



Chapter 3:

Fire Effects on Prehistoric Ceramics

In North America, prehistoric pottery is primarily earthenware (a porous ceramic, fired at a relatively low temperature). It is not glass-like or dense like other kinds of pottery such as stoneware and porcelain (see chapter 6).

Instead of looking at whole vessels (fig. 3-1), archaeologists often examine broken pieces of pottery called sherds (fig. 3-2) to gain information about people who lived in the past (Colton 1953; Rye 1981; Shepard 1956). Fire can affect prehistoric ceramics in a variety of ways. Archaeologists are primarily concerned with fire's effects on the information value of these artifacts. Such damages include physical degradations such as spalling and crumbling, as well as changes to surface color and design (fig. 3-3). These effects can hamper identification of pottery types. Fire may also affect certain laboratory analyses, such as petrography, and dating by thermoluminescence.

The extent to which sherds are affected by heat and flame depends on fire intensity, duration, and a number of environmental factors. The materials from which ceramics are created, the ways in which clay vessels are produced, and the uses to which they are put also affect the reaction of pottery to fire. The depositional environment of discarded pottery plays a final important role in influencing fire's impact.



Figure 3-1—Complete, intact pitchers such as this are typically found in museum settings or archaeological excavations and unlikely to be exposed at the surface and subject to damage from fire.



Figure 3-2—Typical pottery sherds that might be found in surface deposits and subject to thermal alteration, sootting, or mechanical damage during fire or fire management activities.

Most research on fire effects on ceramics focuses on the visual appearance of potsherds. Less work has been done to determine the range of fire effects on analytical properties. Most studies are conducted in the aftermath of wildfires without the benefit of pre-burn comparative data. Still, work that has been done suggests that fire can affect the appearance of potsherds without preventing identification. Fire effects on various technical analyses are not well understood. More controlled and comparative research is needed to predict fire effects on the identification and analysis of various earthenware ceramics.

Materials and Mechanics of Pottery Construction

To understand the effects fire can have on pottery, one must consider how pottery is made, what material it is made from, how it is used, and in what environment it is eventually deposited. Fire may differently affect pottery that is made from various clay types or built and fired by different methods. Certain kinds of decorative paint may be more vulnerable to fire than others. Ceramic vessels used for cooking may be differently affected than other kinds of pottery. The soil conditions to which discarded potsherds are exposed can influence potential fire effects.



Figure 3-3—Pottery sherds including a ladle handle (above ruler) and bowl fragments found at the surface following the 2002 Long Mesa fire, Mesa Verde National Park, Colorado (Buenger 2003).

Pottery as Raw Material

The primary raw material of pottery is clay (sediments eroded from silicate rocks). Clays can be collected as sedimentary rock (shale or mudstone) or loose sediment. Both types of clay are commonly ground into a fine powder before being used for pottery. They can exist *in situ*, in the area of their parent rock, and called primary clays (Rice 1987). Clays can also exist *ex situ*, carried by wind or water and redeposited in areas such as riverbeds. These clays are called secondary or transported clays (Rice 1987). Clay particles also can be re-cemented to form sedimentary rocks. Shales and mudstones are examples of sedimentary rocks that may contain a percentage of re-cemented clay sediments.

Clay particles are extremely small in size, generally less than two microns in diameter. Most clays have specific mineral structures, categorized as hydrous aluminum silicates. The mineralogy and small particle size of clays make them workable (Rice 1987). This means that, when mixed with water, clays can be formed to a shape that holds upon drying.

Non-clay materials such as sand, silt, organic matter, and mineral impurities are generally found mixed with clay sediments. Organic materials are more common in transported clays than in primary clays. Primary clays may contain more coarse-grained fragments of the parent rock (Rice 1987). A potter may sieve or sort through the clay collected to remove coarse-grained sands and gravel, as well as visible organic matter. Fine-grained sands, silts, organics, and mineral inclusions, however, generally remain with the clay used for pottery production. These can benefit the pottery-making process by preventing clays from becoming “sticky” and difficult to work. These non-clay inclusions can also decrease shrinkage upon drying, increase the strength of a vessel, and provide pottery with color.

