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Wildland Fire in Ecosystems

Effects of Fire on Cultural Resources and Archaeology

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Abstract

This state-of-knowledge review provides a synthesis of the effects of fire on cultural resources, which can be used by fire managers, cultural resource (CR) specialists, and archaeologists to more effectively manage wildland vegetation, fuels, and fire. The goal of the volume is twofold: (1) to provide cultural resource/archaeological professionals and policy makers with a primer on fuels, fire behavior, and fire effects to enable them to work more effectively with the fire management community to protect resources during fuels treatment and restoration projects and wildfire suppression activities; and (2) to provide fire and land management professionals and policy makers with a greater understanding of the value of cultural resource protection and the methods available to evaluate and mitigate risks to CR. The synthesis provides a conceptual fire effects framework for planning, managing, and modeling fire effects (chapter1) and a primer on fire and fuel processes and fire effects prediction modeling (chapter 2). A synthesis of the effects of fire on various cultural resource materials is provided for ceramics (chapter 3), lithics (chapter 4), rock art (chapter 5), historic-period artifacts/materials (chapter 6), and below-ground features (chapter 7). Chapter 8 discusses the importance of cultural landscapes to indigenous peoples and emphasizes the need to actively involve native people in the development of collaborative management plans. The use and practical implications of this synthesis are the subject of the final chapter (chapter 9).

Keywords: cultural resources, heritage resources, archaeology, fire regime, fire environment, fuels management, fire management, fire planning, wildfire, prescribed fire, First-Order fire effects, Second-Order fire effects, Third-Order fire effects, Burned Area Emergency Rehabilitation (BAER), fire severity, traditional cultural knowledge (TKE), cultural landscapes

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Wildland Fire in Ecosystems

Effects of Fire on Cultural Resources and Archaeology

Technical Editors

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Summary

Cultural resources refer to the physical evidence of human occupations that cultural resource specialists and archaeologists use to reconstruct the past. This includes the objects, locations, and landscapes that play a significant role in the history or cultural traditions of a group of people. Cultural resources include artifacts of historical significance left by prehistoric aboriginal peoples . Archaeological constituents, the basic units of archaeological analysis, consist of artifacts and features. Artifacts include carved objects, pottery and ceramics, flaked and ground stones, faunal and floral remains, glass, and metal. Features include earthen works, rock art (e.g., petroglyphs and pictographs), midden soils, and structures (e.g., buildings, monuments, etc.). Cultural resources are at risk of being damaged by wildfires as well as active natural resource management. In Canada and the United States, managers have legal requirements to protect cultural resources during fuels treatments, restoration activities, wildfire suppression, and post-fire rehabilitation. The successful implementation of prescribed burning and wildfire suppression in cultural resources sensitive areas requires integration of cultural resources and wildland fire science. Knowledge of the local archaeology, artifact materials, site types, and context is essential to minimizing the negative impacts of all management activities. Likewise, understanding fuels, fire behavior, and heat transfer mechanisms is key to predicting, managing, and monitoring the effects of fire on cultural resources. This volume of the "*Rainbow Series*" synthesizes the relationships between fire and cultural resources. It presents the reader with the context of contemporary fire use and how these fire management tactics may affect prehistoric and historic cultural resources. It synthesizes the impacts of fire and fire management on various types of cultural resources and identifies management strategies to minimize negative impacts on cultural resources.

Chapter 1 provides basic definitions of wildland fire, the categories of cultural resources (including basic operational definitions), and the legal framework for both the United States and Canada for resource protection. It provides a framework for classifying fire effects by direct versus indirect effects into *First-Order* (fire-caused changes), *Second-Order* (post-fire biophysical changes), and *Third-Order* (human actions/reactions). Chapter 2 provides an overview of the various spatial and temporal scales of fire analysis and their relationship to the effects on cultural resources. It includes a primer on the biophysical processes that couples fuels and fire behavior to the observable effects on cultural resource types, and identifies a

number of fire behavior and effects models useful for fire planning and prescription development. Chapter 3 summarizes fire effects on prehistoric ceramics—which in North America are primarily earthenware, a porous ceramic, fired at a relatively low temperature—including the direct effects of heating and sooting on the visual and physical characteristics that affect archaeological dating and sourcing as well as the indirect effects on the depositional environment and its impact on interpretation. Chapter 4 describes common lithic artifacts, including flaked and ground stone objects, and the effects of fire on archaeological interpretation including obsidian hydration, thermoluminesence, and archaeo-magnetic dating. Chapter 5 describes the effects of fire and fire management on petroglyphs and pictographs (rock art) and the significance of these resources in understanding the history and culture of the site. Chapter 6 describes historical sites and artifacts in the context of their material makeup, their susceptibility to fire, and the types of fire damage. It also stresses the need to move beyond describing historic resources solely on the basis of their material properties and physical boundaries, but to asses them in the context of the landscape in which they occur. Chapter 7 focuses on the effects of fire on subsurface archeological deposits: the matrix containing post-depositional fill, artifacts, ecofactual data, dating samples, and other cultural and non-cultural materials. In order to provide a context for understanding these data, this chapter provides a summary of previous research about the potential effects of fire on subsurface cultural materials. Chapter 8 describes the significance of wildland fire and fire management to contemporary communities and provides a clear distinction between the definitions of tangible and intangible resource components. It also challenges us to go beyond the tangible materials science and regulatory compliance measures of cultural resources and begin to integrate the formal, historical, and relational aspects of landscapes into planning and management of cultural resources. It emphasizes the need to develop and implement programs that are integral to the landscape through consultation with affected communities. Finally, chapter 9 presents a framework for integrating cultural resource and wildland fire management, provides practical applications for situations mentioned throughout the text, and clearly defines management roles in fire situations. It also elaborates on the process of identification, evaluation (documentation), and mitigation in both planned (prescribed) and unplanned (wildland) fire situations.

— The Editors
July 2007

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Chapter 1:

Effects of Fire on Cultural Resources—Introduction

The world's diverse cultures have their varying creation stories (Moyers and Campbell 1988; UGA 2000). Many of these stories contain physical features: the mountains, hills, plains, and rivers of their native lands that are integral components of cultural traditions (Berkes and others 2000; Goetcheus 2002; King 2003; Martin 2002; Parker 1993; Parker and King 1990; Smythe and York 2009; Stoffle and others 1997). Fire figures prominently in the traditions of most cultures, both in their beliefs and their practices (Lewis and Ferguson 1988; Stewart 2002; Williams 2001, http://www.wildlandfire.com/docs/biblio_indianfire.htm). Before modern civilizations developed, early civilizations existed for millennia sometimes in urban settings, sometimes in pastoral or agrarian settings, and sometimes in hunter-gather settings, but always in close association with fire as a fuel for light, warmth, cooking/food preservation, security, and industry (Arnold 1961; Brown and others 2009; de Lumley 2006; Gowlett 2006, 2010; James 1989; Webb and Domanski 2009). Indeed, it is argued that before there were hunter-gatherers there were gatherers. Human physiology and anatomy suggest that mastery of fire must have predated specialized hunting (Sussman and Hart 2008). To early cultures, control and use of fire increased their survival through manipulation of habitats to promote desired foods, materials, and medicines. For millennia, bands of hunter-gatherers roamed the land following the rhythms of the seasons—ripening of plant resources and animal migrations. The advent of agriculture roughly 8,000 years ago is widely understood to have caused major changes in land use (c.f., Diamond 1997, 2005; Thomas 1956). In recent years there has been considerable debate as to the role of aboriginal people in altering the landscape (c.f., Boyd 1999; Denevan 1992; Stewart 2002; Vale 2002). It is, however, increasingly understood that those who came before us—whether hunter-gatherer or agricultural-urban dweller—have been major agents of land change through their burning practices (Abrams and Nowacki 2008; Fesenmeyer and Christensen 2010; Nowacki and Abrams 2008; Scharf 2010a,b; Springer and others 2010; Thomas 1956). It is becoming increasingly apparent that the combined effects of agriculture and fire have affected not only the vegetation but also atmosphere and climate (Carcaillet and others 2002; Ruddiman 2003, 2007). Thus, fire and culture are inexorably intertwined, all part of the human experience. We are a fire people and this is a fire planet (Pyne 1982, 1995, 2001, 2004).

> … scholars have wasted (in my view) too much time and effort on a science versus traditional knowledge debate; we should reframe it instead as a science and traditional knowledge dialog and partnership. (Fikret Berkes 2009)

Aboriginal people adapted their tools and fire use to meet the needs of their environment. The details of fire use by various Native people are beyond the scope of this volume. Readers are directed to the archaeological libraries for exploration of those relationships. However, cultural resource management in fire prone environments requires knowledge both of the people who inhabited those lands, historic fire regimes, and current fire activity (fig. 1-1).

Knowledge about the role of fire in the earth's vegetation-climate system and of people's use of fire for a variety of cultural purposes has grown tremendously in the past two decades. Much of this new knowledge stems from the innate desire to understand our origins and more recently from the quest for greater understanding of climate change science and feedback mechanisms within the climate system, including the role humans have played in affecting vegetation and climate (Brown and others 2009; Carcaillet and others 2002; Ruddiman 2003, 2007). The recognition of fire's integral role in the maintenance of many "fire dependent" plant communities (Brown and Smith 2002) and the development of healthy landscapes has also fueled recent research, and led to greater understanding. The preponderance of evidence suggests that the role and use of fire in the United States and Canada have changed markedly since Pre-Columbian times (Abrams and Nowacki 2008; Fesenmeyer and Christensen 2010; Nowacki and Abrams 2008; Scharf 2010a,b; Springer and others 2010; chapter 2; and many others). The 20th century—the era of wide spread cessation of aboriginal burning practices, landscape fragmentation and fire suppression—is the most recent human influence on fire as a natural process in the development of vegetation. The area burned declined for decades in the 20th century (Agee 1993; Leenhouts 1998) but has been increasing since about 1970 (Agee 1993; Westerling and others 2006) (fig. 1-2). With this increase in area burned comes an increased risk of damage to cultural resources. Further, public concern for the impacts of increasingly large (fig. 1-2), damaging, and costly fires has led to greater emphasis on fire management programs, particularly fire use. Wildfires, as well as suppression efforts, hazardous fuels treatments, and post-fire restoration projects all differentially pose a risk to cultural resources (mechanically, chemically, functionally, and aesthetically).

Cultural Resources

What are cultural resources and why should we be concerned about protecting them during fire management activities? Cultural resources are material and non-material items that represent physical and spiritual presence and practices of society throughout its development. Cultural resources are important resources that bind those of us living today with our ancestors, traditions, and histories. They are generally viewed as non-renewable resources. They are often fragile tangible objects susceptible to thermal damage during wildland fires (wildfires and prescribed fires), and physical damage from management-related disturbances. Others, in particular indigenous peoples, view cultural resources as encompassing all the elements of the environment that sustain culture. From this perspective, living organisms (plants, animals, fungi, etc.) and the condition of sites or areas are considered as potential cultural resources. Ethics argue that cultural resources should be protected for their value to this and future generations, and they are protected by numerous laws. Discussion of the many laws is beyond the scope of this review. A primer on the important laws for the United States and Canada may be found at http://www.nps.gov/history/laws.htm and http://www.pc.gc.ca/eng/docs/r/pfa-fap/index.aspx, respectively. Specific laws will be mentioned as needed by the chapter authors.

In the United States, cultural resources generally fall into three types:

1. Prehistoric—As defined in the 1979 Archaeological Resources Protection Act (ARPA), the term "archaeological resources" means "Any material remains of past human life or activities which are of archaeological interest…" and include human remains; burial sites; weapons, tools, vessels (baskets, ceramics, etc.); lithic scatters; milling and quarry sites; refuse or debris piles; middens; rock shelters; temporary camp sites; house, village, ceremonial sites; and sacred places.
2. Historic—As defined in the 1976 National Historic Preservation Act, "historic" includes buildings (cabins, houses, barns, businesses, churches); settlements; improvements (corrals, water works), sites of important events (e.g., battlegrounds, treaties); passageways (canals, trails, roads, railroads, tunnels); refuse piles; cemeteries; distinct districts or communities; and unique landscaping, architecture or construction.
3. Contemporary—National Register of Historic Places has guidelines and procedures for determining places that qualify for inclusion. These include traditional cultural properties (Parker and King 1993); locations of important events; traditional resource collection locations; religious or spiritual sites; sacred places; sites with valued vistas; recreation sites; and cemeteries.

Similar criteria apply in the Canadian Provinces with local variations.

a

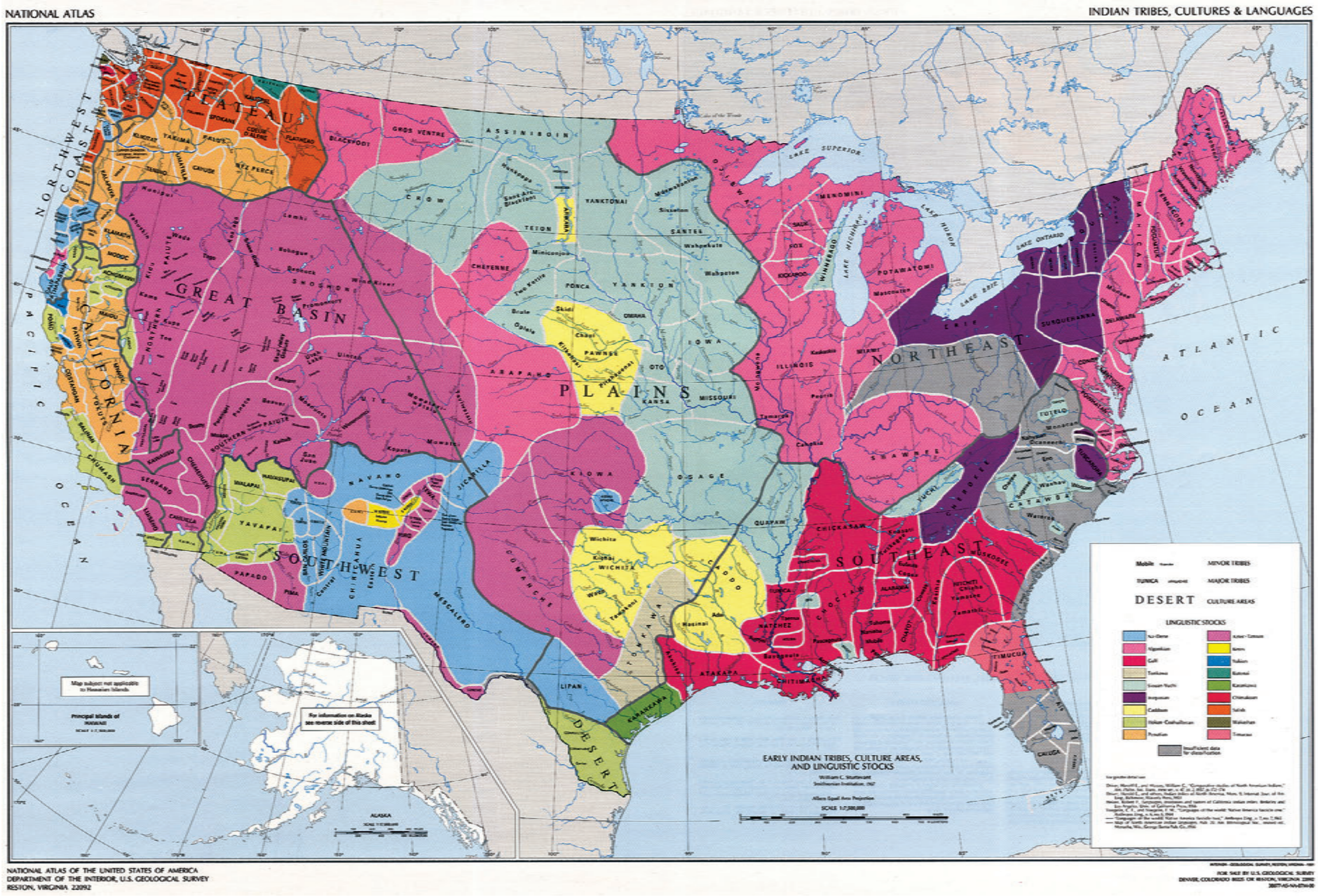
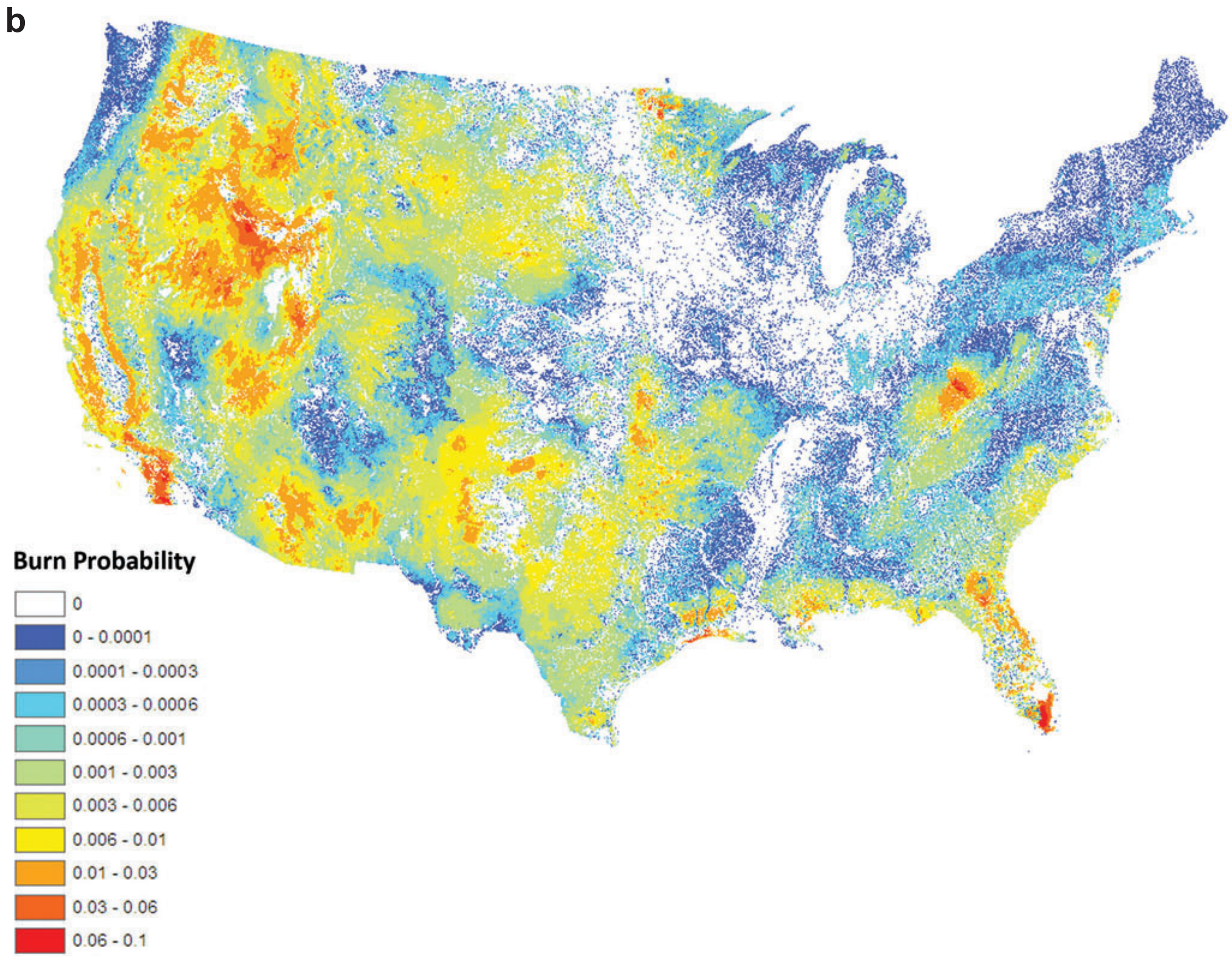


Figure 1-1—(a) Early Indian tribes, cultural areas, and linguistic stocks (Sturtevant 1967) and (b) current probability of fire occurrence (shown on next page) (Finney and others 2011).



