conducting pollen, chemical residue or DNA analysis would also likely be affected by moderate to severe heating of an artifact.

Last, there are implications this study could have on site interpretation as well as fire history information. As an example for site interpretation, if pottery is buried in the archaeological context and clearly has not been exposed to wildfires in the last several centuries, but shows signs of burning, the archaeologist can determine, based on damage type, whether or not it had been exposed to radiant heat and at what levels. This opens room for future implications such as deliberate burning of structures and villages in the ancient past that might profitably begin with some of the observations made in this study. Although the purpose of this thesis is to identify the potential damage radiant heat can cause to ceramics and recommend mitigation tactics, the identified patterns could be used in the opposite direction as well: certain effects are caused by certain heat and duration levels, thus if those effects are seen on an artifact, it's possible to draw the connection between the two.

In the same vein, if fire managers are interested in an area's fire history, but don't have historic records, the damages, or lack thereof, to ceramics may help verify presence or absence of prehistoric or historic wildfires. Currently, fire managers are able to build fire histories with tree cores and cookies, but to add another line of supporting data to their current methods could help strengthen their conclusions about a region's fire history. Although these two research lines could be important for site interpretation and improving fire histories, their implementation lie outside of the scope of this study.

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Appendix A: Kiln Experimental Data

Table A.1. Kneifel's lab notes

*Art#: Artifact #; Kiln °C/sec: kiln temperature in degrees Celsius and duration in seconds; Max Temp (1mm): maximum temperature 1mm beneath the artifact surface; Max Temp (surf): maximum temperature at the surface of the artifact; TC #s: Thermocouple numbers attached to artifact; Notes: Kiln heat loss in notes section is in ferenheight because the kiln read temp in °F.

Artifact #	**Test #**	**Kiln temp °C x Duration (sec)**	**Max Temp (1mm)**	**Max Temp (surf)**	**TC #s**	**Notes**
T1	CK44	600 x 60	172.5	201.3	1, 2, 3	Kiln heat loss 7°F
T2	CK43	600 x 60	155.7	167.5	1, 2, 3	Kiln heat loss 8°F
T3	CK42	600 x 60	157.2	228.2	1, 2, 3	Kiln heat loss 9°F
T4	CK41	600 x 60	167.2	192.6	1, 2, 3	Kiln heat loss 10°F
T25	CK47	600 x 60	109.8	375.9	1, 2, 3	Kiln heat loss 3°F
T26	CK48	600 x 60	115.4	365.2	1, 2, 3	Kiln heat loss 3°F
T5	CK36	600 x 90	151.3	171.1	1, 2, 3	Kiln heat loss 4°F

Artifact #	Test #	Kiln temp °C x Duration (sec)	Max Temp (1mm)	Max Temp (surf)	TC #s	Notes
T6	CK35	600 x 90	249.7	258	1, 2, 3	Kiln heat loss 5°F
T7	CK34	600 x 90	243.1	269.5	1, 2, 3	3 holes, one filled with crushed ceramic during test; Kiln heat loss 6°F
T8	CK33	600 x 90	178.8	222.7	1, 2, 3	Kiln heat loss 6°F
T11	CK32	600 x 90	171.8	259.1	1, 2, 3	3 holes, one filled with crushed ceramic during test; Kiln heat loss 4°F
T12	CK31	600 x 90	245.6	272	1, 2, 3	Kiln heat loss 3°F
T13	CK24	900 x 60	223.1	383	1, 2, 3	Kiln heat loss 62°F
T14	CK23	900 x 60	334.6	405.3	1, 2, 3	Kiln heat loss 64°F
T15	CK22	900 x 60	334.2	380.9	1, 2, 3	Broke during drilling; Kiln heat loss 64°F
T16	CK21	900 x 60	323.9	385.1	1, 2, 3	Kiln heat loss 58°F
T17	CK20	900 x 60	417.6	441.5	1, 2, 3	Kiln heat loss 65°F
T18	CK19	900 x 60	313.3	406.7	1, 2, 3	Broke during drilling; Kiln heat loss 65°F
T19	CK12	900 x 90	448.9	464.8	1, 2, 3	Kiln heat loss 66°F
T20	CK11	900 x 90	365.8	569.5	1, 2, 3	Kiln heat loss 64°F
T21	CK10	900 x 90	307.4	478.9	1, 2, 3	Kiln heat loss 63°F
T22	CK9	900 x 90	288.9	497.4	1, 2, 3	Kiln heat loss 59°F
T23	CK8	900 x 90	363.9	436	1, 2, 3	Kiln heat loss 65°F
T24	CK7	900 x 90	388.7	730	1, 2, 3	No thermocouple holes; Broke during drilling; Kiln heat loss 61°F
C1	CK46	600 x 60			7, 8, 9	Temp data not recorded; Kiln heat loss 14°F
C2	CK45	600 x 60	152.4	191.3	7, 8, 9	Kiln heat loss 14°F