Prehistoric potters added sand, ground rock, shell, or crushed pottery sherds to the clay they used. These additives, known as “temper,” had the same benefits as naturally occurring non-clay inclusions: they minimized stickiness, increased strength, and decreased shrinkage. Some clays (self-tempered clays) contained enough non-clay inclusions that pottery makers did not need to add temper. Variations in clay raw material, natural inclusions, and the make-up of added temper are important factors in understanding pottery’s reaction to heat and open flame.

Vessel Formation and Preparation for Firing

Shepard (1956: appendix E) discusses prehistoric methods of vessel formation in North America. She writes that potters shaped vessels by modeling, molding, piece building, or a combination of techniques. Potter’s wheels were not used prehistorically. Modeled pottery could be crafted from a single lump of clay or shaped from one thick clay ring. Molded pottery was formed by shaping clay around a certain form, such as an already fired vessel. Piece-built pottery, on the other hand, was made by adding together coils or patches of clay (fig. 3-4). Such vessels could be smoothed with a stone or a paddle-and-anvil tool. Coil-built pots could be “corrugated,” their coils left unsmoothed. Vessel-forming techniques could be combined in a number of ways. For example, a vessel’s base could be molded while its walls were formed with coils. The way in which pottery was made may affect how it is altered by fire. For example, fire sometimes separates the coils in corrugated pottery sherds (Lissoway and Proper 1990; Switzer 1974).

The shape and thickness of vessels varied somewhat according to the potter’s intended use. Vessels used for

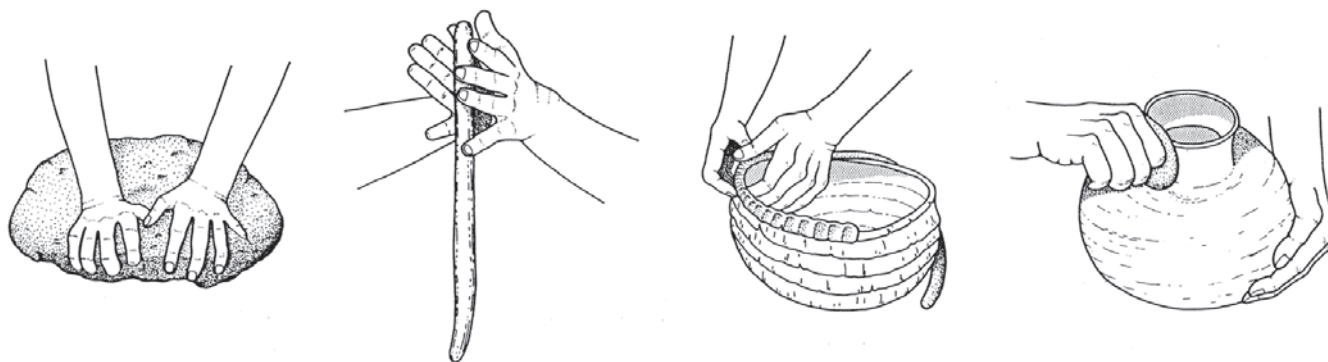


Figure 3-4—Schematic illustrating the making of a clay pot from ribbons.

cooking needed to survive continual exposure to small cooking fires. Thin-walled vessels were more suited to the task; they could withstand thermal shock, a stress caused by heating and cooling (Rice 1987). When exposed to flame, the outer walls of a pot would heat more quickly than the inner walls and expand at a faster rate. In thin walled vessels, differential expansion was minimal and damage less likely to occur. Thin-walled vessels also conducted heat well and allowed food to be cooked more quickly. Vessels exclusively used for storage, however, did not need to withstand continual thermal shock and could be made thicker. Since sherds of differing thickness react differently to thermal shock, fire may affect sherds from storage vessels differently than sherds from cooking pot ceramics.

Variation in wall thickness may also occur within a single vessel. This is particularly true of paddle-and-anvil shaped pottery. Since thermal shock is caused by differential rates of heating and cooling, paddle-and-anvil shaped vessels may be particularly vulnerable to fire.

Variables other than wall thickness may affect pottery's vulnerability to fire. Culinary sherds, often more coarsely tempered than other ceramics, may become friable when exposed to flame (Pilles 1984).