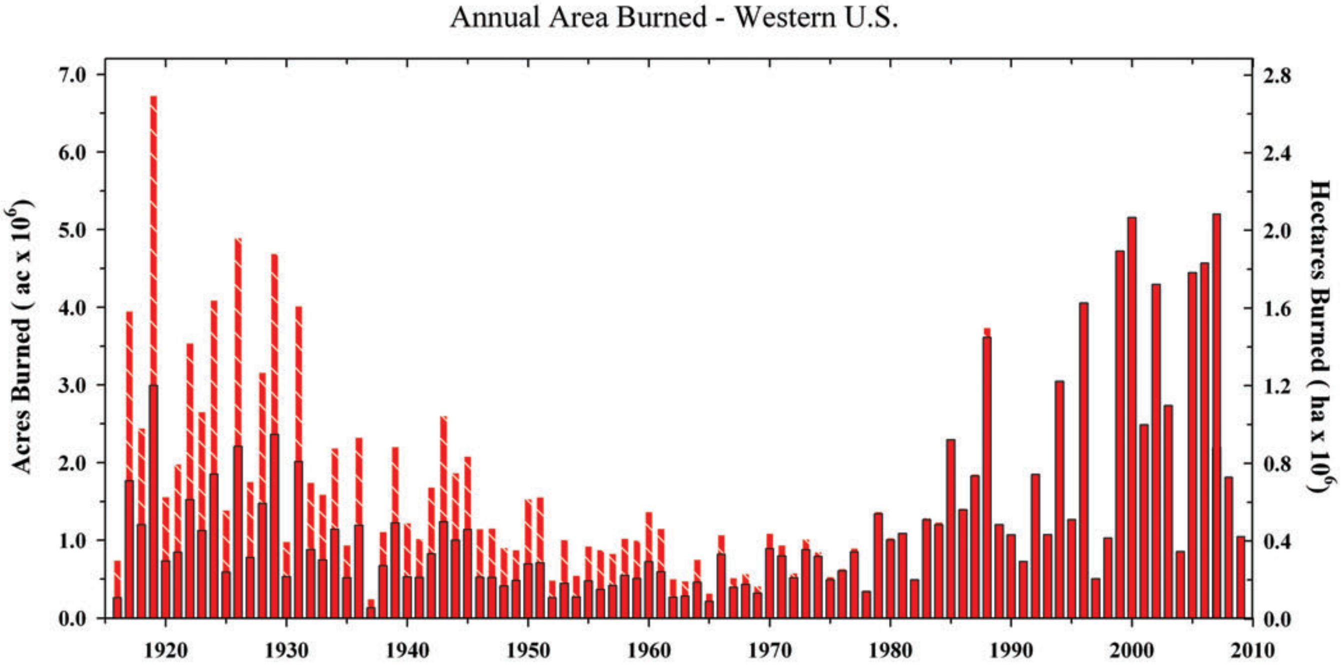


Figure 1-2—Observed and reconstructed area-burned comparison. Time series of observed total wildfire area burned for 11 western U.S. States for the period 1916–2009 (bars, adjusted for area reporting bias) (from Littell and others 2009).

The term "cultural resource" is used throughout this volume because it is the common vernacular used by Federal or State/Provincial land management agencies in the United States or Canada, respectively. Other organizations, governmental bodies, and individuals also use the terms "heritage resources" or "archaeological resources." The three terms—cultural resources, heritage resources, and archaeological resources—may have some unique legal implications but from a fire and materials effect perspective they are indistinguishable and are synonymous herein unless specifically noted by an author.

From an ecological perspective, fire is a process necessary for the maintenance of viable populations of many species because of its direct effects, as well as the creation of landscape mosaic of essential habitat conditions (Brown and Smith 2002; Smith 2000). Although fire is a vital ecological process, the historical archaeological record of many tribes' cultural and social achievements is increasingly threatened by recent increases in fire intensity, frequency, size, and subsequent management activities.

Pre-historically, landscapes typically experienced systematic fire return intervals and fires were routinely set by indigenous people worldwide for various reasons (Denevan 1992; Kay and Simmons 2002; chapter 2). Research has documented the wide ranging use of fire by Native Americans to manipulate the landscape, prepare open areas to plant crops, and increase forage for roaming megafauna, such as buffalo, elk, and deer (Stewart 2002; Williams 2000). In both written and oral histories of many tribes, fire is spoken of as an instrument in bringing in animals and new growth, thus helping to increase food availability and economic security.

> *Indigenous people's detailed traditional knowledge about fire, although superficially referenced in various writings, has not for the most part been analyzed in detail or simulated by resource managers, wildlife biologists, and ecologists…Instead, scientists have developed the principles and theories of fire ecology, fire behavior and effects models, and concepts of conservation, wildlife management, and ecosystem management largely independent of native examples.*
> (in Stewart 2002:4)

Studying ancient cultures and their practices may help to identify fire use tactics and recognize preservation techniques of both tangible and intangible resources that have stood the test of time. Only by looking to the past, can we truly prepare for the future by ensuring that history does not repeat itself through catastrophic events that could be prevented. Thus, the study of traditional cultural knowledge and its integration into land and resource management is increasingly recognized as a valuable contribution (Berkes 2009; Berkes and others 2000; Kimmerer and Lake 2001, 2007). Current research has also shown a close link between the frequency and intensity of anthropogenic and lightning caused fires and the amount of woody fuel accumulation. For example, in long-needled coniferous forest, particularly in the southeastern and western United States, these frequently recurring fires thinned out the trees, pruned the survivors, and kept fuel load low, leading to open grasslands and park-like tree stands (Brown and Smith 2002).

In 1905, the United States Congress created the United States Forest Service (USFS). Several large fires early in the century put fire suppression in the forefront of Forest Service fire management. Following severe fires in Idaho and Montana, the Chief of the Forest Service established in 1935, a "10 a.m." policy (http://www.fs.fed.us/fire/people/aboutus.html). The goal of the 10 a.m. policy was to plan and manage each fire so as to control the fire by 10 a.m. of the next day (Pyne 1982). The 10 a.m. policy became the dominant strategy during much of the rest of the 20th century. Although somewhat less aggressively due to limited resources, other State and Federal agencies also attempted to implement this strategy. In a parallel way, Canadian managers sought to limit fire in much of Canada. This effort across North America effectively lengthened the fire return interval and fostered the accumulation of fuels for many forests, woodlands, shrublands, and grasslands. The results of this fire exclusion policy unwittingly led to hazardous fuel levels, fires of ever increasing size and severity, and a general decline in ecosystem health (Kaufmann and others 2004; Keane and others 2002).

Although the attempted exclusion of fire was debated throughout the 1940s and 1950s, particularly in the academic literature, it was the dominant philosophy. In 1963, the Leopold Committee issued its report to the U.S. National Park Service regarding wildfire management issues (Leopold Report, http://www.nps.gov/history/history/online_books/leopold/leopold.htm). This report identified the importance of fire in restoring and maintaining habitat for several species. Throughout the 1970s and 1980s, research continued to define the importance of fire in ecosystems and the Congress passed several environmental and cultural resource protection laws.

The 1960s and 1970s began a period of transition in fire policy. Sequoia-Kings Canyon National Park in California created the first prescribed natural fire program in 1968 (Stephens and Ruth 2005). In 1977, the Forest Service changed their fire policy to emphasize a balanced fire control program, provide for natural and planned prescribed fires, and to incorporate fire planning into the land management planning process (Nelson 1979). Forest managers, on the other hand, were fighting a battle against fire and major fuel accumulation from over half-a-century of suppression efforts on Federal, tribal, and private lands (Nelson 1979; Stephens and Ruth 2005). It wasn't until years later after several catastrophic fire events that the *Federal Wildland Fire Management Policy* was adopted in 1995 (amended in 2001). The *Policy*, its 2001 revision, the 2003 *Healthy Forests Restoration Act*, and the sequence of costly fire seasons that spurred these developments made it clear that fuels reduction would remain the driving issue in forest management in the United States for the foreseeable future (Franklin and Agee 2003). Finally, fire management included more agencies than just the Forest Service; the National Park Service, Bureau of Indian Affairs, Bureau of Land Management, United States Fish and Wildlife Service, and the National Biological Service all became active participants under the Federal Wildland Fire Management Policy. Additionally, non-governmental organizations (NGOs) (e.g. The Nature Conservancy) developed national, regional, and local programs to address the need for increased fire use for protection of lives, property, and to promote resource benefits (fire@tnc.org).

Under this new policy, managers are expected to reintroduce fire on millions of acres per year to reduce hazardous levels of fuel throughout the landscape and create healthy ecosystems with fire-adapted species. The central message embedded in this policy shift is that the foregoing century of fire suppression and other management practices have disrupted the balance between land and resource use and have also changed people's sense of place and their reliance on public and tribal lands for their livelihood (see Karjala and Dewhurst 2003; Moseley and Toth 2004). It is ironic that, in many cases, frequent past burning may have helped preserve artifacts in the cultural context, while today's wildland fires and prescribed burns are impacting and destroying the artifacts and evidence of their cultural significance.

Legal Protection

The Federal/Provincial, tribal/First Nations, and local governments in the United States and Canada have played a major role in determining the legal protections given to the many different classes of cultural resources. Cultural resource specialists, with the help of local communities, can interpret and apply these legal protections using standards recognized in both the United States and Canada. Tribal governments' primary role in the creation of legal protection for cultural resources is to be consulted by government officials for establishing proper means of protection, conservation or mitigation (for the United States see E.O. 13175: Consultation and Coordination with Indian Tribal Governments). The United States Congress passed the National Historic Preservation Act (NHPA) in 1966. Although not the first Federal historic preservation law in the United States, the NHPA, unlike earlier legislation, such as the Antiquities Act (1906), Historic Sites Act (1935), and Reservoir Salvage Act (1960), very specifically defined what forms cultural resources can take and criteria by which their significance is measured (King 2008; National Park Service 2006).

Section 101 of the NHPA authorized creation of a National Register of Historic Places (NRHP), the official list of significant cultural resources in the United States worthy of preservation. The NRHP includes criteria to evaluate properties for the National Register (http://www.achp.gov/nrcriteria.html). These consist of the following:

> The quality of significance in American history, architecture, archaeology, engineering, and culture is present in districts, sites, buildings, structures, and objects that possess integrity of location, design, setting, materials, workmanship, feeling, and association and
>
> (a) **that are associated with events** that have made a significant contribution to the broad patterns of our history; or
> (b) **that are associated with the lives of persons** significant in our past; or
> (c) **that embody distinctive characteristics** of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction; or
> (d) **that have yielded, or may be likely to yield, information** important in prehistory or history.

To become a historic property, a cultural resource must satisfy several requirements:

- Classifiable as a site, building, structure, object, or district (aggregates of one or more of these categories) (table 1-1);
- Except under unique circumstances, achieved significance 50 or more years ago;
- Assigned definitive geographic boundaries;
- Meet one or more of four NRHP criteria for evaluation;
- Possess and exhibit integrity of location, design, setting, materials, workmanship, feeling, and association.

Section 106 of the NHPA requires U.S. federal agencies to take into account the effects of their management actions on historic properties. Simply put, without a historic property designation, a potential cultural resource is not provided assurances by Federal policy as an important cultural resource,

Sidebar 1-1—La Mesa Fire Study

La Mesa Fire, Bandelier National Monument, New Mexico, June 16–22, 1977
References: Traylor and others (1990)

General Information

- Elevation: 1,981.2 to 2,743.2 m (6,500 to 9,600 ft)
- Vegetation: 75% ponderosa pine or spruce fir and aspen forest; 25% pinyon-juniper
- Topography: canyons, drainages and mesas
- Type of study: post-fire qualitative analysis of surface materials

Fire Description

- Temperature range: temperature not recorded but may have reached a maximum of 800 °C (1472 °F). Estimated temperature of top 2 inches (5.1 cm) of soil: well below 100 °C (212 °F) with maximum temperature. Fire sustained for 10 to 15 minutes.
- Duration: 7 days
- Relative humidity: 8 to 25%
- Fuel: variable
- Type of fire: wildland
- Energy release component (ERC): 74 to 80
- Burning index (BI): 60 to 104

The La Mesa Fire study in Bandelier National Monument was the first major post-fire investigation of fire effects on heritage resources. The La Mesa Fire started June 16, 1977, and burned uncontrolled for 7 days. This was a high intensity wildfire, burning more than 60 km^2 (15,000 acres) of forest and pinyon-juniper woodland. It was the first burn in which archaeologists were enlisted to help firefighters avoid damage to archaeological sites.

After the fire, archaeologists surveyed handlines and bulldozer lines to record site disturbances caused by the fire suppression activities. Pre-burn wildlife transects were also surveyed archaeologically to evaluate fire effects on sites within a variety of ecological zones. Post-burn surveys covered only a small sample of the previously unsurveyed burn area. Survey crews encountered 99 archaeological sites, 54 of which were burned (Traylor and others 1990). Fire effects were recognized at 51 of these 54 sites (Traylor and others 1990). Major impacts of the fire included spalling and crumbling of tuff masonry. Increased soil erosion was also recorded as a major indirect fire impact. Fire effects on surface artifacts included color change, breakage, and the adherence of residues and sticky adhesions.

Four prehistoric sites, consisting of small (1 to 2 room) masonry structures were excavated to further assess fire effects on artifacts, architecture, plant and animal remains, and dateable materials. Two of the sites were moderately burned and two had been burned severely. Structures were excavated to a floor-depth of about 30 cm (11.8 in). Sub-floor test pits were also excavated inside the rooms. Laboratory analyses of macrobotanical remains, pollen, soil, and faunal remains were conducted to assess fire effects at surface and subsurface levels. Samples for obsidian hydration, tree ring dating, archeomagnetic dating, and radiocarbon dating were also collected and analyzed (Traylor and others 1990).

In addition to fire impacts, damages caused by fire suppression and rehabilitation activities were also common. Forty-four of the sites surveyed exhibited some suppression impact (Traylor and others 1990:100). Bulldozer impacts to archaeological sites were the most severe. Although archaeological monitors worked with hand crews and bulldozer operators during the fire suppression, miscommunications caused some sites to be damaged. Fire lines were sometimes widened and large safety areas bladed without archaeological consultation. Also, bulldozers used for rehabilitation work were not monitored by archaeologists. Due to these problems, bulldozers completely leveled eight sites and caused significant architectural damage to seven sites (Traylor and others 1990).

Table 1-1—Comparability of U.S. Department of the Interior, National Park Service, National Register of Historic Places and Canadian Register of Historic Places Cultural Resource Categories.

USDI, National Park Service	National Register of Historic Places	Canadian Register of Historic Places
Archeological resources	Site Structure Object District	Archeological site District
Structures	Building Structure Object District	Building Structure District
Cultural landscapes	Site District	Landscape District
Ethnographic resources	Site Building Structure Object District	Archeological site Building Structure District
Museum objects	N/A	N/A

Adapted from USDI, National Park Service (1997), National Register of Historic Places (NRHP); Parks Canada 2003.

and therefore afforded no consideration under the NHPA. However, as seen in table 1-2, museum objects, though not on the list of NHPA approved fields, contain elements of other entities and are often considered outside of their NPS grouping as a structure or object.

Owing to the circumstances of history and the benefits of hindsight, historic preservation in Canada has taken a different trajectory than in the United States. Only recently has the Canadian Federal government taken a major role in establishing uniform nationwide preservation standards. Rather, it is provincial and territorial governments that have the most explicit laws related to historic preservation, albeit they vary from one another and are restricted to archaeological resources (Parks Canada 2000). The Canadian Federal government currently has no umbrella legislation akin to the NHPA, relying instead on various policies and directives that support the preservation of cultural resources, as well as the Canadian Environmental Assessment Act (CEAA) (Canadian Environmental Assessment Agency 1996), which is effectively the counterpart of NEPA.

In an effort to promote a standardized approach to cultural resources management, Federal, Provincial, territorial and local governments launched the Historic Places Initiative in 2000 (http://www.pc.gc.ca/progs/plp-hpp/plp-hpp1_E.asp). Two important consequences of this initiative were the Canadian Register of Historic Places (http://www.historicplaces.ca/) and *Standards and Guidelines for the Conservation of Historic Places in Canada* (Parks Canada 2003). The Canadian Register lists those cultural resources, called "historic places," formally recognized as significant by Federal, Provincial, territorial and local governments. The *Standards and Guidelines* define historic places as structures, buildings, groups of buildings, districts, landscapes, and archaeological sites possessing heritage value.

In some respects, the Canadian concept of cultural resources, as portrayed in law, policy, directives, guidelines, and philosophy, is what many practitioners of cultural resources management in the United States wish was more explicitly reflected in the NHPA, NRHP, and other key components of historic preservation. For example, cultural landscapes are recognized as a formal resource type in Canada, whereas in the United States the nexus between landscapes and the NRHP can be awkward, particularly with respect to those associated with traditional socio-cultural groups (for example, Evans and others 2001; Goetcheus 2002; King 2003).

Table 1-2—Cultural resource categories of the United States.