Artifact #	Test #	Kiln temp °C x Duration (sec)	Max Temp (1mm)	Max Temp (surf)	TC #s	Notes
C3	CK40	600 x 60	143.7	170.6	7, 8, 9	Kiln heat loss 8°F
C4	CK39	600 x 60	165.5	175.6	7, 8, 9	Kiln heat loss 5°F
C5	CK38	600 x 60	163.8	185.8	7, 8, 9	Kiln heat loss 6°F
C6	CK37	600 x 60	143.5	212.8	7, 8, 9	Kiln heat loss 3°F
C7	CK30	600 x 90	106.6	239.1	7, 8, 9	Kiln heat loss 3°F
C8	CK29	600 x 90	205.7	270.8	7, 8, 9	Kiln heat loss 2°F
C9	CK28	600 x 90	197.6	237.9	7, 8, 9	Kiln heat loss 4°F
C10	CK27	600 x 90	191	231.4	7, 8, 9	Kiln heat loss 3°F
C11	CK26	600 x 90	171	261.6	7, 8, 9	Kiln heat loss 7°F
C12	CK25	600 x 90	199.9	263.5	7, 8, 9	Kiln heat loss 2°F
C13	CK18	900 x 60	335.9	397	7, 8, 9	Kiln heat loss 62°F
C14	CK17	900 x 60	280.2	411.1	7, 8, 9	Kiln heat loss 63°F
C15	CK16	900 x 60	328.9	399.7	7, 8, 9	Kiln heat loss 63°F
C16	CK15	900 x 60	289.9	358	7, 8, 9	Kiln heat loss 62°F
C17	CK14	900 x 60	373.9	372.3	7, 8, 9	Kiln heat loss 64°F
C18	CK13	900 x 60	349.5	400.9	7, 8, 9	Kiln heat loss 64°F
C19	CK6	900 x 90	493.4	528.2	7, 8, 9	Kiln heat loss 63°F
C20	CK5	900 x 90	447.1	539.1	7, 8, 9	Kiln heat loss 62°F
C21	CK4	900 x 90	494.9	556.7	7, 8, 9	Kiln heat loss 58°F
C22	CK3	900 x 90	479.5	538.1	7, 8, 9	Kiln heat loss 63°F
C23	CK2	900 x 90	557.5	598.8	7, 8, 9	Kiln heat loss 62°F
C24	CK1	900 x 90	355.4	479.7	7, 8, 9	Kiln heat loss 67°F
M1	CK40	600 x 60	174	204.5	4, 5, 6	Kiln heat loss 8°F
M2	CK39	600 x 60	147	224.6	4, 5, 6	Kiln heat loss 5°F