Decoration

Pottery can be decorated before or after firing with the use of organic or mineral paint. Organic or carbon-based paints are generally derived from plant extracts, while mineral paints include iron oxides, manganese ores and some clay minerals (Shepard 1956). Pottery can also be intentionally smudged black with exposure to smoke. Before firing, a slip (a coating made from a thin solution of clay and water) can also be added to the surface of a vessel. Pieces of clay can be attached to pottery as appliqué designs or to create legs and handles. Glaze paints (substances that vitrify when fired and turn to glass) were also used for decoration prehistorically. Glazes, however, were not used as sealants to coat vessels.

Fire's impact on pottery decoration is of concern to archaeologists who use decorative design as a criterion for identifying potsherds. This impact of fire can vary according to the way in which clay vessels have been decorated.

Clay Firing

Ceramics are the products of heating clay in an open fire, firing pit, or kiln. By looking at changes that occur to clay during heating, one can infer what changes may later occur to pottery exposed to fire (table 3-1).

The way in which clay is fired determines the atmosphere, temperature, and duration of heating to which pottery is subjected. In open firing (fig. 3-5), the

amount of available oxygen will fluctuate; temperature will rise quickly and fall quickly. The heating atmosphere and temperature of pottery fired in a pit are more constant, and firing lasts longer than it does in open flame. Kilns, not as frequently used in prehistoric North America, provide the steadiest, hottest, and longest lasting firing conditions.

The type of fuel used for firing also influences the firing environment. Grass, for example, burns more quickly than most types of wood; wood, in turn, burns faster than coal. Slow-burning fuels may hold high temperatures for longer time periods, allowing clay to react more fully to heating conditions. Depending on firing methods and fuels used, firing can last as little as an hour or as long as a week.

The composition of clay material and the proportion of clay to additives, also influence clay's reaction to firing. In extreme circumstances, clay cannot survive firing; it will crack, bloat, or spall. This may be caused by a flaw in the clay material, vessel form, or firing atmosphere. Changes to pottery, including damaging effects, occur at certain temperatures, dependant on clay composition, firing environment, and duration of heat.

One of the first changes to pottery during intentional firing is water evaporation, often referred to as water smoking. When heated to 100 °C (212 °F), water loosely bound to the surface of clay particles begins to evaporate. Between 300 and 800 °C (572-1472 °F), depending on clay type, water chemically bound to clay molecules also evaporates. If water loss occurs too quickly, the force of water that escapes as steam may cause a vessel to crack or explode. Sometimes potters preheat their vessels to avoid rapid water loss during open firing (Rye 1981).

The next stage in the firing process is the burning off, or oxidation, of organic matter in the clay material. This reaction, in which carbon joins with oxygen to form carbon dioxide and carbon monoxide gas, begins to occur between 200 and 350 °C (392-662 °F). The length of time it takes for all organic material to oxidize depends on the temperature, the amount of carbon present, and the availability of oxygen in the firing atmosphere. Often some carbon is left unoxidized by firing. The dark core, known to some archaeologists as a "carbon streak," is visible in cross-sections of some pottery sherds. It testifies to incomplete carbon oxidation during intentional firing, although it may be produced by later wildfires (Ryan, personal communication, 4/4/2001).

Between 400 and 850 °C (752-1562 °F), clay minerals are heated nearly to their melting point. During this stage of firing, water chemically bound to clay is lost and clay particles ionically adhere to each other. This irreversible process of adhesion, known as sintering, causes pottery to become hard and dense. It is the

Table 3-1—Stages of firing and other changes due to heating.

Temp (°C)	Temp (°F)	Changes to ceramics
100-200	212-392	Evaporation of loosely bound water. ^a
200-350	392-662	Decomposition of organics. ^b
300-800	572-1472	Water chemically bound to clay molecules evaporates. ^c
350	662	Carbon paint burns off (Bennett and Kunzmann 1985).
400-850	752-1562	Clay minerals undergo sintering. ^a
500	932	Organic matter oxidizes. ^c
500-800	932-1472	Minimum temperature for effective firing of pottery (varies according to clay type). ^a
573	1063.4	Molecular change: Alpha-beta inversion of quartz, causing quartz inclusions to expand slightly; could theoretically cause structural damage. ^c
800	1472	Most iron minerals will oxidize by the time this temperature is reached. ^d
750-870	1382-1598	CaCO ₃ (calcium carbonate) dissociates to form CO ₂ gas (carbon dioxide) and CaO (calcium oxide). CaO bonds with water to form Ca(OH) ₂ (quicklime). ^{a,c}
870	1598	Mineralogical change: Beta quartz becomes tridymite, a very slow reaction that rarely occurs in clay firing. ^c
900-1100	1652-2012	Clay begins to vitrify, melting and forming glass. This process is often aided by fluxing agents. Vitrification creates loss of pore space and a glassy texture. ^{a,c}
Above 1200	Above 2192	Gases formed during vitrification (without fluxing agents) will restore pore space and may cause bloating. ^c