Category	Definition	Examples
Archeological resources	The material evidences of past human activities. Comprised of materials of prehistoric and historical origin deposited by individuals of any ethnic affiliation, indigenous and other. Classified and managed as discrete archeological sites comprised of a combination of artifacts, ecofacts and/or features.	Prehistoric: structural remnants, burials, fire hearths, midden (Ch 7), storage facilities, flaked and ground stone tools (Ch 4), ceramics, caves and rock shelters, rock images (Ch 5), and raw material sources (such as lithic quarries or culturally modified trees). Historic (Ch 6): structural ruins, minor features, artifacts and ecofacts associated with homesteads and other occupation sites; industrial complexes related to mining, logging, fishing, and agriculture; battlefields, refuse dumps, trails, roads, and railroad grades.
Structures	Constructed and usually immovable works intended to serve human activities in prehistory and history. Prehistoric and some historic structures are also archeological resources, the structural designation often being applied in cases where a structure is actively maintained to a pre-determined condition*	Dams, millraces, ditches, canals, reservoirs, bridges, roads, trails, forts, defensive works, fences, corrals, rock cairns and earthworks. *Some publically-accessible prehistoric cliff dwellings in the American Southwest. See also Ch 6
Cultural landscapes	Geographic areas containing both cultural and natural resources associated with events, activities, or people that reflect human social and ecological adaptations and perceptions. Characterized by the way humans settle, divide, utilize and circulate through them.	Historic sites or landscapes (cemeteries, battlefields, rural communities); historic designed landscapes (gardens, parks, estates); vernacular landscapes (farming, ranching, mining, and ethnic districts, ghost towns); ethnographic landscapes (massive geologic structures; festival, spiritual, ceremonial grounds; sacred sites).
Ethnographic resources	Variations of natural resources, standard cultural resource types, and intangible attributes assigned importance by traditional users and seen as vital for cultural perpetuation.	With regard to tangible manifestations, in addition to landscapes, ethnographic resources are comprised of culturally-important objects, plants and animals, archeological sites and structures.
Museum objects	Comprised of prehistoric and historic materials obtained from archeological investigations, natural resources such as plant specimens and geological samples, and archival documentation such as field notes and maps, photographs, and electronic files. Displayed or stored in facilities where environmental conditions are strictly regulated, such as public museums and curation buildings or may be found in outdoor exhibits, historic structures, or exposed through excavation and left in place.	Museum objects include specimen, archival, and manuscript collections relating to archeology, ethnography, history and natural history.

Modified from USDI National Park Service (1997a).

Cultural Resources Categorized

The USDI National Park Service (1997a,b) employs a classification system for cultural resources that is, with some clarification, well suited for the purposes of this volume. Specifically, five categories of cultural resources are recognized—none of which is mutually exclusive.

Canada has a similar system to categorically divide its resources, which is represented in table 1-3. We will use the NPS system described above for the purposes of this volume. For both United States and Canadian workers, it is important to understand the connections between the two groupings of historic places that are represented in table 1-1.

Tangible and Intangible Cultural Resources

While both tangible and intangible cultural resources can be affected by wildland fire and fire management actions, it is the culturally independent (not necessarily identified with a specific group of individuals) tangible attributes that are the primary focus of this volume (culturally dependent intangibles are addressed in chapters 8 and 9). Intangible resources are often overlooked because they are not clearly defined, may be difficult to place "value" on, and, therefore, are often given only limited protection.

All tangible cultural resources are ultimately comprised of materials—raw and synthetic, singular and composite, inanimate and living, prehistoric and historic—and it is those materials and their spatial associations, or context, that are altered by direct, independent, and operational effects. Importantly, as described in subsequent chapters, cultural resources display different vulnerability to those effects.

Traditional Cultural Properties (TCPs) are places eligible for inclusion on the NRHP based on associations with traditional living communities, and specifically those historically rooted in and important for maintaining the cultural identity of such communities (Parker and King 1990). TCPs were devised to account for the nexus between the tangible and intangible aspects of cultural resources that had generally been ignored, and included places of spiritual power, traditional practices, stories, therapeutic qualities, and remembrances (King 2003). The importance of such places was reconfirmed with the issuance of Executive Order (EO) 13007 in 1996, which explicitly addresses American Indian "sacred sites," and requires Federal agencies to accommodate access and ceremonial use of such sites to religious practitioners, avoid physical impacts to these sites, keep the locations of sacred sites confidential, and ensure consultation with tribal governments regarding sacred sites.

Fire Management

In the United States, the 2001 Federal wildland fire management policy recognizes three types of wildland fire: *wildfire*, *prescribed fire*, and *wildland fire use* (National Wildfire Coordinating Group 2006, http://www.nwcg.gov/pms/pubs/glossary/w.htm). Wildland fires are non-structure fires that occur in

Table 1-3—Cultural resource categories of Canada.

Category	Definition
Archeological sites	Physical evidence of past human activity found in a specific location on or below the ground, or underwater.
Landscapes	Exterior spaces that have been assigned cultural—including spiritual—meaning or have been deliberately altered in the past for aesthetic, cultural or function reasons. Landscapes include land patterns, landforms, spatial organization, vegetation, circulation systems, water features, and viewsheds.
Buildings	Constructed works created in the past to shelter activities related to habitation, business or social functions.
Structures	Engineered works created in the past primarily for purposes other than habitation, including transportation, energy development, communications, industry, resource extraction and processing, flood control and irrigation, and defense.

Adapted from Parks Canada (2003).

wildlands—tracts with few or no developments—ranging from remote wilderness to the interface with suburban and urban areas (Canadian Council of Forest Ministers 2005; National Wildfire Coordinating Group 2006). Wildland fires can result from natural phenomena such as lightning, accidental or intentional human sources, or when managed wildland fires escape or exceed predetermined parameters. *Wildfires* are unplanned, unwanted wildland fires where the management objective is to suppress or extinguish the fire. *Wildland fire use* refers to naturally ignited (lightning-caused) fires managed to accomplish specific resource management objectives within predetermined locations. *Prescribed fires* are intentionally ignited to meet specific management objectives. These fires—usually set in the late fall or early spring, or when seasonal conditions are moist and relatively stable—are a primary means for fuel reduction. In addition to prescribed fire and wildland fire use, other techniques such as mechanical thinning and chemical treatments are also employed to achieve fuel reduction and resource management objectives.

In 2008, the Fire Executive Council (FEC), which is charged with providing interagency Federal executive-level wildland fire policy leadership, direction and program oversight in the United States, unveiled modifications to the 2001 policy to allow wildland fires on Federal lands to be managed with a full spectrum of response alternatives (also known as appropriate management response or AMR) (Fire Executive Council 2009). The changes include removing the distinction between wildfires and wildland fire use, calling both wildfires, and allowing all naturally ignited wildfires to be simultaneously managed for multiple objectives (for example, protection *and* resource benefits). Federal wildland fire policy will now recognize *two*, rather than three, categories of wildland fire—wildfires (unplanned ignitions) and prescribed fires (planned ignitions). The Canadian Council of Forest Ministers (2005) also recognizes these two terms and uses similar definitions.

Categories of Effects

For the purposes of this volume, the term *effects* simply refers to the observable alterations—permanent or temporary, reversible or irreversible—to the tangible or intangible attributes of cultural resources resulting from wildland fire or fire management actions. In most contexts, observable changes will have a negative connotation with respect to the "pristine" pre-disturbance conditions where an artifact, feature, site, or landscape presumably had its maximum value as a cultural resource for purposes of meeting the intent of various laws. However, in some cases fire or fire management may play a positive role in restoring or maintaining a cultural landscape or Traditional Cultural Property (TCP). Likewise it may be instrumental in the application of Traditional Ecological Knowledge (TEK) in the maintenance or restoration of cultural traditions (c.f., Kimmerer and Lake 2001; Lake 2007; Stewart 2002). The purpose of the following classification is to attempt to develop an objective, non-value-laden perspective on fire effects. The classification attempts to isolate observable, measureable effects (i.e., tangible fire effects) from those that involve one's inner relationship with the cultural resource (i.e., intangible fire effects) (fig. 1-3).

The classification emphasizes the distinction between biophysical processes and human actions/reactions. Biophysical processes are further distinguished by the time of occurrence: those that occur at the time of the fire (First-Order) vs. those that act upon the fire-altered biophysical system after the fire (Second-Order). The classification is intended to emphasize the interdisciplinary nature of the relationship of cultural resources to fire and fire management. It is recognized that the classification stems from a western scientific perspective. It is argued, however, that the knowledge, skills, and methods applied to understand each component of the classification are substantially independent. Earlier volumes of the "*Rainbow Series*" provide substantial synthesis and review of tangible fire effects on fauna (Smith 2002), flora (Brown and Smith 2002), air (Sandberg and others 2003), soils and water (Neary and others 2005), and exotic-invasive plants (Zouhar and others 2007).

The effects of wildland fire, prescribed burning, and related fire management actions on cultural resources are divided into two major categories, direct and indirect:

- ***Direct effects*** are those caused by fire and its byproducts, such as smoke and ash. Direct effects result from the physical state of the fire environment (fuels, weather, terrain) and the ignition pattern (heading-fire, flanking-fire, backing-fire) (chapter 2). Direct effects are the result of combustion and subject to all the laws of physics and chemistry. Because temperature is a readily measurable metric, many direct effects are described as functions of the temperature and duration of heating (chapters 2, 3, 4, and 6). However, in most cases fire and cultural resource material temperature histories are unknown. Thus fire severity and direct effects are observed *ex post facto*. Cracking, crazing, spalling, pot-lidding, melting, smudging, and sooting are all direct effects that result from combustion, combustion byproducts, and heat transfer mechanisms acting upon various material artifacts, features, sites, or landscapes (table 1-4). Regardless of what role humans may have had in creating the fire environment (e.g., past cultural and management

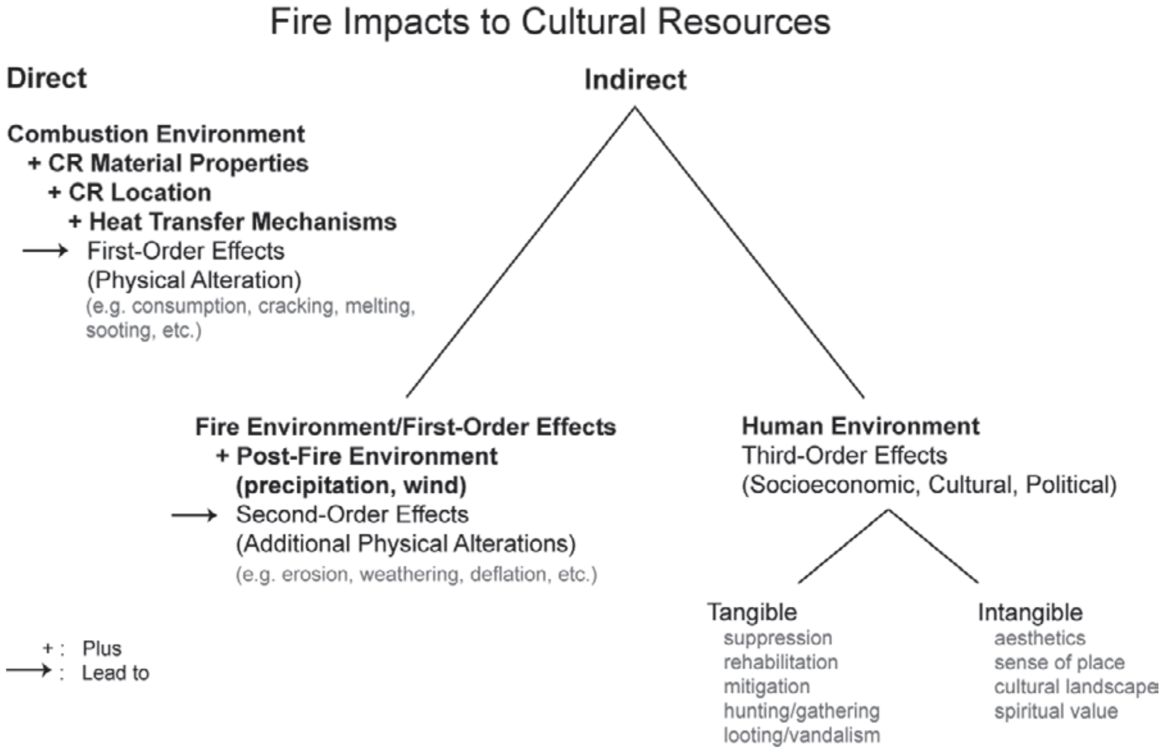


Figure 1-3—Fire impacts on cultural resources. Direct, First-Order effects result from biophysical processes related to the local combustion environment as it is juxtaposed to cultural resources and the physical properties of the resource. Indirect effects derive from biophysical processes following the fire (Second-Order effects) or human responses to fire (Third-Order effects) (synthesized from numerous sources).

practices), the direct effects would occur regardless of whether or not people were there to observe. The term "*First-Order Fire Effects*" is frequently applied to describe the direct effects, particularly in National Wildfire Coordinating Group (NWCG) sponsored fire effects training courses in the United States, (e.g., Rx-310 and Rx-510).

- ***Indirect effects*** are those effects that are derived from or dependant on the fire's occurrence. If the fire had not occurred indirect effects could not occur. Indirect effects are of two types: biophysical processes acting on the fire-altered environment and human responses. *Indirect effects* occur when wildland fire or associated fire management actions change the context in which a cultural resource is found, leaving it vulnerable to impacts. Common examples of indirect effects include post-fire erosion, carbon contamination in archaeological deposits, disturbances from fire-killed tree-fall (see for example sidebars on tree root burnout and retardants in chapter 9), and vandalism/looting (Christensen and others 1992). If fire occurred in the absence of human observation or intervention, post fire biophysical processes, such as erosion, weathering, succession, and herbivory would still take place following the laws that govern such processes. These effects are referred to as "*Second-Order Fire Effects*." Humans are affected by, and respond to, fire and the threat of fire in various ways that are as complex as the human experience. The impacts of fire on the human environment are defined as "*Third-Order Fire Effects*." Third-Order effects[1] may be *tangible* or *intangible*. *Tangible* effects are the purposeful, intentional, observable, measurable human responses to the perceived risks or opportunities presented by fire.

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[1] The concept of Third-Order fire effects developed from discussions with Frank K. Lake while Ryan and Lake were on the Rx-510 Advanced Fire Effects Course cadre at the National Advanced Fire and Resource Institute, Tucson, AZ. Lake (2007) discusses Third-Order effects in the context of traditional ecological knowledge (TEK).

Table 1-4—Common nomenclature to describe the first order fire effects of fire on archaeological resources (adapted from Buenger 2003).

CB = Combustive Residue – The presence of tar deposits on the surface of a specimen formed as a by-product of the pyrolysis and combustion of organic materials. The residue is a by-product of combustion and is not composed of pure carbon, nor is it an intact organic compound (DeBano 1998). It is a highly nitrogenous condensate tar substance (Yokelson et al. 1997). The residue can be tacky or semi-solid immediately post-fire and generally appears as dark brown to black droplets on the surface of a specimen, may give artifacts a blackened appearance if sufficiently combusted.

CC/OX = *Color Change/Oxidation* – (1). An overall darkening or reddening of a specimen from its original color. It is generally the result of exposure to temperatures sufficient enough to alter the mineral composition of the specimen (this definition used to code sandstone blocks within architectural sample units) (i.e., Cliff House Formation Sandstone changing from its original orange-buff to a deep red color).

(2). The presence of and orange/brown discoloration on an artifact. It is generally due to the presence of oxidized sediment on a specimen where sediment had adhered to its surface prior to exposure to heating. Heating of the sediment results in discoloration that adheres or permeates the surface of a specimen.

POX = *Paint Oxidation*– The oxidation of pigment (organic or mineral) on decorated ceramic specimens. Alterations can include a change in color from the original pigment (black to red), or the combustion of the pigment entirely.

CC = *Color Change* – (lithic specimens only) An observable color change of a specimen from original, pre-fire, color. Generally due to an alteration in the mineral composition of a specimen during exposure to heat.

CZ = *Crazing* – The presence of fine, non-linear or latticed cracks on the surface of a specimen.

SP = *Spalling* – The exfoliation of a portion of the original surface of exposed rock or a specimen due to differential heating and pressure release. It is generally the result of steam buildup in areas of the specimen that have impurities or elevated moisture content.

SPS = *Spall Scars* – The presence of concave depressions on the surface of a specimen where it is evident that a portion of the surface was exfoliated due to spalling, but the actual spall was not observed in situ. Over time, associated spalls have weathered or eroded.

PL = *Potlid Fracturing (lithic specimens only)* – Similar to spalling, but specific to lithic artifacts manufactured from cryptocrystalline silicate rocks such as chert. The fracture is characterized by a circular pit on the surface of the specimen. The pit represents the area in which the original portion of the surface has been exfoliated due to differential heating and pressure release. The exfoliated section is generally circular, flat on the dorsal side, and convex on the ventral side (resembling the lid of a cooking pot).

FR = *Fracturing* – The fracturing of a specimen into multiple pieces, and/or the presence of fractures or fissures that penetrate deeply into a specimen.

WFR = *Weathered Fracturing* – The fracturing of a thermally altered architectural block over time due to mechanical weathering. Fine cracks or fracture lines induced by exposure to heat become exacerbated due to mechanical weathering processes. Fracturing is often patterned and affects a large portion of the specimen.

These include suppression, rehabilitation, and mitigation about which volumes are written. These "real-time" active management-related effects are often referred to as *Operational Effects* because they are associated with typical fire management operations. Changes in recreational use, hunting, and gathering, for example, are observable and measurable and are, therefore, also *tangible* Third-Order effects. In contrast, the effects of fire, fire suppression, or fuels treatment-restoration activities on humans' spiritual or emotional sense of well being are intangible Third-Order fire effects. These intangible effects are a reflection of humanity's complex co-evolution with fire. Traditional Cultural Properties (TCP) are identifiable and documentable places and as such are tangible cultural resources (King 2003; Parker 1993; Parker and King 1990), but how a person or group of people feel about the impacts of fire or fire management on a TCP is an intangible fire effect. The development of intangible Third-Order fire effects knowledge can only be obtained through close communication and collaboration with cultural leaders of affected communities (chapter 8).

Material effects receive greater attention than operational and intangible effects in this Volume, particularly in chapters 2 through 7. The processes influencing direct effects are presented in chapter 2, while chapters 3 through 7 address those impacts with respect to specific materials. Operational effects resulting from activities associated with managing wildland fires, such as the construction of firelines, application of fire retardants, and vegetation clearing are discussed in "Management Implications," chapter 9.