Artifact #	Test #	Kiln temp °C x Duration (sec)	Max Temp (1mm)	Max Temp (surf)	TC #s	Notes
M3	CK38	600 x 60	153.7	197.7	4, 5, 6	Kiln heat loss 6°F
M4	CK37	600 x 60	185.7	212.8	4, 5, 6	Kiln heat loss 3°F
M25	CK46	600 x 60			1, 2, 3	Temp data not recorded; Only has one hole (1mm) due to artifact fragility; Kiln heat loss 14°F
M26	CK45	600 x 60	142.4	397.9	1, 2, 3	Only has one hole (1mm) due to artifact fragility; Kiln heat loss 14°F
M5	CK30	600 x 90	220.7	198.7	4, 5, 6	Kiln heat loss 3°F
M6	CK29	600 x 90	212.5	244.3	4, 5, 6	Kiln heat loss 2°F
M7	CK28	600 x 90	234.6	271.1	4, 5, 6	Kiln heat loss 4°F
M8	CK27	600 x 90	228.1	261	4, 5, 6	Kiln heat loss 3°F
M9	CK26	600 x 90	193	235.1	4, 5, 6	Kiln heat loss 7°F
M11	CK25	600 x 90	215.1	275	4, 5, 6	Kiln heat loss 2°F
M12	CK18	900 x 60	321.3	324.6	4, 5, 6	Kiln heat loss 62°F
M13	CK17	900 x 60	351.7	395.1	4, 5, 6	Kiln heat loss 63°F
M14	CK16	900 x 60	343.4	385.2	4, 5, 6	Kiln heat loss 63°F
M15	CK15	900 x 60	409.3	388.5	4, 5, 6	Kiln heat loss 62°F
M16	CK14	900 x 60	362.6	343.3	4, 5, 6	Kiln heat loss 64°F
M17	CK13	900 x 60	341.5	322	4, 5, 6	Kiln heat loss 64°F
M18	CK6	900 x 90	510.8	729.4	4, 5, 6	Only has one hole (1mm) due to artifact fragility; Broke during drilling; Kiln heat loss 63°F
M19	CK5	900 x 90	542.3	727.6	4, 5, 6	Only has one hole (1mm) due to artifact fragility; Broke during drilling; Kiln heat loss 62°F
M20	CK4	900 x 90	461.5	547.1	4, 5, 6	Kiln heat loss 58°F

Artifact #	Test #	Kiln temp °C x Duration (sec)	Max Temp (1mm)	Max Temp (surf)	TC #s	Notes
M21	CK3	900 x 90	439.7	406.2	4, 5, 6	Kiln heat loss 63°F
M22	CK2	900 x 90	323	570.2	4, 5, 6	Kiln heat loss 62°F
M24	CK1	900 x 90	380.8	558.9	4, 5, 6	Kiln heat loss 67°F
P1	CK44	600 x 60	181	223.2	4, 5, 6	Kiln heat loss 7°F
P2	CK43	600 x 60	154	192.9	4, 5, 6	3 holes, one filled with crushed ceramic during test; Kiln heat loss 8°F
P3	CK42	600 x 60	164	164	4, 5, 6	Kiln heat loss 9°F
P4	CK41	600 x 60	73	224.7	4, 5, 6	Kiln heat loss 10°F
P25	CK47	600 x 60	111.4	425.6	4, 5, 6	Kiln heat loss 3°F
P26	CK48	600 x 60	135.2	416.5	4, 5, 6	Kiln heat loss 3°F
P5	CK36	600 x 90	211.1	233	4, 5, 6	Kiln heat loss 4°F
P6	CK35	600 x 90	224.7	266.3	4, 5, 6	Kiln heat loss 5°F
P8	CK34	600 x 90	236.4	261.3	4, 5, 6	Kiln heat loss 6°F
P9	CK33	600 x 90	259.4	275.9	4, 5, 6	Kiln heat loss 6°F
P10	CK32	600 x 90	239.2	264.1	4, 5, 6	Kiln heat loss 4°F
P11	CK31	600 x 90	201.9	235.6	4, 5, 6	Kiln heat loss 3°F
P12	CK24	900 x 60	373.4	445.3	4, 5, 6	Kiln heat loss 62°F
P13	CK23	900 x 60	182.3	675.6	4, 5, 6	No thermocouple holes; Kiln heat loss 64°F
P14	CK22	900 x 60	278.9	408.2	4, 5, 6	3 holes, one filled with crushed ceramic during test; Kiln heat loss 64°F
P15	CK21	900 x 60	312.5	441	4, 5, 6	3 holes, one filled with crushed ceramic during test; Kiln heat loss 58°F
P16	CK20	900 x 60	227.4	731.7	4, 5, 6	No thermocouple holes; Broke during drilling; Kiln heat loss 65°F