^a Rye (1981)

^b Ryan (2001)

^c Rice (1987)

^d Shepard (1956)



Figure 3-5—Firing of a clay pot over an open fire.

most essential reaction for making pottery; without it, clay can regain water and lose its shape. The exact temperature required for sintering to occur varies according to clay type and duration of firing.

If firing temperature exceeds 900 °C (1652 °F), clay minerals can melt to form glass. Glass is a material with no molecular structure, formed from a molten solid. The process in which clay melts and becomes glass is known as vitrification; it is often aided by inclusions that lower clay's melting point (Rice 1987). Such inclusions, known as fluxing agents, are present in most raw clays and include alkaline earths, alkalis, and ferrous oxides (Shepard 1956). With vitrification, ceramics lose their porosity, shrink, and obtain a glass-like texture. As temperatures increase above clay's melting point, new minerals crystallize from molten clay (Rice 1987). If very high temperatures are reached, vitrified pottery can appear bloated or warped, with a "sponge-like" texture and blistered surface (Rye 1981).

Firing Effects on Non-Clay Inclusions

Firing changes non-clay particles in ceramic material. These may be naturally occurring inclusions in clay raw material, additives, or temper for example. Common inclusions consist of quartz (often sand temper), calcium carbonate (CaCO_3 , often crushed shell or limestone), iron (generally naturally occurring), and crushed pottery sherds (as temper).

At about 573 °C (1053.4 °F), quartz undergoes a change in molecular structure that causes it to expand by 2 percent volume (Rice 1987; Shepard 1956). This alteration is known as the inversion from alpha to beta quartz. Rice (1987) writes that quartz expansion does not often cause damage to pottery because it occurs simultaneously with water loss, which creates more pore space. Damage is more likely to occur during later cooling when beta quartz reverts to its original form. As this happens, quartz particles sometimes shatter and cause tiny cracks within the pottery. These small cracks decrease the strength of the fired vessel, making it easier to break.

The temperature required for quartz inversion (573 °C, 1063 °F) is certainly within the range obtained by prehistoric firing. However, Shepard (1956) writes that she never observed shattered quartz grains in her petrographic analyses of North American pottery sherds. She suggests that temperatures were not maintained long enough for the reaction to occur or that the softness of heated clay prevented quartz from shattering. Wildfires may subject pottery sherds to this temperature or higher, but the duration will most likely be of very short duration (Ryan, personal communication,

4/4/2001). Thus, wildfires may cause more damage to pottery sherds than prehistoric firing of vessels, but it seems unlikely due to the short duration. This may warrant some additional research.

Calcium carbonate (CaCO_3), in the form of crushed shell or limestone, is sometimes added to clay as temper. This mineral also naturally occurs in some clay deposits. At temperatures between 750 and 870 °C (1382-1598 °F), calcium carbonate disassociates to form carbon dioxide gas (CO_2) and calcium oxide (CaO). Once this reaction occurs, CaO , also known as lime, bonds with water to form calcium hydroxide (Ca(OH)_2), a large crystal known as quicklime. The formation of quicklime may cause miniature spalling in the walls of a vessel (Rye 1981).

Iron occurs naturally in many types of clay. At about 600 °C (1112 °F), iron may react with oxygen to form new compounds that make pottery red in color. This reaction, called oxidation, occurs only when sufficient oxygen is available in the firing environment. At about 900 °C (1652 °F), if oxygen is not significantly present, iron takes on a reduced form, turning black or gray (Rye 1981). Post-firing exposure to heat in the absence of oxygen may cause iron reduction in pottery sherds. However, this temperature is rarely reached during wildfire, except under certain conditions (for example, the burn-out of a stump) (Ryan, personal communication, 4/4/2001). Post-firing exposure to heat in the presence of oxygen may cause additional oxidation and reddening of ceramics.