What is the Objective of This Volume?

The main objective of this volume is to define cultural resources, provide information about the mechanisms that affect cultural resources, and identify management alternatives to prevent (or limit) adverse impacts within the proper legal framework. This basic information creates a level playing field in fire situations, where fire managers value cultural resources, cultural resource specialists understand fire, and both management groups comprehend what effects could occur without proper mitigation. Chapters 8 and 9 also identify techniques to facilitate better communication between groups to improve protection through consultation.

This volume is intended to be used as a reference for both cultural resource specialists and fire managers during their planning processes. The intended audience includes resource and fire managers employed by public, tribal, and private land management agencies, non-governmental organizations, private contractors, historic preservation officers, and researchers. Particular emphasis is given to providing guidance for those in the realm of cultural resource management (often called CRM), individuals actively engaged in identifying and managing cultural resources before, during, and after wildland fires, and preparing and reviewing fire-related environmental compliance and land management documents (for example, land and fire management plans, prescribed fire burn plans, and community wildfire protection plans).

We hope to inform the reader not only of the subject matter, but provide meaningful examples, legal implications, and a well defined connection between the effects of fire and cultural resources. In addition to understanding these connections, the reader can also understand their role in both planned and unplanned fire situations. Each chapter provides basic information and discussion that could be used for public education on the subject. This volume is also intended to provide direction for protection of cultural resources within the legal framework. Our hope is to bring both cultural resource and fire managers to a clear understanding of their mutual legal responsibility for the protection of cultural entities. Above and beyond legalities, this volume highlights the importance of working together with local communities.

This is the first comprehensive summary of fire and cultural resources inclusive of Canada and the United States, covering a wide range of cultural resource categories as well as describing the variability of fire on different landscapes. The United States Department of Agriculture (USDA) Forest Service, Rocky Mountain Research Station has produced a series of documents that assimilate current knowledge of wildland fire effects relevant to the management of ecosystems, including fauna (Smith 2000), flora (Brown and Smith 2000), air (Sandberg and others 2002), soil and water (Neary and others 2005) and non-native invasive plants (Zouhar and others 2008). Many of these same topics were addressed in the first version of this "Rainbow Series" volume that was published in the late 1970s and early 1980s. The Rainbow Series volumes encompass the United States and Canada in geographic coverage, but many of the principles can be applied to other regions of the globe where wildland fires occur.

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Chapter 2:

Fire Behavior and Effects: Principles for Archaeologists

Fire is a natural component of earth's ecosystems. Fire has impacted most landscapes of the Americas, having left evidence of its passing in trees, soils, fossils, and cultural artifacts (Andreae 1991; Benton and Reardon 2006; Biswell 1989; Bowman and others 2009; Boyd and others 2005; Cochrane and others 1999; DeBano and others 1998; Jurney and others 2004; Kilgore and Taylor 1979; Moore 1972; Nevle and Bird 2008; Pausas and Keeley 2009; Scott 2000, 2009; Swetnam and Anderson 2008; Swetnam and Betancourt 1990, 1998). Fires burn throughout a range of intensities from smoldering flameless fires producing little if any smoke to creeping fires with short, thin flames to raging crown fires with walls of flames 50 meters (164 feet) high, or more. The duration of a fire's passing may be as short as tens-of-seconds in the case of a fast moving surface or crown fire or as long as a day in smoldering ground fire. As fires burn throughout this range of intensities and durations the impact on the environment and the cultural resources therein varies tremendously.

Wildland fire behavior is highly varied due to such factors as the type of vegetation/fuel and its moisture content, atmospheric humidity, wind speed, and terrain. The spread and behavior of each fire is fairly unique, which can make fire seem both mysterious and unpredictable at times. However, the process is a fairly well understood phenomenon. Wildland fire is predictable in so far as both the current and antecedent weather conditions are reasonably well known. The state of the pre-burn fuels and weather are highly variable both spatially and temporally. The largest source of variation in fire behavior is local variation in the vegetation/fuel distribution (Ryan 2002; Turner and others 1999). It is this variability that most limits our ability to predict a fire's effects on cultural resources. This is why it is desirable to have local fuels and weather data when planning, implementing, monitoring and reconstructing a fire. In the case of wildfire, pre-burn conditions often must be inferred from post-fire proxy data, for example inferring preburn conditions from those in a "similar" near-by unburned area. Predicting fire behavior and understanding its effects requires knowledge of the fire environment, heat transfer principles, the responses of various artifact materials to heat, and to a lesser extent, the chemicals released by fire (such as ash or smoke) or used in fire suppression (such as retardants or foams). Models exist to predict fire behavior and its effects through interpreting weather and fuel conditions. It is important for managers to recognize that some factors cannot be controlled; there will always be spatial variation, adverse environmental conditions, and complex vegetative structures that make prescription development an inexact science. As we gain a better understanding of the effects of fire on cultural resources, we must take appropriate action to reduce and manage risk to these assets.

The fire science literature includes a broad spectrum of interrelated topics. Terminology within the field varies in part because of the varying space and time scales. For example, spatial scales vary from individual fuel particles to landscapes, and time scales vary from fire residence times measured in seconds to fire return intervals measured in years to fire regimes measured in centuries, depending on the author's subject matter. Numerous previous authors have described fire processes at multiple scales from combustion fundamentals to broad-scale ecological interpretations. The reader interested in more fully understanding the field of wildland fire science is referred to those texts (see Agee 1993; Chandler and others 1983a,b; DeBano and others 1998; Gill and others 1981; Johnson and Myanishi 2001; Omi 2005; Pyne and others 1996; Sugihara and others 2006; Wright and Bailey 1982).

The purpose of this chapter is to provide cultural resource specialists with a primer on fuels and fire to enable them to work more effectively with fire managers in developing fuel treatment and restoration plans, managing wildfires, and conducting post-fire rehabilitation. This chapter provides a scientific foundation for predicting the potential impacts of fire on cultural resources. It also defines terms and concepts and identifies their practical implications to cultural resources. Prescribed fire and wildfire conditions associated with damage to cultural resources are discussed, as are ways to integrate planning measures to mitigate fire's effects on cultural resources.

Fire Basics

To either predict or assess the effects of fire on cultural resources, it is necessary to understand a few basic fire concepts. There are three essential conditions that must be present for a fire to ignite and continue burning; these three factors comprise the "fire triangle" (fig. 2-1 bottom left). There must be fuel to burn, a supply of oxygen to support combustion, and sufficient heat to cause successive ignition of fuel particles. Without all three components, fire cannot exist. Indeed, fire suppression tactics rely on this fundamental principle and design suppression strategies to either remove fuel (for example fireline construction and burnout), remove oxygen (for example to smother with dirt or foam) or reduce heat (for example to quench with water or retardants).

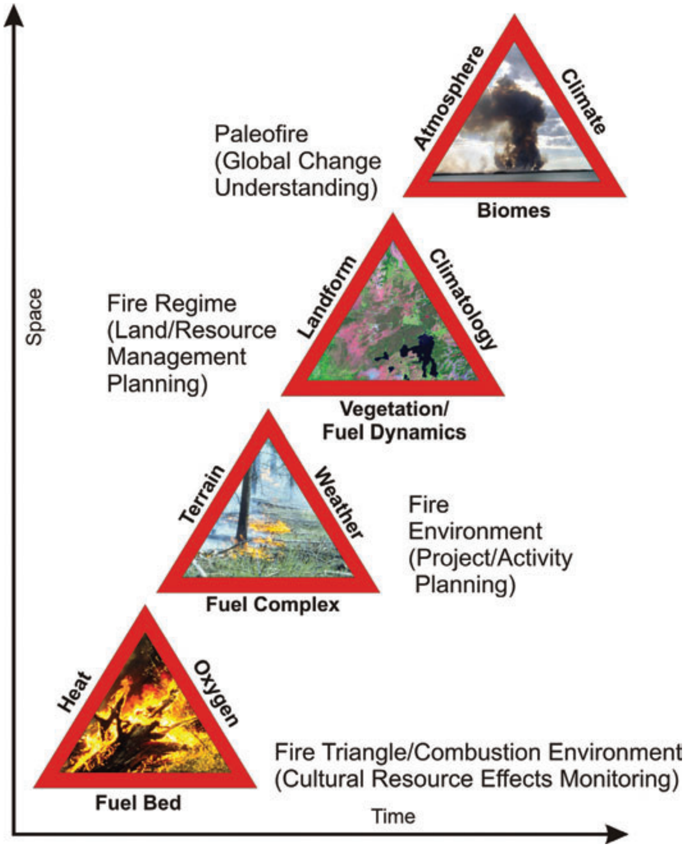

Figure 2-1—The multiple scales of fire (adapted from Scott 2000; Reinhardt and others 2001; Moritz and others 2005; Cochrane and Ryan 2009).

Fire affects biophysical processes across multiple temporal and spatial scales from micro-scale phenomenon (e.g., an effect on an individual plant or single cultural resource) to broad landscape patterns and processes. The "fire triangle" (fig. 2-1 lower left) is appropriate at the combustion scale, a small localized area where fuels making up the fuel bed are relatively homogeneous. The "fire environment scale" (fig. 2-1 second from bottom) is appropriate at the scale at which fuels treatment and restoration projects are planned and implemented. The "fire regime scale" (fig. 2-1 second from top) is appropriate for describing the role of fire in shaping ecosystem structure and function. Archaeologists, paleontologists, and those who study human development and migration often consider a higher, paleo-fire scale (Rickards 2010; Ruddiman 2003, 2007; Scott 2000, 2009) (fig. 2-1 upper right) (adapted from Cochrane and Ryan 2009; Moritz and others 2005; Reinhardt and others 2001; Scott 2000).

Combustion

Combustion is a physical process involving the rapid oxidation of fuels releasing carbon dioxide, water, mineral ash (e.g., Ca, Mg, K) and numerous other compounds, the chemistry of which varies with the type of fuel burning and the efficiency of combustion. The rapid oxidation of fuels also produces detectable heat and light.

Combustion is divided into four phases: preheating (or preignition), flaming, smoldering, and glowing (DiNenno and others 1995; Grishin 1997; Pyne and others 1996; Williams 1982). The fire's phase is dependent on the nature and condition of the fuel and oxygen availability. Wildland vegetation burns by turbulent diffusion flames in successive interactions between combustion gases and unburned fuel. Energy released by combustion of gases is absorbed by solid fuel particles in the preheating or first phase of combustion.

Preheating is an endothermic or energy absorbing phase. As the flame front approaches a fuel particle its temperature increases, gradually at first, then more rapidly. At about 100 °C (212 °F), free water begins to rapidly boil leaving an outer shell of dry fuel (table 2-1). The amount of energy needed to vaporize water contained in the fuel increases with the moisture content of the fuel. In the case of live, actively growing fuels the moisture content may be quite high (100 to 200 percent on an oven dry basis). As the particle continues to absorb heat, bound water and low molecular weight volatile compounds (such as waxes, terpenes, and resins) vaporize, and decomposition (pyrolysis) of solid fuel (principally composed of cellulose) begins. If the decomposition rate is fast enough to form a combustible mixture of vapors (carbonaceous gases), flaming combustion results.

Flaming combustion, the second phase where nearly all destructive fires occur (DeHaan 1997; Williams 1982), is an exothermic process. Flaming involves the combustion of gases (gas-phase) evolved from the preheating of the solid fuel. This energy is critical to the preheating of adjacent fuel particles and sustaining the chain reaction. In wildland fuels where oxygen is not usually limiting, fuel particles burst into flame at around 325 °C to 350 °C (617 °F to 662 °F) (ignition temperature) with a rapid rise in the local temperature. During the flaming phase, luminescent flames are produced as a flame envelope develops above the solid fuel. Theoretically, temperatures are much higher, 1800 °C to 2200 °C (3272 °F to 3992°F) where chemical bonds are being broken and flames can't exist below around 1300 °C (2372 °F) (Satio 2001). However, as the flame envelope includes many products of incomplete combustion, noncombustible particles, and cooler air entrained into the combustion zone from the surrounding area, measured flame temperatures are usually between 500 °C and 1000 °C (932 °F and 1832 °F) (Butler and others 2004; DeBano and others 1998; Pyne and others 1996; Sullivan and others 2003). Solid fuels burn at high temperatures, distilling volatile substances while creating charcoal. To continue to burn, fuels must continue to produce energy faster than it is lost to the surrounding environment. When the energy release rate drops before all volatiles have been liberated, flames become discontinuous and the fire transitions into the smoldering phase (Bertschi and others 2003).

Table 2-1—Temperatures associated with phases of combustion.

Temperature °C	Effect
0-100	Preheating of fuel: free water is evaporated
100-200	Preheating of fuel: bound water and low molecular weight compounds volatilized, decomposition of cellulose (pyrolysis) begins, solid fuel is converted into gaseous vapors
200-300	Preheating of fuel: thermal degradation continues more rapidly
300-325	Ignition temperature in well aerated wildland fuels: transition to flaming
325-400	Flaming phase: rapid increase in decomposition of solid fuel
400-500	Flaming phase: gas production rate peaks around 400 °C and declines between 450 °C and 500 °C as all residual volatile compounds are released.
500-1000	Flaming phase: Maximum flame temperatures within flames may approach 1600 °C in deep flame envelops but temperatures of 500 °C to 1000 °C are more typical.
500-800	Glowing phase: residual carbonaceous fuel (charcoal) burns by glowing combustion. The combustion of charcoal is associated with the liberation of CO and CO_2

Smoldering combustion is often characterized by a complex suite of carbon-rich compounds produced by incomplete combustion including large amounts of hydrocarbon-rich (e.g., tars) smoke (Bertschi and others 2003; Urbanski and others 2009; Yokleson and others 1997). Smoldering fire often occurs when oxygen depletes during flaming combustion. The fire still emits high temperatures but produces no visible flame. Once the entire fuel particle has been heated to around 500 °C (932 °F) the volatile compounds necessary to support flaming (gas-phase) combustion have been exhausted, smoke ceases to rise from the charcoal, and the remaining charcoal burns by **glowing** (solid-phase) combustion. This phase continues until either all the fuel becomes non-combustible ash and the fire goes out, or until the fuel is quenched or cooled leaving charcoal residues. Until the latter cool-down stage of a fire, flaming and smoldering occur simultaneously to some degree as evidenced by the flickering flames of a dying campfire, for example.

Fires vary in their combustion efficiency. Combustion efficiency is the ratio of heat released to the maximum heat that could be released in complete combustion in a well ventilated dry environment (Urbanski and others 2008; Ward 2001). This is a function of the fuel's chemistry, principally its moisture content and the fuel bed packing ratio, which affects the flow of air to the combustion zone. The packing ratio is the proportion of the fuel bed volume that contains fuel particles (fuel volume + air volume = total fuel bed volume). It is a measure of how tightly fuels are packed together, which affects air flow into the fuel bed during combustion. To illustrate the influence of packing ratio, consider the spatial distribution of needles in a conifer tree vs. those same needles compacted in the forest floor duff after a number of years on the ground. The former burns rapidly and efficiently by flaming combustion whereas the latter burns slowly and inefficiently by smoldering combustion. Combustion efficiencies range from as high as 95 percent to as low as 50 percent (Grishin 1997; Pyne and others 1996; Urbanski and others 2009). Flaming, the second phase, which is gaseous combustion, is the most efficient. Products of incomplete combustion include carbon monoxide, nitrous oxides, sulfurous oxides, hydrocarbons, and solids (soot). The darker the smoke, the more unburned carbon particles (soot) are present and the lower the combustion efficiency (Bytnerowicz and others 2008; Urbanski and others 2009). Light colored smoke indicates more complete combustion of fuel elements, lower production of soot and, therefore, higher combustion efficiency. If pyrolysis occurs in the absence of oxygen, such as may occur in buried wood or organic artifacts, destructive distillation occurs at higher temperatures (600 °C (1112 °F)).

Heat Transfer

The three primary mechanisms of heat transfer are radiation, convection, and conduction. All bodies emit radiant energy as a function of their surface temperature. **Radiation** is the flow of electromagnetic energy through space at the speed of light. The radiant energy received at the surface of a body (for example, a fuel element, artifact, or rock art) decreases rapidly with distance from the heat source or flame and increases rapidly as the temperature of the emitting source increases (that is, as fire intensity increases as exhibited by the size or temperature of the flames) (sidebar 2-1) (Butler and others 2004; Pyne and others 1996; Sullivan and others 2003). The emissivity of a flame increases with the depth of flaming zone and approaches unity (i.e., the maximum possible for a black body emitter at around 1 meter (3.28 feet) (Butler 1993; Butler and others 2004). The actual distance depends somewhat on the efficiency of combustion. Beyond this distance deeper flame zone depths do not emit more radiation. Deeper flame zone depths are, however, associated with taller flames that can heat bodies at somewhat greater distances. Larger flames also are associated with greater convective heat transport.

Sidebar 2-1—Impact of Flames on Rock Art

Cultural resources may be directly or indirectly impacted by the passage of a wildland fire. Direct or first order impacts include the effects of heat (fig. S1.1); the deposition of combustion products (e.g., tars, soot and ash); and the exposure of cultural resources to discovery. The latter may lead to increased vandalism. Cultural resources may also be indirectly impacted by fires. Indirect or second order effects include the destruction or redistribution of artifacts due to accelerated erosion of the burned site. Of the direct impacts, the effects of exposure to high heat are the most critical concern. Elevated temperature during wildland fire is the issue of greatest concern. Above ground cultural resources may be bathed in flames where they are exposed to both high convective and radiant heating (fig. S1.2). Resources may be exposed to the smoke and hot gasses above the flames where convective heating is the dominant source of damage. The potential for damage increases with the intensity or energy release rate of the fire as is visually apparent by larger flames. The distance at which damage can occur increases with the size of the flames (fig. S1.3).

Figure S1.1. Spalling of rock art following the 2003 Hammond Fire, Manti LaSal NF, Utah (Johnson 2004). Pictograph damaged by heat from forest fire (photo Clay Johnson, Ashley NF).

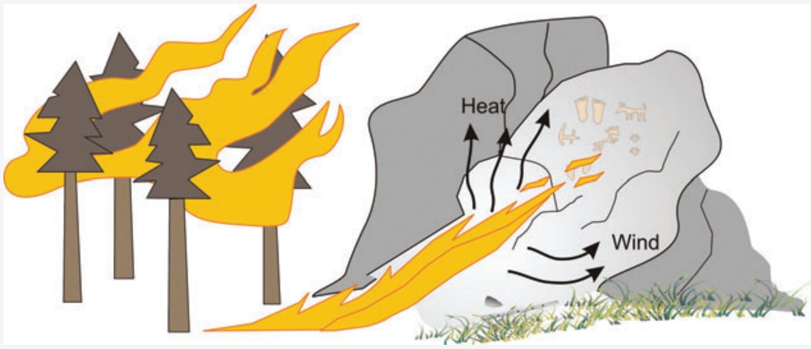

Figure S1.2. Convective and radiant heat from fires are a major source of damage to above ground cultural resources such as rock art.