Artifact #	Test #	Kiln temp °C x Duration (sec)	Max Temp (1mm)	Max Temp (surf)	TC #s	Notes
P17	CK19	900 x 60	242.7	719	4, 5, 6	No thermocouple holes; Broke during drilling; Kiln heat loss 65°F
P18	CK12	900 x 90	273.3	706.7	4, 5, 6	No thermocouple holes; Kiln heat loss 66°F
P19	CK11	900 x 90	291.4	723	4, 5, 6	No thermocouple holes; Broke during drilling; Kiln heat loss 64°F
P20	CK10	900 x 90	279.6	750.3	4, 5, 6	No thermocouple holes; Kiln heat loss 63°F
P21	CK9	900 x 90	347.3	549.7	4, 5, 6	Kiln heat loss 59°F
P22	CK8	900 x 90	251.5	766.2	4, 5, 6	No thermocouple holes; Kiln heat loss 65°F
P23	CK7	900 x 90	304.8	785.4	4, 5, 6	No thermocouple holes; Kiln heat loss 61°F
G1	CK46	600 x 60			1, 2, 3	Temp data not recorded; Kiln heat loss 14°F
G2	CK40	600 x 60	143.7	184.2	1, 2, 3	Kiln heat loss 8°F
G3	CK39	600 x 60	143.6	187.5	1, 2, 3	Kiln heat loss 5°F
G4	CK38	600 x 60	155.4	184.1	1, 2, 3	Kiln heat loss 6°F
G5	CK37	600 x 60	153.6	206	1, 2, 3	Kiln heat loss 3°F
G25	CK45	600 x 60	159.1	216.6	4, 5, 6	Kiln heat loss 14°F
G6	CK30	600 x 90	197	242.4	1, 2, 3	Kiln heat loss 3°F
G7	CK29	600 x 90	280.6	327.8	1, 2, 3	Kiln heat loss 2°F
G8	CK28	600 x 90	182	276	1, 2, 3	Kiln heat loss 4°F
G9	CK27	600 x 90	290.9	300.7	1, 2, 3	Kiln heat loss 3°F
G11	CK26	600 x 90	236.7	231.7	1, 2, 3	Kiln heat loss 7°F
G12	CK25	600 x 90	231.9	263.5	1, 2, 3	Kiln heat loss 2°F
G13	CK18	900 x 60	353.7	390.6	1, 2, 3	Kiln heat loss 62°F

Artifact #	Test #	Kiln temp °C x Duration (sec)	Max Temp (1mm)	Max Temp (surf)	TC #s	Notes
G14	CK17	900 x 60	298.2	447.7	1, 2, 3	Kiln heat loss 63°F
G15	CK16	900 x 60	315.4	388.4	1, 2, 3	Kiln heat loss 63°F
G16	CK15	900 x 60	406.1	386.9	1, 2, 3	Kiln heat loss 62°F
G17	CK14	900 x 60	336.9	386.7	1, 2, 3	Kiln heat loss 64°F
G18	CK13	900 x 60	376.9	428.1	1, 2, 3	Kiln heat loss 64°F
G19	CK6	900 x 90	423.4	755.4	1, 2, 3	Only has one hole (1mm) due to artifact fragility; Broke during drilling; Kiln heat loss 63°F
G20	CK5	900 x 90	434.3	529.6	1, 2, 3	Kiln heat loss 62°F
G21	CK4	900 x 90	513.9	564.6	1, 2, 3	Kiln heat loss 63°F
G22	CK3	900 x 90	356.5	446.1	1, 2, 3	Kiln heat loss 58°F
G23	CK2	900 x 90	385.8	681.7	1, 2, 3	Kiln heat loss 62°F
G24	CK1	900 x 90		487.6	1, 2, 3	Thermocouple recording 1mm below surface temperature data stopped working during test; Kiln heat loss 67°F