Pottery Use and Post-Depositional Changes

Once a vessel survived firing, it could be used to meet a variety of needs. Utility vessels could be used for cooking food, storing water, keeping dry goods, or boiling pigment for dye. Ceramic bowls could be used as dishes, and clay ladles used for serving food. The specific use of pottery may have changed its appearance. Painted decorations could fade with continual use. Storage pots accrued traces of the materials they held. Vessels used for cooking accumulated carbon on their exterior surface and possibly carbonized food remains within their interiors (Rye 1981).

Carbonization caused by cooking fires resembles intentional smudging for decoration and post-depositional smudging caused by wildfires and prescription burns. Decorative smudging may only be distinguished from other types of smudging if striations caused by the use of a polishing stone are present on top of the layer of carbon. Smudging caused by cooking fires may be indistinguishable from smudging caused by wildfires or prescription burns.

After pottery is used and discarded, it is exposed to a variety of factors that cause change (figs. 3-6, 3-7). These post-depositional changes include the accumulation



Figure 3-6—Corrugated vessel illustrating natural weathering and cracking.



Figure 3-7—Neck of a broken vessel naturally weathered.

of calcium carbonate (CaCO_3) on the surface of potsherds; whether or not CaCO_3 collects within the pore space of sherds is still debated (Rice 1987). If wildfires reach temperatures over 750°C (1382°F), the possible dissociation of calcium carbonate and the formation of quicklime may cause structural damage to ceramics.

Exposure to acidic soil and plant roots can cause certain elements, such as alkali metals, calcium, sodium, zinc, cobalt, and barium, to leach from ceramics (Rice 1987). In some environments, sherds might also accumulate a layer of adhering salt. These post-depositional changes to pottery may be the final alterations that affect wildfire's influence.

Fire Effects Research

Research concerning fire effects on ceramics falls into two categories: fire effects on appearance and fire effects on analytical properties. Fire can change the visual appearance of pottery in a number of ways, including smoke-blackening, spalling, oxidation and burn-off of decorative paint. Archaeologists are most concerned with how visual impacts may affect pottery identification, although lab processing and analysis may correct for these. Fire effects on analytical properties may not be visibly noticeable and include effects to ceramic temper identification, thermoluminescence (TL) dating, and residue analyses. Archaeologists will be concerned if ceramic analyses needed to answer specific research questions are foreclosed by this type of effect, which cannot be compensated for in the lab.

Literature describing fire effects has mainly consisted of post-fire qualitative observations for which pre-burn data are not available (Eininger 1989; Pilles 1984; Switzer 1974). Only a small number of studies (such as Gaunt and Lentz 1996; Jones and Euler 1986; Ruscavage-Barz 1999) have attempted to quantitatively record fire effects on ceramics; few have compared pre-fire data with post-burn observations, as do Picha and others (1991).

Fire Effects on Appearance

Burgh (1960) introduced the idea that wildfires may affect the visual identification of potsherds. Since that time, most fire effects research on ceramics has focused on alterations to the visual appearance of sherds (for example Gaunt and Lentz 1996; Jones and Euler 1986; Picha and others 1991; Ruscavage-Barz 1999). Fire may visually affect ceramics by causing surface spalling, altering painted decoration, changing sherd color, and depositing soot on sherds. The adhesion of a dark sticky substance is possibly residue from burned pine pitch. These tar-like substances are sometimes also noted on burned sherds (Gaunt and Lentz 1996; Pilles 1984). Ceramic slips and glazes may undergo cracking and vitrification. Appliqué designs may break off under the pressure of heating and cooling. Such changes are significant when the visual characteristics used to identify pottery are affected.