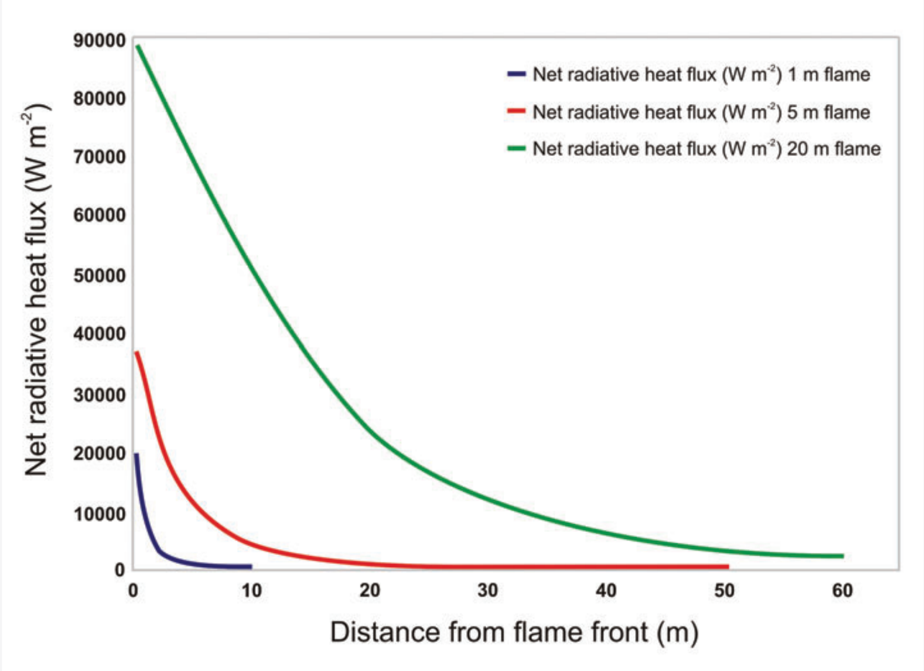

Figure S1.3. Radiant heat flux received by a rock surface or a log cabin wall decreases with distance from the flame envelope and increases with the size of the flame envelope. The more intense the fire, as exhibited by the larger the flame, the greater the distance that damage can occur.

Convection is the transfer of energy within liquids and gases from a heat source (flame) to a cooler area by transport of energy in the form of heated molecules. In contrast to the typical lay use of a fluid as describing a liquid, gasses behave as fluids in a physics and engineering context, that is gasses flow from places of high temperature towards places of lower temperature. Convective heat transport is a result of the fluid motion of gases and particulates (Cheney and Sullivan 2008; Cochrane and Ryan 2009; DeBano and others 1998; Pyne and others 1996; Van Wagtendonk 2006). Flame and billowing smoke above a wildland fire are the most visible examples of convective heat transport.

Radiation and convection can only heat the surface of an opaque substance (for example, fuels or artifacts). The heating of the interior of the substance occurs through conduction. **Conduction** is the transfer of energy through a substance by the direct imparting of heat from molecule to molecule without appreciable movement of molecules within the substance, which is extremely important for heat transfer within solids such as fuel particles. Likewise, conduction is critical for transferring heat to artifacts buried in the soil profile. The rate of heat movement within objects depends on the temperature gradient across the object and its thermal conductivity. Metals generally are great conductors but wood, forest litter, and air are poor.

Spatial and temporal variation in fire behavior, variations in the exposure of cultural materials, and the thermal properties of those materials all interact to influence how fire affects cultural resources. From a small fire that could be considered a point source, radiation decreases with the square of the distance. However, in wildland fires where flame fronts approximate two-dimensions (for example a line of surface fire burning through a fuel bed) or three-dimensions (for example a wall of flames from a crown fire) radiation decreases much more slowly with distance (sidebar 2-1). This helps explain, however, why two surfaces or surface artifacts in close proximity might experience different degrees of damage. If two nearby artifacts "see" significantly different flame emissivities owing to their particular viewing of the fire, they will be differentially affected. Most substances found in nature as well as most human-made materials consist of mixtures of compounds each with their own thermal properties. Differences in thermal conductivity and thermal expansion of various compounds within a material lead to variable heat transfer rates and internal stresses. These forces can cause structural failure such as exfoliation or spalling of rock (lithic) materials, fracturing of ceramic artifacts, and shattering of glass. Because soils are porous, multiple heat transfer mechanisms occur simultaneously in soils, but conduction dominates, particularly after moisture has been driven off at around 100 °C (212 °F) (Albini and others 1996; Campbell and others 1994, 1995; Massman and others 2010).

Under suitably severe conditions, fire may spread beyond a fire's perimeter by spotting, the lofting and transporting of burning embers or sparks through the convection column and wind thereby initiating new fires up to 1 km (0.6 mi.) or more (Albini 1981b, 1983). This fourth mechanism, a special case of convective heat transfer, is referred to as mass transport and is of particular concern to the protection of organic cultural resources—for example, cabins—at some distance from a fire (see chapter 9).

The practical significance of heat transfer mechanisms to cultural resources will be discussed in subsequent sections.

Fire Behavior Principles

Fires in wildland fuels are predominantly free burning, that is they expand or propagate by successive ignition of fuel elements along their perimeter. Figure 2-2 illustrates combustion zones and flame characteristics commonly found in the fire science literature. Prior to ignition, fuels must be raised to ignition temperature. Fuels ahead of the spreading fire are preheated by radiation and convection (fig. 2-2a). The radiative power of the flame approaches unity, the theoretical maximum, as the depth of the flame zone approaches 1 m (3.28 feet) as illustrated by yellow in the flame. Radiation from deeper flames, as illustrated in red, no longer contributes to preheating of fuels ahead of the fire. Energy from larger flames does contribute to increased turbulence and convective heat transport thereby increasing the likelihood and effectiveness of flame contact with unburned fuels ahead of the fire as well as the lofting of embers. Flames typically pulsate with the local wind and the flame tilt angle varies, periodically bathing fuels ahead of the fire in flames. Thus both radiation and convection are important for preheating and igniting fuels ahead of the fire. Flame zone temperatures are variable depending on the rate of spread and type of fuel burned but are typically in the 325 °C to 800 °C (617 °F to 1472 °F) range. The deeper the flame zone, the higher the temperature. Where the human eye sees the visible flame tip depends somewhat on local lighting conditions. Flame tip temperatures are in the 500 °C to 600 °C (932 °F to 1112 °F) range. Flame length is the best visual indicator of the fire's energy release rate (fig. 2-2b). The depth of burn is illustrated by the reduced thickness in the fuel bed plane with the passage of the fire (fig. 2-2a,b). Flames at the head of an advancing fire lean into unburnt fuel preheating it. Fireline intensity, as manifested in the length of flames as well as the flame zone depth (fig. 2-2), is at its maximum at this location on the perimeter (Cheney and Sullivan 2008) (fig. 2-3).

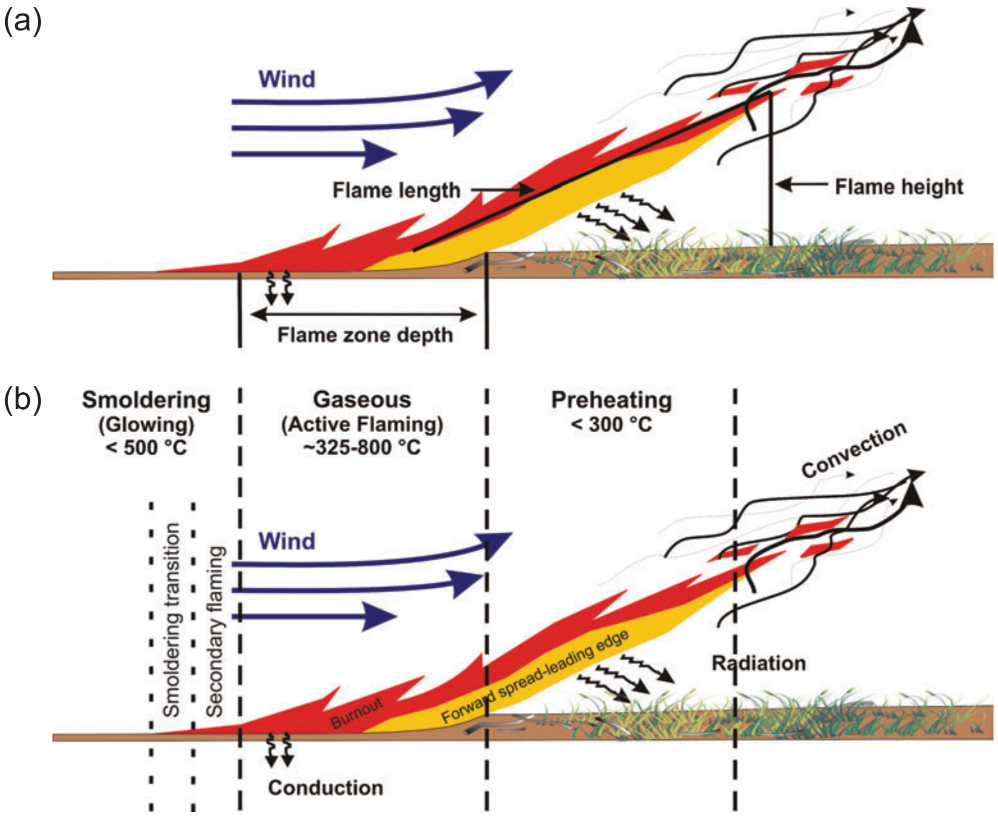

Figure 2-2—Stylized flame zone characteristics (a), combustion phases, and dominant heat transfer mechanism (b) (adapted from Rothermel 1972; Pyne and others 1996; Cochrane and Ryan 2009).

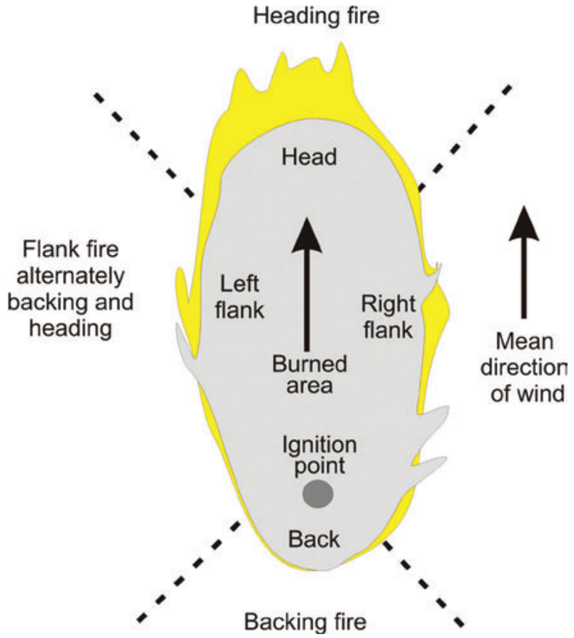

Figure 2-3—The parts of a moving fire (from Cheney and Sullivan 2008).

Here heat transfer by radiation and convection are also at their maximum. Likewise, the potential for lofting burning embers and downwind spotting is maximized at the head of a fire's perimeter (fig. 2-3). At the rear of the fire, where the fire is backing either into the wind or down-slope, flame length is at its minimum and flames typically lean over the burned fuel, reinforcing the smoldering phase. The flame zone depth is also at its minimum but, particularly in fine surface fuels, the slower advance of the fire (termed spread rate) is also associated with more complete burnout and greater duration of surface heating (Cheney 1981; Cheney and Sullivan 2008). On the flank, the fireline intensity and flame length are intermediate. Flames may lean either over the unburned fuel or the burned fuel depending on local variations of in-drafts or wind. The effect can often be seen in char marks on tree trunks or physical structures, which indicate the direction of wind at that point in time when a fire passed. It is common to find char marks that indicate local winds at right angles to the prevailing spread direction. Fires often pulsate, surging forward at several areas along the fire's perimeter, and fireline intensity increases where adjacent flanks of the fire converge. Thus, there can be considerable variation in fire behavior and effects even within relatively homogeneous fuels (Catchpole and others 1982, 1992; Cheney and Sullivan 2008; Finney 1998, 1999; Ryan 2002). Fire intensity, flame size, and temperatures within a fire generally vary within a fire's perimeter. Head fires are more intense overall but backfires can be more effective at heating the ground surface (Fahnestock and Hare 1964; Hare 1961; Lindenmuth and Byram 1948; Martin and Davis 1960; Stinson and Wright 1969; Trollope 1978). For example, in light surface fuels Lindenmuth and Byram (1948) found head-fires were hotter at heights above 0.5 meters (~18 inches) whereas backing-fires were hotter below 0.5 meters (~18 inches).

There are numerous decision support tools that enable managers to predict and manage fire behavior and effects whether in planning fuels treatment or restoration projects or suppressing and rehabilitating wildland fires. The succeeding sections provide cultural resource specialists with additional knowledge and background necessary to work effectively with fire managers in order to predict and manage fire effects on cultural resources. Principles and models commonly used by fire managers in the United States and Canada are described.

The Many Scales of Fire

The characteristics of fire vary within individual fires as fuel and environmental conditions vary in time and space (fig. 2-1). Fire concepts change across spatial and temporal scales. At the finest scale, individual fuel beds ignite, burn, and transfer energy to their surroundings at the combustion scale. This is the scale of the fire triangle familiar to all fire fighters. At this scale, heat, oxygen, and fuel are the important elements. At this microsite scale, combustion events range on the order of several seconds for the passage of a flaming front to a few days in the case of smoldering peat fires. Their effects are monitored at the small sample plot or quadrat scale. The next higher scale is the scale of the fire environment. The fire environment is the summation of all the combustion environments within an individual fire. At this scale, fire behavior monitoring and modeling are used to evaluate fire as fuels, heat, and oxygen vary with terrain and weather within individual fires. Temporal variations of individual fires range from hours to days as fires spread across landscape-scale land areas. Their effects are assessed by stand and community-level surveys. At the next higher spatial and temporal scale, fire regime concepts describe the modal fire type that occurs at stand/community, landscape, and biome levels across decadal to century-long time-scales. At these scales, broad class descriptors of impacts on major processes are inferred from dendroecological and paleoecological techniques. At the fire regime scale, fire characteristics vary between successive fires on the same site as the time since, and severity of, the last disturbance varies. Site productivity, disturbance history, periodic weather anomalies (such as drought), and variations in climate cycles all contribute to fire's variability in time and space (Clark 1989; Clark and Royall 1995; Kitzberger and others 2007; Morgan and others 2001; Power and others 2008; Swetnam and Betancourt 1990).

Fire affects societies and natural biophysical processes in numerous ways. As such, it has attracted scientists from fields ranging from combustion science to ecology, hydrology, geosciences, anthropology, and archaeology. At the combustion science scale, the physics and chemistry of fuels and heat transfer mechanisms predominate in the study of small scale fire phenomenon on the order of seconds to minutes. This is the fundamental scale at which fires burn. It is at this scale that investigators study stationary fires and their impacts on organisms and individual cultural resources. At the fire behavior scale, the spatial and temporal variability in fuels, weather, and terrain dominate in the evaluation of fire potential within and between stands and across landscapes on the order of hours to weeks. This is the scale at which actively spreading individual fires are studied and their effects understood on multiple processes (for example plant community dynamics, erosion, or hydrologic effects). This is also the scale at which most fire management projects occur. At the even higher scale of land management planning, managers are concerned with broad-brush differences in fuels and fire potential for large planning areas on the order of multiple seasons to centuries. At these spatial and temporal scales, scientists synthesize patterns of fire occurrence to better understand the relationship of fire to numerous ecosystem properties that occur on the order of years to centuries. This scale of wildland fire science is the fire regime scale (fig. 2-1). Above the fire regime scale is the paleo-fire scale. Understanding fire at this longer scale is important for understanding climate-vegetation-human interactions (Boyd and others 2005; Pausas and Keeley 2009; Power and others 2008). There is some interaction between scales. Insights from one scale inform our understanding of fire phenomenon at the next higher scale. For example, conceptually, fuel particles aggregate up to make fuel beds and fuel beds aggregate up to make fuel complexes necessary for predicting behavior of individual fires.

As each discipline has studied fire phenomena, they've focused on their particular disciplinary aspect of fire and each has developed their own concepts, terms, and sets of measures. As one describes fire at finer scales, terms and illustrations are based on precisely measured biophysical parameters that typically require specialized instrumentation (such as, fireline intensity and heat transfer mechanisms). As one describes fire at successively broader temporal and spatial scales, illustrations rely more on broad concepts and general trends and tendencies based on outcomes (for example, fire periodicity and severity) and less on the physics and chemistry of specific fire events (fig. 2-1). The use of similar terms developed by specialists who are focused on one discipline or scale vs. another leads to confusion, which can be particularly difficult for professionals from quite dissimilar disciplines such as cultural resources. It is, however, important to consider the purpose for which an investigation was conducted, or a model constructed, when applying concepts and models to fire and cultural resource problems.

Fire Behavior and Effects: Concepts and Models

Fire Environment

An essential element of wildland fire is the biophysical fire environment, which is composed of three factors: weather, terrain, and fuels. Each of these varies in both time and space (fig. 2-1). **Weather** is the state of the atmosphere surrounding the earth. The primary weather factors affecting wildland fire are temperature, wind speed, wind direction, humidity, precipitation, and sky condition (dark vs. cloudy vs. sunny). **Terrain** is the shape of a particular landform on the earth's surface and is often described by slope, aspect, elevation, and drainage properties. **Fuels** are fire's source of energy released in combustion. Fuels are comprised of living and dead biomass from the ground, the surface, and the canopy stratum and come in many shapes, sizes and varieties (fig. 2-4).

Fire managers have long recognized that weather conditions, terrain steepness, and the amount of available fuel have a dominant effect on a fire's energy release characteristics (Albini 1976; Grishin 1997; Pyne and others 1996; Rothermel 1972; Stocks and others 1989; Wotton and others 2009). Of more interest in bioconservation and restoration studies is the understanding that the energy released by fire has the potential to do ecological work, that is, to change a host of ecosystem state variables (Dickinson and Ryan 2010). Thus, quantification of the energetics of fires is desirable in ecological studies (Butler and Dickinson 2010; Johnson 1992; Johnson and Miyanishi 2001; Kremens and others 2010; Massman and others 2010). Likewise the energy released during a fire has the potential to directly impact cultural resources through the thermal effects on artifacts and the cultural landscape. However, fire behavior is highly variable in non-uniform fuels, instrumentation is costly, and it is often impractical to sample fire behavior except on small experimental plots, making it difficult to quantify the magnitude of fire treatments in ecological studies or restoration projects.

Weather—Weather generally refers to the day-to-day temperature, relative humidity, wind, cloudiness, and precipitation activity. Meteorology is the interdisciplinary scientific study of the atmosphere. It focuses on weather processes and forecasting. In contrast, climatology is the study of climate, which is scientifically defined as weather conditions averaged over a period of time. By convention the climate of an area is as the average weather for the preceding 30 years, but also includes data on extreme events. Climatology is an important consideration in the study of fire regimes (fig. 2-1). As the fire environment is concerned with the behavior of an individual fire on a specific site, fire weather is the meteorological process of concern for predicting and understanding fire behavior and effects.

Weather is a set of all atmospheric phenomena occurring at a given time. Weather phenomena occur in the lower atmosphere, the troposphere, an air layer varying from roughly 7 km (4.3 mi) thick in Polar Regions to 20 km (12 mi) thick in the tropics. The troposphere contains approximately 75 percent of the atmosphere's mass and 99 percent of its water vapor and aerosols. Weather patterns result from differences in atmospheric density caused by differences in temperature and moisture content of the atmosphere in one region of the globe versus another. Short term weather, hours to days, is most critical for determining the fire environment. However, longer term weather, seasonal patterns, and periodic wet or dry cycles (e.g., drought) have major effects on the moisture content

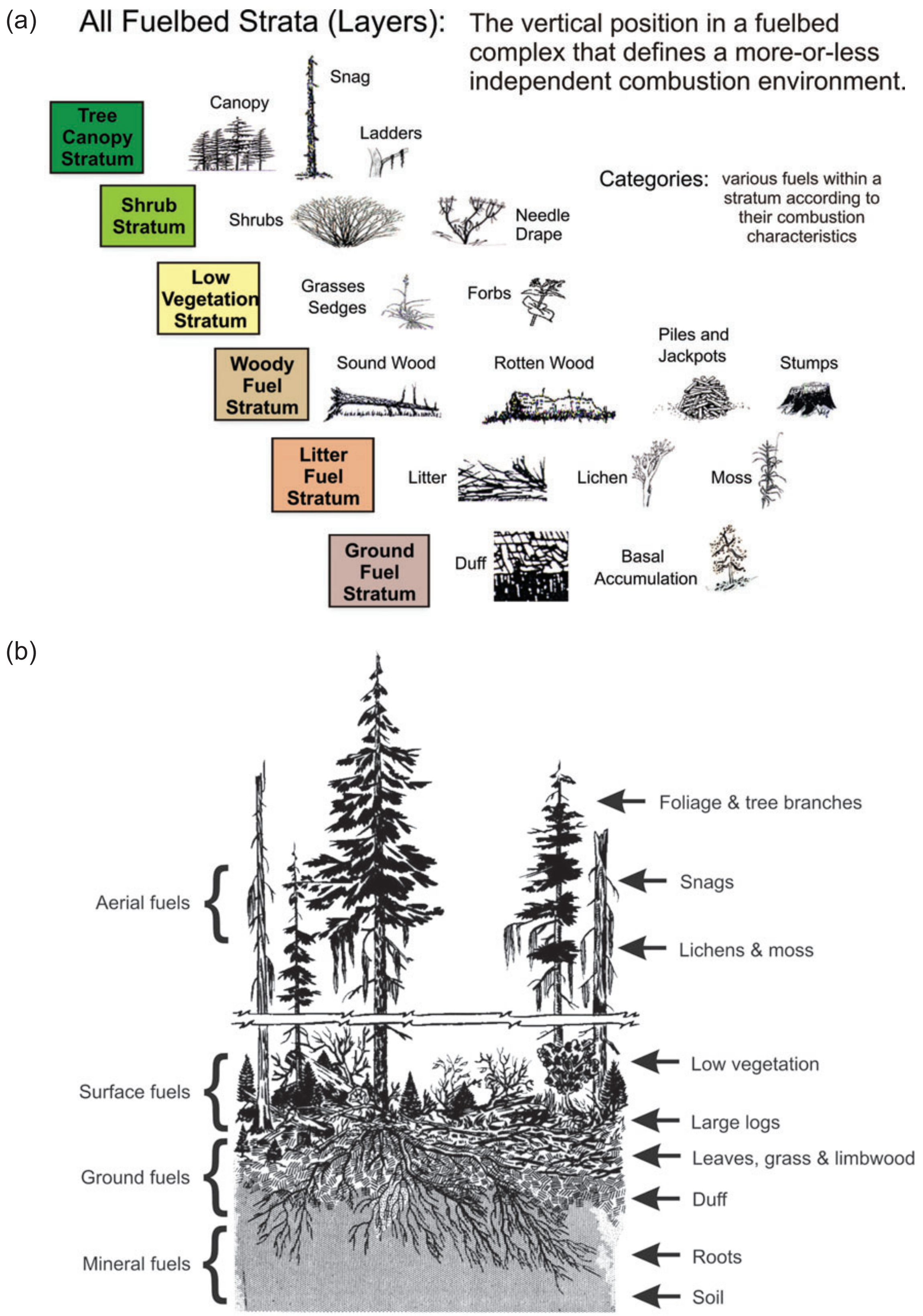

Figure 2-4—Fuel elements by stratum (a) (from Sandberg and others 2001) aggregate to make a fuel bed (b) (from Barrows 1951).

of large logs and duff (Deeming and others 1977; Van Wagner 1987) as well as live fuel moisture. These fuel moistures also affect the amount of available fuel and, therefore, the fire environment. Those readers interested in more details about fire weather are referred to the classic Fire Weather Handbook (Schroeder and Buck 1970) or subsequent fire science texts (see for example Chandler and others 1983a,b; Flannigan and Wotton 2001; Gill and others 1981; Lawson and Armitage 2008; Minnich 2006; Omi 2005; Pyne and others 1996).

Weather—specifically temperature, relative humidity, wind, and drought—defines the fraction of the total fuel that is available to be consumed in a given fire. The short-term weather history is the primary determinant of the flammability of the moss and lichen layers, loose litter, foliage, and fine twigs (Albini 1976; Stocks and others 1989; Wotton and others 2009). The moisture content of fine fuels is reflected in the U.S. National Fire Danger Rating System (NFDRS) 1- and 10-hour time-lag fuel moistures (Deeming and others 1977) and the Canadian Forest Fire Danger Rating System (CFFDRS) fine fuel moisture content (FFMC) (Stocks and others 1989; Van Wagner 1998; Wotton and others 2009). Long-term weather determines the moisture content and combustibility of deeper organic layers and dead logs. The moisture content of these fuels is reflected by the NFDRS 1,000-hour time-lag fuel moisture (Deeming and others 1977), Canadian Duff Moisture Code and Drought Code (Hirsch 1996; Stocks and others 1989; Van Wagner 1987, 1998; Wotton and others 2009), Keetch-Byram Drought Index (Burgan 1988, 1993; Fujioka and others 2008), or Palmer Drought Index. Wind is perhaps the single most important cause of spatial and temporal variation within boreal forests. Fires often pulsate between intense surface fires and crown fires with only modest changes in wind speed (Finney 1998; Scott 1998; Scott and Reinhardt 2001; Van Wagner 1977, 1993). The result is a mosaic of small crown fire patches instead of the large expanses that occur in sustained wind-driven fires.

Terrain—Terrain refers to the general relief or topography of an area. Terrain is the most constant factor in the fire environment. It strongly influences fuels and weather. The earth has been shaped through millennia by wind, water, and tectonic forces creating mountains, valleys, plains, and canyons. The resulting landforms affect the amount of solar radiation incident on a site, precipitation patterns, wind flow patterns, and evaporation, all of which affect the frequency duration of flammable periods and a site's ability to grow biomass. Slope steepness and aspect are important terrain features affecting the fire environment. Slope is measured as the increase or decrease in elevation over a fixed horizontal distance and is usually expressed as a percent. In the field, slope is typically measured over a distance of 30 meters (98 feet) or calculated from contour lines on a map. The steepness of a slope influences fire behavior through convective preheating fuels thereby increasing a fire's intensity and rate of spread. Because heat rises, fuels on steeper slopes above fires dry quickly and ignite faster than fuels on relatively flat slopes. The direction a slope is facing is called the aspect. Aspect is most commonly expressed as one of the four cardinal directions and their bisectors (e.g., N, NE, E, SE, etc.) and occasionally as the compass azimuth in degrees. The shape of the terrain influences wind speed and direction as solar radiation differentially heats the ground on varying aspects throughout the diurnal cycle. In addition to slope and aspect, elevation affects both the temperature and humidity of the air and, therefore, vegetation/fuels and fire potential. Slope also interacts with subsurface geology resulting in moist microsites (e.g., seeps and springs) that affect vegetation/fuels and fire potential. Gravity, through its influence on erosion and ground water, affects hill-slope hydrology (Neary and others 2005; Potts and others 1986; Swanson and others 1988; Wohlgemuth and others 2006) leading to spatial differences in soil water content. These microsite differences also directly affect surface and ground fuel moisture contents (Hatton and others 1988; Samran and others 1995).

The influence of terrain and landform on surface energy and water budgets follows physical laws and is, therefore, well known (Kunkle 2001; Schroeder and Buck 1970). However, due to the sparse coverage of weather stations, a lack of good spatial data on weather often leads to considerable uncertainty in predicted fire weather. This is particularly true for winds (Butler and others 2006). For fuels treatment and restoration planning, reasonably robust models are available for extrapolating weather and fuel moisture from weather stations to the fire environment (e.g., FireFamilyPlus http://www.firemodels.org/index.php/national-systems/firefamilyplus).

Fuels—Fuel is the burnable organic biomass on a site. Fuel is the source of energy that does the work of change, whether it is a change in the state of various ecosystem components or damage to a cultural resource. The most important aspect of fuels is to understand that fuels can ignite and burn only when a certain combination of conditions is met. These conditions are described in this section. Fire influences fuels in three ways. First, fire consumes fuel. Second, it creates fuel by killing vegetation. Third, it indirectly affects fuels by altering the site, thereby influencing post-fire vegetation dynamics, the resultant fuel complex, and the potential for future fires (Ryan 2002).

Wildland fuels are all chemically similar. Vegetative biomass fuels are of a class of chemicals called polymers consisting of cellulose (41-53%), hemicellulose (15-20%), and lignin (16-33%), with lesser amounts of secondary plant metabolites (for example fats, oils, waxes, resin), and minerals (calcium, potassium, magnesium, silica) (DeBano and others 1998; Grishin 1997; Pyne and others 1996; Ward 2001). Wildland fuels are described by their physical and chemical properties when modeling fire danger or potential fire behavior in the United States (Albini 1976; Andrews 2005; Deeming and others 1977; Rothermel 1972), but in Canada they are described by a vegetation-based physiognomic nomenclature (for example, dominant species composition and stand structure) (Hirsch 1996; Stocks and others 1989; Wotton and others 2009). Likewise, field ecology studies primarily rely on vegetative physiognomic characteristics to characterize fuels and fire potential.

At the finest scale, fuels are characterized by their physical and chemical properties as they affect combustion. More specifically, fuels are described by their particle size and chemical composition (for example, heat and moisture contents). For modeling purposes in the United States and elsewhere where the Rothermel (1972) model and its variants are used, the commonly recognized particle sizes are broken down based on the time-lag equilibrium moisture concept (Schroeder and Buck 1970) (table 2-2). Biomass fuels are hygroscopic, meaning that they absorb or lose moisture in response to changes in atmospheric moisture, which is generally defined in terms of the relative humidity (Deeming and others 1977; Nelson 2001; Schroeder and Buck 1970). As humidity rises or falls, so does fuel moisture. One time-lag is the time it takes for a fuel element to change approximately 63 percent from its initial moisture content to its new equilibrium following an atmospheric humidity change. The concept of equilibrium moisture content is valid for dead fuels over the range of about 2 percent up to the fiber saturation point of 30 to 35 percent, depending on the species characteristics and the degree of rottenness. Above this point, free water begins to form in intra- and inter-cellular spaces of the fuel. It takes approximately five time-lags for a fuel particle to come into equilibrium with the atmosphere. The atmosphere is not often stable for five time-lags so fuel moisture is almost constantly changing. Relative humidity changes throughout the day as the temperature rises and falls through its diurnal cycle. Relative humidity also changes when weather fronts bring in a new air mass to a site of interest. However, the time-lag concept is useful not only because it describes the direction of moisture change (drying or wetting) but also how fast fuels respond to weather changes. It is also related to how fast particles ignite and burn in wildland fires. For fire modeling purposes, the size class is expressed as a function of the surface-area-to-volume ratio (SAV, often represented by the Greek σ in U.S fire modeling literature). Commonly, downed woody debris in the 1-, 10-, and 100-hour time-lag classes (i.e. woody fuels less than 7.6 cm diameter (< 3.0 in.)) are referred to as fine woody debris (FWD) whereas logs greater than 7.6 cm diameter (> 3.0 in.) are referred to as coarse woody debris (CWD) (Sikkink and others 2009). CWD typically includes all logs both sound and rotten. The time-lag concept is a useful one for describing fuel properties but cannot be interpreted rigidly. Fine-fresh needles from conifer and schlerophoulos (i.e., waxy evergreen) broadleaved species have longer time-lag responses than weathered needles and non-schlerophoulous species (e.g., pine needles) (Anderson and others 1978). Lags larger than 20 cm (~8 in.) and rotten logs have longer time-lags than 1,000 hours (Deeming and others 1977).

Table 2-2—Fuel moisture time lag, size class and description (Schroeder and Buck 1970). These size classes are commonly used in fire danger rating (Deeming and others 1978), fire behavior prediction (Rothermel 1972, Albini 1976, Andrews 2008), and fuel consumption calculations (Reinhardt and others 2005, Ottmar and others 2007).

Time lag	Size class, area/volume (range), cm (in)	Common surface m^{-1} (ft^{-1})	Fuel description
1 hour	<0.64 cm (<0.25 in)	630 to 10,800 m^{-1} (192 to 3300 ft^{-1})	lichens, mosses, weathered pine needles, loose leaf litter, grass straw
10 hour	0.64 - <2.54 cm (0.25 - <1.0 in)	157 to 629 m^{-1} (48 to 192 ft^{-1})	fresh pine needles, twigs
100 hour	2.54 - 7.62 cm (1.0 - <3.0 in)	52 to 156 m^{-1} (16 to 48 ft^{-1})	branch wood
1,000 hour	7.62 - 22.86 cm (3.0 - 9.0 in)	17 to 51 m^{-1} (5.3 to 16 ft^{-1})	sound logs

Finely divided (small) fuel particles have high SAVs, wet and dry quickly, and ignite and burn out quickly. The larger the SAV, the faster particles ignite and burn (table 2-2). Anderson (1969) determined that the duration of flaming was a function of particle diameter. Fuel pieces burn at an approximate rate of 3.15 minutes per centimeter of diameter (8 minutes per inch). Similarly, Harmathy (1972, 1976) found that the duration of smoldering was approximately as long as that of flaming. Thus the total duration of fuel burnout, flaming plus smoldering, is around 6.3 minutes per centimeter (15.75 minutes per inch) of fuel diameter consumed (Peterson and Ryan 1986). Thus, for example, if woody fuels up to 3 cm (1.2 in) in diameter were consumed on an area then a rough estimate of the duration of heating would be about 19 minutes. As available fuels in wildland fires burn at a relatively fixed rate, increasing the rate of spread also increases the depth of the flame zone in addition to increasing the length of the flames (fig. 2-2). This translates directly into higher fireline intensity, greater radiative heat flux, and an increased potential for damage to exposed cultural resources (sidebar 2-1).

Fuel particle characteristics vary continuously in space and time. In all but the most homogeneous of fuel-beds (e.g., productive grasslands), the mass and size distribution of fuels varies across an area with varying height as the physiognomy of the vegetation changes. Fuel particles change moisture content as a function of their size, relative humidity, and temperature (Sandberg and others 2001; Schroeder and Buck 1970; Van Wagtendonk 2006) (table 2-3) (fig. 2-4a). That variation is large relative to the spatial and temporal scales over which fires burn in natural communities. Thus, in practice, fuels are not described on the basis of individual fuel particle attributes, rather they are described in aggregate at the next higher scale as an agglomeration of several types of fuel (fig. 2-4b), referred to as a fuel complex or a fuel bed. In the Rothermel model and its variants (Andrews 2005; Deeming and others 1977; Finney 1998; Rothermel 1972; Scott 1998), fuel beds are described in the form of stylized fuel models (Albini 1976; Anderson 1982; Scott and Burgan 2005) that describe the mass per unit area, physical distribution (weighted particle size, fuel bed depth, bulk density), and chemistry (heat, moisture, and mineral content) of the surface fuels. Common U.S. terminology is the "Anderson-13" (Anderson 1982) and the "Scott and Burgan-40" (Scott and Burgan 2005). In contrast, the Canadian Forest Fire Behavior Prediction System (FBP) organizes fuel types into 16 discrete fuel types where the user selects the fuel type that best fits a particular situation. Fuel types in the FBP system are described qualitatively, rather than quantitatively (Forestry Canada 1992; Wotton and others 2009).

Fuel compactness refers to how tightly packed fuel particles are within the fuel bed. Compactness is described as a weight of fuel per unit volume of the fuel bed. It is estimated by measuring depth and loading of fuel by a standard methodology. The most commonly used technique in the United States is the planar intersect (Brown 1974; Brown and others 1982). Increasing density of fuels like grasses, woody debris, shrubs and forbs increases the amount of available fuels. Compactness influences drying rate and heat transfer during a fire. The more compact the fuels, the slower the drying rate. Maximum combustion occurs when particles are close enough together to effectively transmit heat by radiation and convection but far enough apart to not restrict oxygen flow to burning fuels.