Depending on the presence of non-clay inclusions such as iron and carbon, sherds may undergo color change when exposed to fire (see above). Different kinds of paint and glaze will also react differently to fire. Sherds decorated with organic paint are more vulnerable than ones decorated with mineral paint. Paints added to ceramics after firing are also likely to burn off more easily than paints that have survived the firing process (Shepard 1956). Bennett and Kunzmann (1985) observe that organic paint begins to burn off

when heated to temperatures above 350 °C (662 °F) in a laboratory experiment; mineral paint requires higher temperatures to burn off. Shepard (1956) discusses an oxidation test for distinguishing between black organic and iron paints on potsherds. In this test, hydrofluoric acid is applied to loosen the paint from clay. Sherds are then heated to 800 °C (1472 °F). According to Shepard, organic paint will burn off in this test while iron paint will oxidize and turn red. Wildfires and hot prescription burns may have similar effects, turning iron-based paints red and burning off carbon paints (as observed by Gaunt and Lentz 1996).

Studies of fire effects have found that smoke blackening, or sooting, is the most common fire effect on ceramics. Jones and Euler (1986) note that soot was the only fire effect they observed on ceramics from the Dutton Point Wildfire (fig. 3-8). Gaunt and Lentz (1996) recorded soot on 23 percent of all sherds collected for the Henry Fire study (57 percent of all burned sherds) and Ruscavage-Barz (1999) found that smoke blackening was the most common effect of the Dome Fire on ceramics.

In the Dutton Point Fire study, smoke blackening rendered five sherds (21 percent of the sample) unidentifiable (Jones and Euler 1986). This soot could not be washed off completely, even with the use of hydrochloric acid. Observing unblackened sherds at earlier burned sites in Mesa Verde, Jones and Euler (1986) proposed that cumulative rainstorms and exposure to the elements would cause soot to eventually deteriorate. Gaunt and Lentz (1996) found that soot was easily washed off sherds in the lab and that it did not impede identification. More permanent smoke blackening, however, was observed and not recorded because it was assumed to be a product of earlier fires. Ruscavage-Barz (1999) noted that most ceramics were still identifiable, even when they had been "fire-blackened over both sides."

In their study of prescribed fire effects, Picha and others (1991) had no difficulty identifying burned sherds. The ceramics underwent only minor changes, exhibiting soot and becoming darker or lighter in color. After the high intensity Dome Fire, Ruscavage-Barz (1999) found that most sherds could still be identified. Gaunt and Lentz (1996) found that the Henry Fire vitrified a number of sherds that were misidentified in the field as glazewares. Oxidation, vitrification, and crackling of slip also hampered field identification of some Henry Fire sherds. All sherds misidentified in the field, however, were later correctly identified in the lab (Gaunt and Lentz 1996). This is not an unusual occurrence. Even unburned sherds can be misidentified in the field, and Gaunt and Lentz (1996) do not indicate whether all sherds at their unburned control site were identified correctly.



Figure 3-8—Dutton Point fire, Grand Canyon National Park archaeological site burned by wildfire (Jones and Euler 1986).

A few attempts have been made to correlate fire effects on ceramics with burn severity. Gaunt and Lentz (1996) found that fire effects were more severe at heavily burned sites but the relationship between fire effects to ceramics and burn severity was not statistically predictable. Areas of burned logs in one moderately burned site caused fire effects to be more severe than those observed at heavily burned sites (see also chapter 7). Picha and others (1991) found the effects of grass fire on ceramics to be minimal in prescribed burn plots; however, there was a range of severities.

While studies indicate that fire will generally have minimal impacts on pottery identification, this may not be the case for all types of pottery. Switzer (1974) described fire effects to potsherds in the 1972 Moccasin Fire at Mesa Verde National Park. He noted that spalling was quite common and that the coils of corrugated potsherds became separated. Carbon paint burned off decorated sherds, and organic matter (called “carbon streaks” by archaeologists) within the body of grayware sherds oxidized, causing these sherds to turn light gray or white in color. Such dramatic fire effects may have impeded pottery identification and affected the durability of potsherds. However, fire effects such as these have not been recorded in any controlled study. They occurred primarily to pottery that was corrugated, carbon painted, and/or made of paste with a high organic content.

Generally, if potsherds can still be identified after a fire, visual changes are not of much concern to archaeologists. The few studies that examine fire effects on pottery show that most sherds can be identified in the lab, even after intense wildfires. The most common effect on pottery is smoke blackening. Soot can sometimes be washed off (Gaunt and Lentz 1996) and might otherwise dissipate with exposure to rain and weather (Jones and Euler 1986). Potential effects on pottery vary according to fire intensity, environment, and ceramic type. Practical consideration of local pottery characteristics should reveal ceramic types vulnerable to fire damage. Loss of information due to adverse fire effects may be overcome by increasing the sample size of sherds collected for archaeological study.