It is important to understand that the emphasis for focusing on surface fuels is a reflection of the historic need to predict fire behavior for fire control purposes. Operational fire behavior prediction systems in the United States are based on the semi-empirical Rothermel (1972) mathematical model and in Canada on empirical field data (Stocks and others 1989; Hirsch 1996). These were developed to predict fire potential for strategic and tactical fire planning and management, not for predicting fire effects. One problem with using current fire behavior prediction systems in ecological studies is that they do not predict all of the combustion and, therefore, all of the energy released over the duration of the fire (c.f. Johnson and Miyanishi 2001; Ryan 2002). In particular they are insufficient for understanding below-ground effects. Thus, other fuel bed descriptors are common in the fire science and ecology literature (for example, see Barrows 1951; DeBano and others 1998; Ottmar and others 2007; Pyne and others 1996; Sandberg and others 2001, 2007). These fuel bed components are described on the basis of the physiognomic characteristics (tree, shrub, grass, forb, moss, etc.) (figs. 2-4a,b). Fuels are described typically on the basis of the stratum in which they occur (ground, surface, canopy) (table 2-3), how the type of fuel burns, (the dominant combustion characteristic such as smoldering vs. flaming), and potential duration of burnout during severe fire weather (Ottmar and others 2007; Sandberg and others 2001, 2002).

Conventional nomenclature defines fuels based on whether they are alive or dead, their availability for burning, their physical size, and chemical properties. Conceptually, total biomass is the sum of all plant material on the site and includes both above-ground and below-ground carbon. Historically, little organic mass within the mineral soil burns; therefore, the fire literature typically ignores the below-ground fraction. However, buried soil wood (e.g., rotten roots) may be of concern in some archaeological contexts (see chapter 7). Total aboveground biomass is the site's total dry mass of living and dead plant tissue found above

Table 2.3—Fuel bed strata and categories, and their physiognomic and gradient variables (from Ottmar and others 2007).

Fuelbed strata	Fuelbed categories	Physiognomic variables	Gradient variables
Canopy	Tree	Canopy structure Crown type	Canopy height Height to live crown Percentage cover
	Snag	Snag class	Diameter Height Snags per acre
	Ladder fuels	Vegetation type	Significance
Shrub	Shrub	Foliage type Growth habit Accelerant potential	Percentage cover Height Percentage live vegetation
	Needle drape		Significance
Low vegetation	Grass/sedge	Leaf blade thickness Growth habit	Percentage cover Height Percentage live vegetation
	Forb		Percentage cover Height
Woody fuel	Sound wood	Size class	Loading (tons/acre) Fuelbed depth
	Rotten wood	Size class	Loading (tons/acre)
	Stumps	Decay class	Stems/acre Diameter
	Woody accumulations	Piles, windrows or jackpots Clean or dirty	Height Width Length Number/acre
Moss/lichen/litter	Moss	Moss type	Percentage cover Depth
	Lichen		Percentage cover Depth
	Litter	Litter type Litter arrangement	Percentage cover Depth
Ground Fuel	Duff	Character	Depth Percentage rotten wood
	Basal accumulation	Accumulation type, e.g. litter, bark slough	Depth Trees per acre affected

the mineral soil. Above-ground biomass is further divided based on whether it is alive or dead. Live and dead fuel may be broken down into total and available fuel, as illustrated in the Venn diagram (fig. 2-5). Total fuel is the total amount of biomass capable of burning in a given area under a worst-case scenario. Available fuel is that biomass that actually burns in a specific fire. Total above ground biomass (≥ total fuel ≥ available fuel) is the total of all carbon stored on the site above the mineral soil including such things as living tree boles that are not consumed by surface or crown fires. In figure 2-5, the degree to which the Venn areas represented by the biomass classes are similar or different varies with the biome ranging from a tall grass prairie, where available fuel, total fuel, and above ground biomass are essentially equal under drought conditions, to a rain forest where an initial fire leaves substantial unburned biomass in the stems and canopy. The magnitude of these inequalities varies with the physiognomic structure of the biome and the prevailing moisture and wind at the time of the fire. Differences are small in grasslands and large in long undisturbed forests. The total amount of fuel available on a site depends on the stand structure and plant composition as well as the site's disturbance history (Graham and others 2004; Peterson and others 2005). "Structure" includes the quantity, distribution, and horizontal and vertical arrangement of live and dead trees, understory vegetation, woody debris, litter, and humus (Artsybashev 1983; Brown and Bevins 1986; Johnson 1992; Ryan 2002).

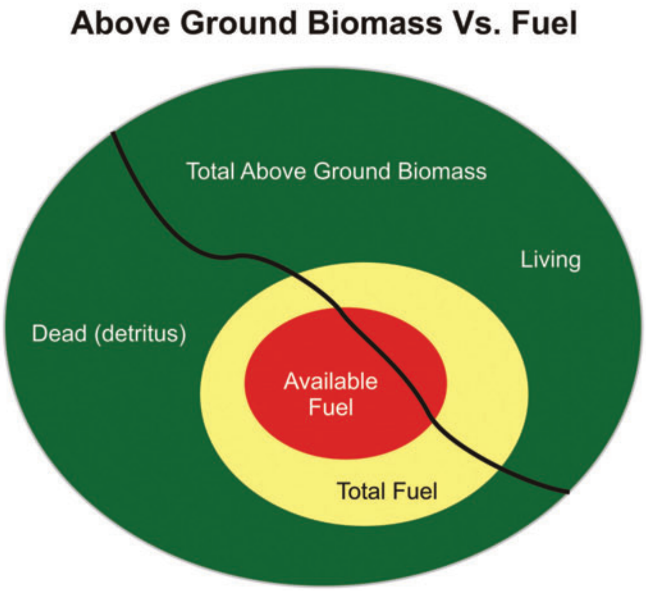

Figure 2-5—Venn diagram schematic representation of classes of biomass and their potential availability for combustion in a wildland fire. The degree to which live vs. dead fuel (black line) dominates a fuel complex varies by the biome, site disturbance history, seasonal phenology, and climatic cycles (e.g., drought vs. wet).

Fuel moisture is the single most important factor determining how much of the total fuel is available for combustion (Albini and others 1995; Nelson 2001). Moisture content is expressed as a percentage of water to the dry weight of fuel.

$$\{[(\text{wet} - \text{dry}) / \text{dry}] \times 100\} = \text{mc}\% \qquad [1]$$

The moisture content of fine fuels is critical because they are the primary carriers of fire. Increasing moisture content reduces the likelihood that an ignition will lead to a propagating fire, and reduces the available fuel fraction. Within the range of moistures where fires can spread, increasing moisture content increases the duration of burning, and possibly leads to more emissive flames due to less efficient burning (Thomas 1970). Once conditions for fire spread are met, the moisture content of longer time-lag fuels becomes important to predicting below-ground fire effects. Wind increases the burning rate and decreases the duration of burnout (Cheney 1981; Miyanishi 2001).

The primary factor distinguishing living fuels versus dead fuels is their moisture content. Dead woody fuels (twigs, branches, logs) rarely exceed 30 to 35 percent moisture, the fiber saturation point on a dry mass basis, but may be as low as 2 or 3 percent during extended dry spells. In contrast, live fuels may have moisture contents approaching 300 percent early in the growing season, and rarely drop below 80 percent prior to senescence. In contrast to woody fuels, dead herbaceous fuels are typically less dense, have more pore space, and are thus capable of holding more free moisture at saturation. However, they are invariably much dryer than when they were alive. Fuels in an advanced state of decomposition, such as rotten logs and organic soil horizons, can hold much more moisture (up to 250 percent moisture content and occasionally higher). Rotten fuels can also ignite and burn at much higher moisture contents, approaching 200 percent under ideal burning conditions. The transition from solid fuel to rotten is a gradual process, often characterized by decay classes (Marcot and others 2004). Often, only a portion of the total above-ground biomass is capable of burning. In forests, for example, solid tree boles are too widely spaced to mutually reinforce each other's combustion. Even in the most destructive fires the trunks and most branches on standing live trees are not consumed. In contrast, in grasslands, virtually all of the above-ground biomass is available fuel under severe burning conditions.

The fire environment concept can be extended from its suppression-derived simplicity to a more ecological construct (fig. 2-6a). Fire behavior varies in time and space with changes in the terrain, weather, and vegetative structure and whether or not the area experiences a head fire, flank fire, or backing fire. As the fire behavior changes so do the effects (fig. 2-6b) (from Ryan 2002).The extension of the fire environment concept to ecological studies requires that fuels be considered in the broader context of the structure of biomass on the site. **Structure** defines the total amount of biomass that can be burned and, therefore, the total energy that can be released from all combustion phases in a fire. The size distribution of the structural components defines the rate at which energy will be released during favorable burning conditions. The rates at which fuels wet, dry (Nelson 2001), and burn (Anderson 1969) are functions of particle surface-area. These rates can be approximated from diameter for most dead fuels above the ground fuel stratum (i.e., above the duff layer) (table 2-2).

Given that the various components of a fuel bed have rather unique burning characteristics, fires burn throughout a continuum of energy release rates and durations depending on the complexity of fuel elements present (appendix) (Artsybashev 1983; Rothermel 1991; Rowe 1983; Van Wagner 1983).

Ground fuel includes organic matter below the loose surface litter including deep duff (fermentation and humus soil horizons), tree roots, decomposing buried logs, duff mounds around tree bases, and rodent middins (fig. 2-4). Peat and organic muck soils are also ground fuels. Because of the lack of aeration, ground

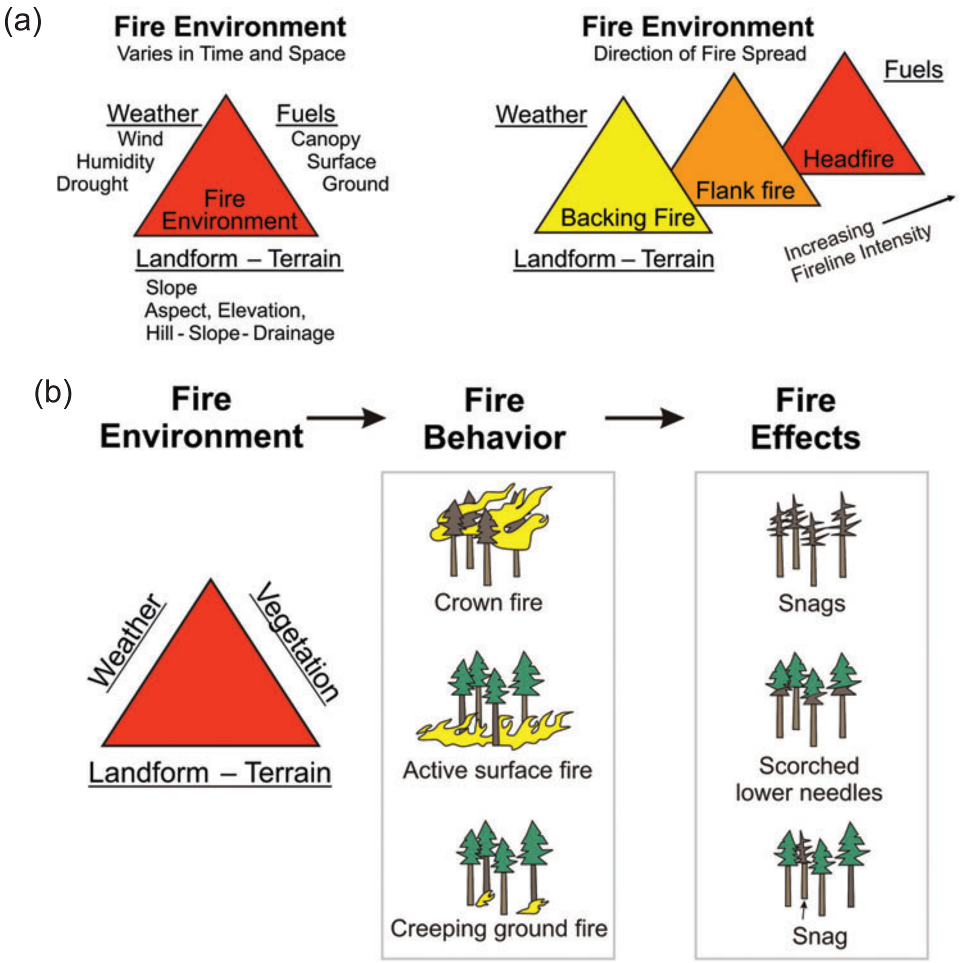

Figure 2-6—Fire environment, behavior, and effects (from Ryan 2002).

fires burn these densely compacted organic soil horizons primarily by smoldering combustion (fig. 2-7). Such fires typically burn for hours to weeks, exhibit forward rates of spread in the range of a few decimeters to a few meters (feet to yards) per day, and exhibit temperatures at a point in excess of 300 °C (572 °F) for several hours (Agee 1993; Frandsen and Ryan 1986; Grishin and others 2009; Hartford and Frandsen 1992; Ryan and Frandsen 1991) (e.g., fig. 2-8). Burning rates and intensities of organic soils vary somewhat with moisture content and availability of air. Frandsen (1991a) found the rate of spread in laboratory analysis of duff fuels to be on the order of 3 cm (1.2 in) per hour. The conditions necessary for ground fires are organic soil depth greater than about 4 to 6 centimeters (1.6 to 2.4 in.) and extended drying (Hawkes 1993; Miyanishi 2001; Miyanishi and Johnson 2002; Palmer 1957; Reinhardt and others 1997). Duff thinner than this can actually buffer mineral soil (Bradstock and Auld 1995; Valette and others 1994) and artifacts from significant heating associated with the passage of the flaming front. This is because the energy lost from the duff surface exceeds that produced by burning duff and the fire self extinguishes after the passage of the flaming front.

The occurrence of ground fires is strongly dependent on the moisture content of the organic horizon (Brown and others 1985; Frandsen 1987, 1997; Grishin and others 2009; Hawkes 1993; Hungerford and others 1995; Lawson and others 1997a,b; Miyanishi 2001; Miyanishi and Johnson 2002; Reardon and others 2007, 2009; Rein 2009; Reinhardt and others 1991; Sandberg 1980; Van Wagner 1972). In particular, peat and organic muck soils fuels, which require extended drought or disruption of ground water flow, reach moisture contents low enough to burn (Grishin and others 2009; Hungerford and others 1995; Reardon and others

Figure 2-7—Smoldering combustion in ground fuels (a) creeping surface fire igniting duff mound beneath old growth western larch, *Larix occidentalis* in the 2005 Girard Grove prescribed burn, Seely Lake Ranger District, Lolo National Forest, Montana; (b) burnout of smoldering duff mound in (a); (c) burnout of organic muck soil on the 1994 Fish Day wildfire, Croatan National Forest, North Carolina; and (d) smoldering duff from squirrel midden in jack pine forest, Northwest Territories, Canada. ,

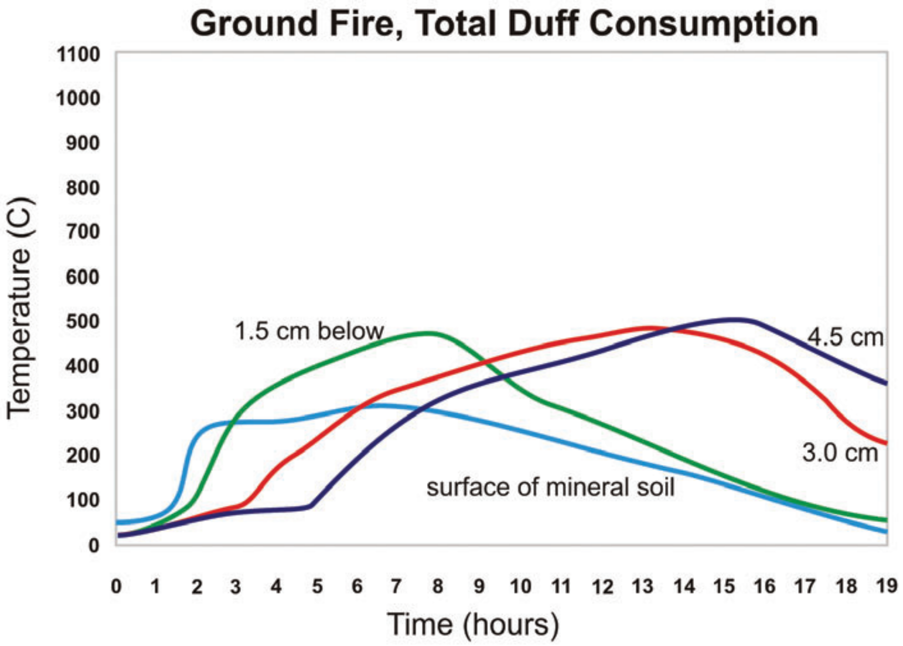

Figure 2-8—Example of temperatures associated with smoldering ground fire in western larch *Larix occidentalis* duff, Lolo National Forest, Montana. Duff depth = 6.5 cm (2.6 in.), moisture content = 18.3% (from Hartford and Frandsen 1992).

2007, 2009; Rein 2009; Rein and others 2008). Ground fuels are good insulators and protect deeper organic strata and the mineral soil from heating during the passage of surface and crown fires (fig. 2-9). However, when ground fuels are dry enough to burn, they are ignited by the passage of the flaming front. Surface fire penetrates the litter and fermentation layer where pine cones, branches, or rotten wood create a localized hot spot. Once ignition is established in the humus or peat soil, the fire propagates laterally evaporating moisture and raising dry organic soil up to combustion temperatures (endothermic phase) where smoldering combustion occurs (exothermic phase.) (Grishin and others 2009; Hungerford and others 1991, 1995; Rein 2009; Rein and others 2008). Ground fuels have a slow burning rate and burn independently from surface and crown fires, so most ground fuels are consumed after the flaming front has passed, often some hours after passage of the flaming front (Artsybashev 1983; Hungerford and others 1995; Rowe 1983; Van Wagner 1983). An exception occurs when surface fires are burning in heavy loadings of coarse woody debris (CWD), which is a legacy from previous disturbances (e.g., logging slash, insect and disease epidemics, or storm damage). Even in such situations, CWD rarely covers more than 10 percent of the surface area of the forest floor, which is small in comparison to that covered by organic soil horizons such as duff (Albini 1976; Albini and Reinhardt 1995, 1997; Peterson and Ryan 1986). Thus burnout of ground fuels is the primary source of deep heating in mineral soils. When duff is too wet to burn, heating from above is negligible except under heavy concentrations of burning CWD.

Surface fuels are those fuels that support surface flaming: recently fallen, partially decomposed loose litter (dead leaves and conifer needles), mosses, lichens, grasses, forbs, low shrubs, arboreal regeneration, fine woody debris (FWD), CWD, and stumps. The surface fuel stratum is defined as those being above the ground fuels (i.e., organic soil horizons) and below the canopy stratum, and is normally <2.0 m, (~6 ft)) (fig. 2-4b). The intensity of a surface fire depends on the mass and type of total fuel and prevailing moisture, wind, and slope conditions on the site (i.e., the fire environment).