Fire Effects on Analytical Properties

Fire effects on the analytical properties of ceramics have been studied less than fire effects on appearance. Technical analysis of pottery may include microscopic identification of temper, petrography, analysis of pollen or protein residue on ceramics, neutron activation analysis (NAA) to determine clay source, and dating by thermoluminescence. The importance of different analytical properties depends on local research needs.

Sidebar 3-1—Henry Fire Effects on Ceramics

Henry Fire, Holiday Mesa, Jemez Mountains, New Mexico, June 27–29, 1991

References: Lentz and others 1996

General information:

- Elevation: 2,438.4 m (8,000 ft)
- Vegetation: second growth ponderosa pine
- Topography: mesa top delineated by canyons on three sides
- Type of study: post-fire study of surface and subsurface fire effects

Fire description:

- Temperature range: 25-28.3 °C (77-83 °F)
- Duration: 3 days
- Relative humidity: 14-36%
- Fuel: dense ponderosa pine saplings and dry fuels
- Type of fire: wildland
- Energy release component (ERC): 64-72
- Burning index (BI): 55-67

Discussion

The Henry Fire occurred in the Jemez Mountains of New Mexico in June, 1991, burning approximately 3 km² (800 acres). After the fire, archaeologists resurveyed the burn area, relocating 45 out of 52 known sites and encountering nine previously unrecorded sites.

In 1992, archaeologists from the Museum of New Mexico's Office of Archaeological Studies (OAS) and the U.S. Forest Service conducted fieldwork for Phase 1 of a post-fire study. Their purpose was to record fire effects on surface and subsurface archaeological resources and to investigate the relationship between fire effects and fire severity. Their work included preliminary investigations at seven prehistoric sites and analysis of fire effects on ceramics, lithics, groundstone, architecture, and obsidian hydration dating. Phase 2 of the project included more detailed research and controlled experiments, the results of which remain to be published.

The seven archaeological sites investigated during Phase 1 of the study included two lightly burned sites, two heavily burned sites, two moderately burned sites, and one unburned control site. All sites had masonry structures made up of volcanic tuff. Surface artifacts were collected from the southeast quadrant of each site. Test units (1- by 1-m) were then established in the southeast quadrant of each site and excavated to a depth of 20 cm (7.9 in). Subsurface artifacts were compared to the surface collection. Additional excavations were conducted in burned log areas within architectural remains.

Fire effects on architecture were recorded in the field while effects on ceramics and stone artifacts were assessed in a laboratory setting. Categories were developed to identify fire effects on different artifact types. Fire effects categories for ceramics included portion affected by fire (the percentage of a sherd's surface area), sooting, spalling, oxidation, modification of pigment, and other physical alterations (Lentz and others 1996). Fire effects on lithics included portion affected by fire, sooting, potlidding, oxidation, reduction, crazing, and other physical alterations (Lentz and others 1996). Groundstone fire effects were similar to those for lithics, excluding potlidding and crazing (Lentz and others 1996).

The study found that most fire effects on artifacts occurred at the surface. A direct relationship between fire effects and burn severity was established, although dramatic fire effects were observed in all severities. In lightly burned areas, artifacts near burned logs were highly affected. In Phase 1 of the project, archaeologists recorded fire effects without attempting to measure the loss of archaeological information. They stressed that not all fire effects recorded could be considered damage. In Phase 2 of the project, fire damage to archaeological information was to be assessed separately from general fire effects on heritage resources. Through controlled burn experiments, Phase 2 was also planned to distinguish the effects of recent fire from impacts of earlier burning.

In most cases, for example, thermoluminescence dating is not conducted on ceramics because with fewer resources we can use design type and cross-dating materials with known dates to define properties of the item in question.

Pilles (1984) writes that fire can alter temper, compromising its identification. He notes that inability to recognize temper can make identification of undecorated sherds impossible. Identification of temper is also important because it provides information about the origins of materials used to create pottery. Archaeologists routinely carry out microscopic identification of sherds for temper identification. Petrography, a specialized geological analysis of sherds in thin sections, is a more detailed method of examining temper.

Fire may alter organic temper, calcium carbonate or shell more easily than some types of mineral temper. Identification of these types of temper may, therefore, be more easily compromised by fire. However, no study has yet investigated fire effects on petrography or on the routine identification of temper in the lab and field. Gaunt and Lentz (1996) and Ruscavage-Barz (1999) do not mention any adverse effects on laboratory identification of temper in their archaeological studies of sherds recovered from the Henry and Dome fires. Microscopic identification of temper was conducted for archaeological study and not included in the fire effects studies mentioned above. They do not indicate whether or not temper could be recognized using a 10X hand lens, an instrument archaeologists can carry into the field.

Rowlette (1991) discusses fire effects to thermoluminescence (TL) dating of nine potsherds recovered from the 1977 La Mesa Fire excavations. TL dating detects the amount of time passed since a crystalline material was exposed to high temperatures. When a ceramic vessel is initially fired, its clay releases energy in the form of light. After firing, this energy begins to re-accumulate and can be measured by a TL specialist to determine how long ago the vessel was made. Rowlette (1991) writes that TL measurements can be altered if a material is subjected to heat over 400 °C (752 °F). In his analysis of La Mesa pottery sherds he finds that the fire affected TL readings for ceramics located less than 10 to 15 centimeters (3.9-5.9 in) below ground surface. Rowlette (1991) notes, however, that due to standard procedure for TL dating, materials located at the surface are routinely avoided.

Animal proteins, blood residue, and pollen found on ceramics may be altered when subjected to high temperatures. Identification of these residues can sometimes yield important information about past food resources and processing methods. Fish (1990) observed that fire can make pollen near to the ground surface unidentifiable. Subsurface pollen located near

tree roots or logs that conduct heat may also be affected. Fire effects on blood residue and animal protein have not been studied.

In summary, fire effects on a number of technical analyses have yet to be examined. Potential effects on petrography and visual temper identification are probably of the most concern to archaeologists. Archaeological studies of fire effects on less commonly used analyses such as blood residue and neutron activation are also called for. The importance of different analytical properties varies according to local research needs. Most studies show that subsurface sherds will be subjected to less heat and be less affected by fire than surface-level ceramics. Technical analysis of subsurface ceramics might, therefore, be reliable even when the analytical properties of surface-level sherds are held in question.

Conclusions

Few studies have evaluated fire effects on prehistoric ceramic artifacts. Most studies are conducted in the aftermath of wildfire when pre-burn comparative data are not available. These studies present a problem, as discussed by Gaunt and Lentz (1996), in distinguishing recent fire effects from the effects of prior burning. Because fire behavior also affects the impacts to ceramics, studies need to record fire temperature and duration of heating to which sherds are exposed.

Experimental studies focus mainly on the visual impacts of fire on potsherds. Fire effects on analytical properties of ceramics are less understood. Smoke blackening of sherds located at the ground surface is the most common fire effect noted. The permanency of smoke blackening on sherds remains a significant research question. Soot that cannot be washed off and other effects such as spalling, vitrification, oxidation, and crackling of slip can lead to the misidentification of some sherds. However, studies have found that potsherds affected by fire can most often be correctly identified in the lab.

In the absence of definitive research findings, resource managers should consider research needs and the characteristics of local pottery when evaluating potential fire effects. Local environment and expected fire behavior should also be considered (see chapter 2). Managers need to evaluate how differences in clay paste and temper might influence fire effects. The different ways pottery was constructed, decorated, fired, and used by prehistoric people are also important considerations. Finally, post-depositional changes to potsherds may influence fire impacts.

Fire impacts on ceramic artifacts will not always result in loss of archaeological information. Sherds that are smoke blackened or oxidized might be iden-

tifiable in the lab if not in the field. Loss of analytic properties for surface sherds may not be of concern if subsurface sherds are available and can be reliably analyzed. When a large number of sherds are present at a site, increasing the sample size in a study may compensate for damage done to a few sherds. Fire

effects on ceramics are of much higher concern when sherds are less abundant, subsurface sherds are not present, high intensity wildfire can be expected, or local ceramics have properties specifically vulnerable to heat and flame.