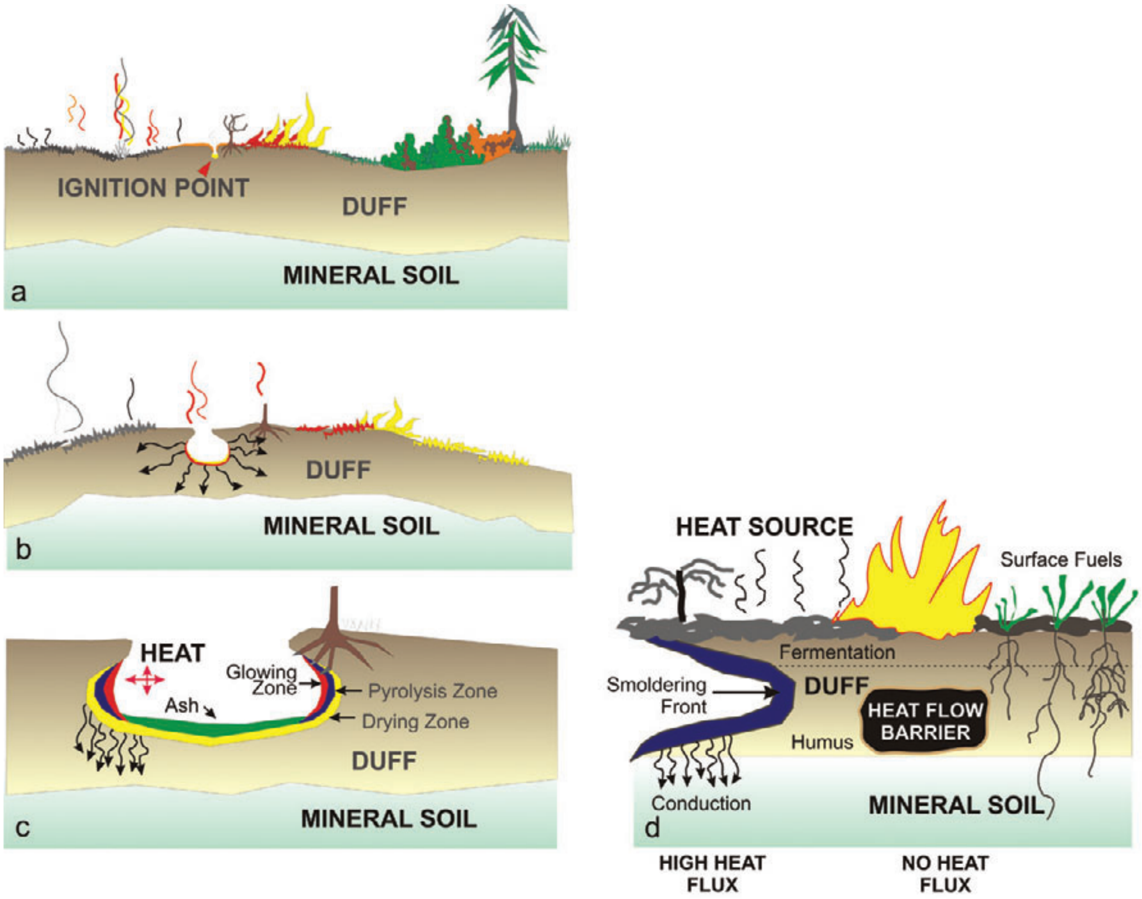

Figure 2-9—Schematic of duff burnout (adapted from Hungerford and others 1991, 1995).

As the vegetative physiognomy of forests, woodlands, shrublands, grasslands, and wetlands vary across the landscape surface, fires are likewise highly variable. Surface fires in light flashy fuels, such as grasslands, have a broad range of intensities often producing surface temperatures in excess of 300 °C (572 °F), but because of the high surface-area-to-volume ratio of grass fuels and the relatively low fuel bed compactness burn durations last only for 1 to 2 minutes (fig. 2-10). Under marginal burning conditions, surface fires creep along the ground at rates of decimeters (~1/3 foot) per hour with flames less than 5 decimeters (<2 feet) (appendix).

As fuel, weather, and terrain conditions become more favorable for burning, surface fires become progressively more active with spread rates ranging from tens of meters to kilometers (yards to miles) per day. The duration of forest surface fires is on the order of 1 to a few minutes (Butler and others 2004; Cruz and others 2006a,b; Despain and others 1996; Frandsen and Ryan 1986; Hartford and Frandsen 1992; Vasander and Lindholm 1985) except where extended residual secondary flaming (fig. 2-2a) occurs beneath logs or in concentrations of CWD where flaming combustion may last a few hours resulting in substantial soil heating

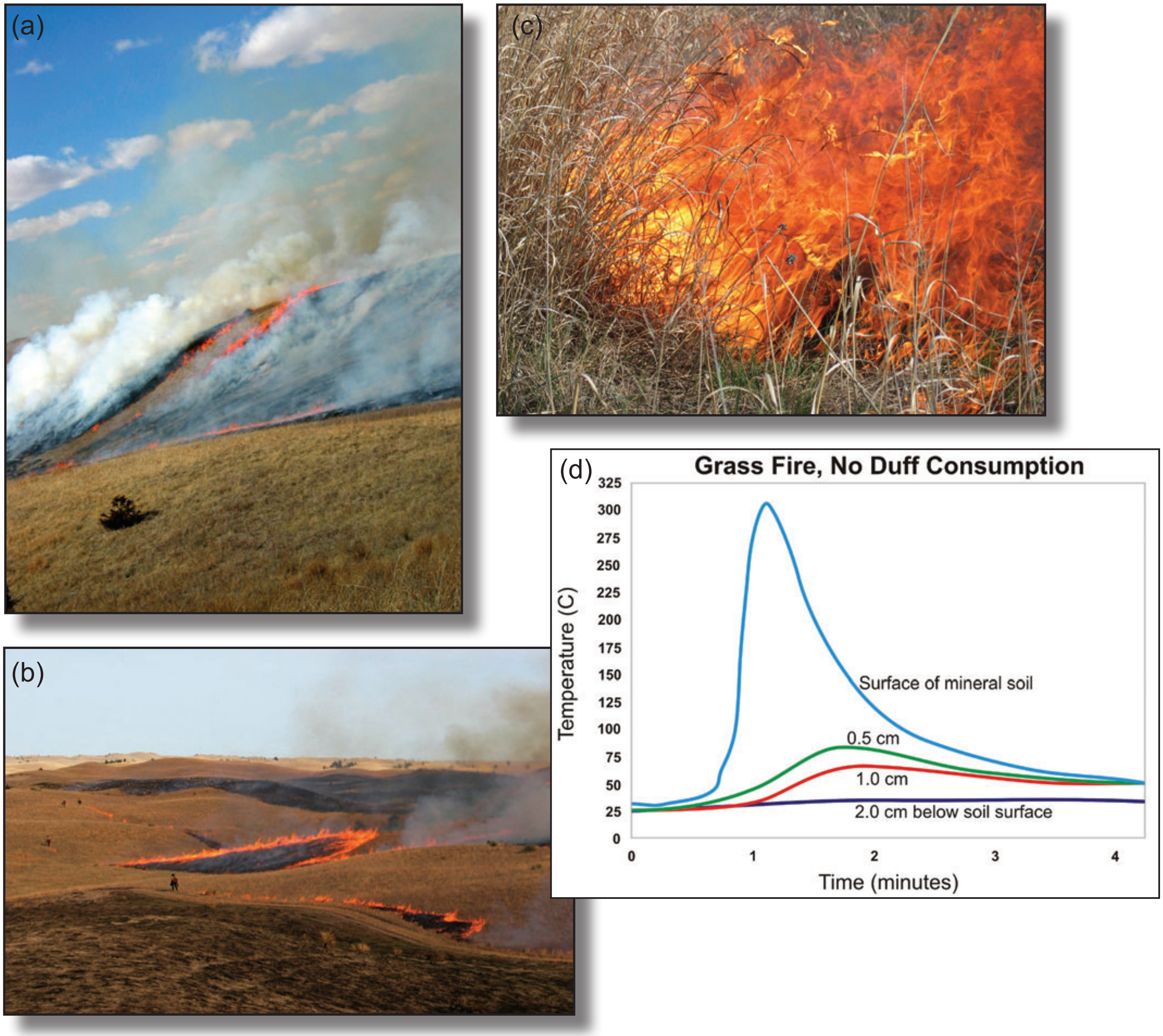

Figure 2-10—Surface fire in grasslands (a) backing fire in short-grass prairie (photo M. Lata); (b) strip head fires in short-grass prairie (note range of flame lengths, fire intensities from the back, flank, and head of the fires) (photo M. Lata); (c) intense head-fire in heavy grass fuels; and (d) temperatures associated with surface fire a in grass fuel bed (from Ryan 2002).

(Hartford and Frandsen 1992; Monsanto and Agee 2008; Odion and Davis 2000; Werts and Jahren 2007). If canopy fuels are plentiful and sufficiently dry, surface fires begin to transition into crown fires (Scott and Reinhardt 2001; Van Wagner 1977). Given that fine surface fuels burnout quickly by flaming combustion, it follows from the fireline intensity equation (eqn. 2, discussed in the Fire Intensity section), that increasing the available fuel loading (mass per unit area) will increase the intensity of the fire as reflected both in the size of the flames and the temperatures experienced at the soil surface (Stinson and Wright 1969; Wright and others 1976) (fig. 2-11). The considerable variation in surface temperatures reported from burning fine surface fuels (see Wright and Bailey 1982, ch. 2 for review) reflects the complexity of free-burning fires where local variations in fuel load and wind result in flames of varying emissivity and, therefore, potential damage to cultural resources.

Aerial or **crown** fuels include live and dead burnable biomass in the forest and woodland canopy stratum above the surface fuels (>2 m, ~ 6 ft.) (fig. 2-4b): branches and foliage of trees and tall shrubs, snags, epiphytes, hanging mosses and lichens (figs. 2-12a,b), (table 2-2). While surface fires are the dominant type of wildland fire, ground and crown fires commonly occur. The prediction of crown fires is an active area of fire research (see Cruz and Alexander, 2010, for recent review). Critical gaps in our understanding include (1) how moisture content affects the fraction of the crown biomass burned during a crown fire, (2) how to define crown volume, (3) how to define the distribution of biomass within that volume, and (4) how to define the continuity between surface fuels and canopy fuels. The height, shape, and density of crowns vary from tree to tree; trees are not uniformly distributed in natural stands. Surface fuels are of an irregular height; likewise the base of the crown (i.e., height of lower branches) varies from tree to tree, thus, the gap between surface and canopy fuels is often difficult to define. The following paragraphs are intended to inform cultural resource specialists about these important concepts.

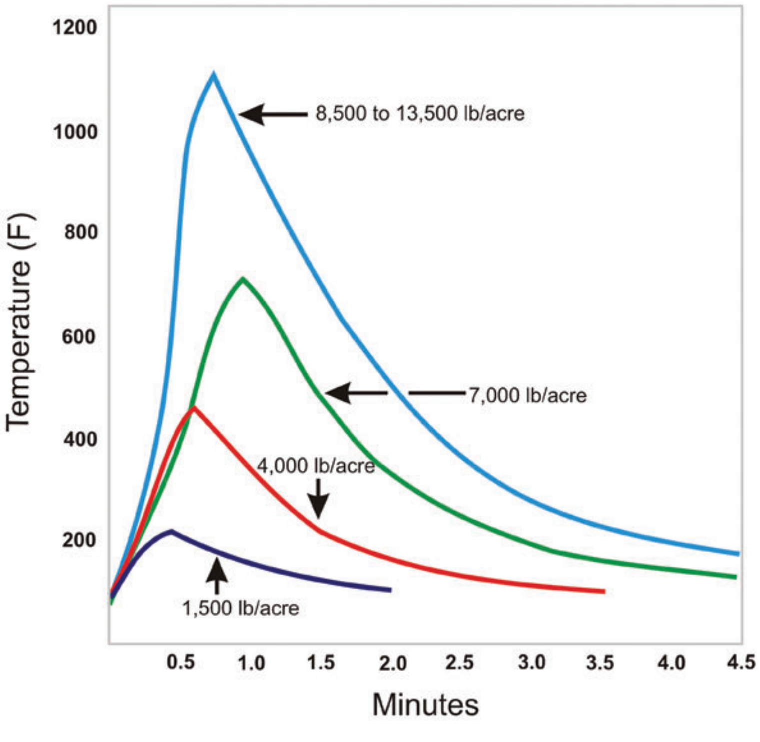

Figure 2-11—Variation in temperature history (maximum temperatures and durations) associated with increasing amounts of available fuel in a Texas grassland. Environmental conditions during the experimental burns were air temperatures, which varied from 21 °C to 27 °C (70 °F to 80 °F); relative humidity, which ranged from 20 to 40 percent; and wind speed, which varied from 13 to 24 km/hr (8 to 15 mph) (From Wright and others 1976).

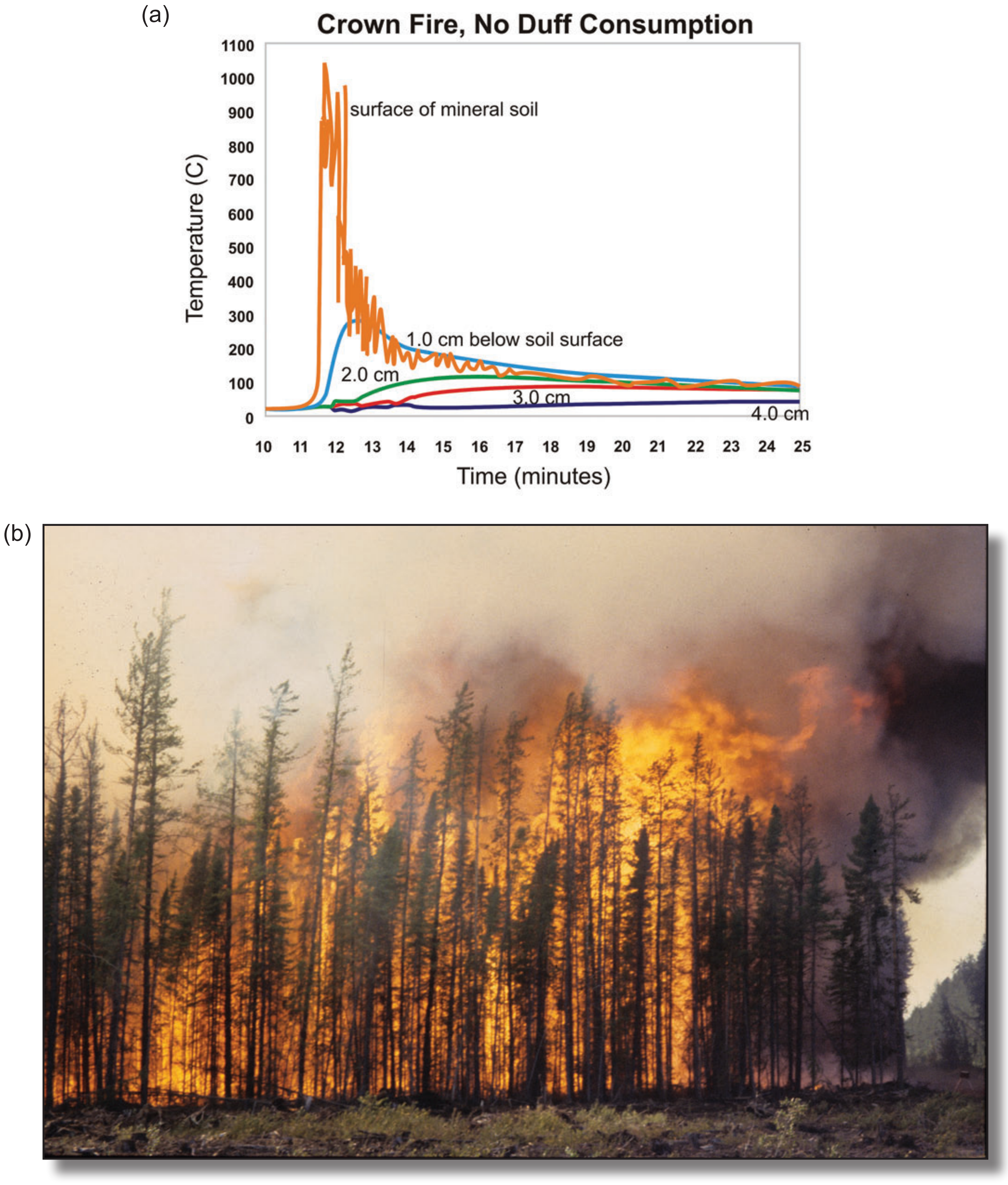

Figure 2-12—Crown fire in coniferous forest (a) example of temperatures associated with a crown fire in jack pine (*Pinus banksiana*) in the Northwest Territories, Canada. Such fires typically produce temperatures in excess of 1000 °C (1832 °F) for about 1 minute (from Ryan 2002); (b) photograph of crown fire associated with (a).

Canopy fuels are predominantly fine fuels and are quickly consumed. Thus crown fires exhibit the maximum energy release rate but are typically of short duration, 30 to 80 seconds (fig. 2-12b). On rare occasions, under specialized conditions, crown fires can occur without the support of a surface fire. Such fires are referred to as **independent crown fires** (Van Wagner 1977). More commonly, crown fires are tightly coupled with the surface fire in a continuous three-dimensional involvement of surface and crown fuels advancing as a unified flaming front referred to as an **active crown fire**. Commonly, individual trees and clumps of trees experience torching in association with the passing of a surface fire. This is referred to as a **passive crown fire** (Van Wagner 1977).

As a fire burns across the landscape, it encounters different communities with varying site productivity and differing disturbance histories that result in varying stand structures and flammability (Graham and others 2004; Peterson and others 2005) (fig. 2-13). For example, stands with a high open crown (canopy) and short understory fuels have poor vertical fuel continuity. Such stands will frequently carry a surface fire due to increased sunlight and wind at the surface (Albini 1976; Kunkel 2001; Stocks and others 1989; Wotton and others 2009) but have a low crown fire potential because of the large gap between surface aerial fuels (Artsybashev 1983; Grishin 1997; Scott 1998; Scott and Reinhardt 2001; Van Wagner 1977, 1993). In contrast, forest stands with a dense understory of shrubs or immature trees have relatively high vertical fuel continuity. Such stands can support intense surface fires leading to crowning and torching of the tree canopy stratum. If the canopy stratum is a patchy over-story, then the stand has poor horizontal fuel continuity in the canopy layer. Such stands readily support passive crowning (torching) and spotting under low relative humidity, especially when surface fuels are in an

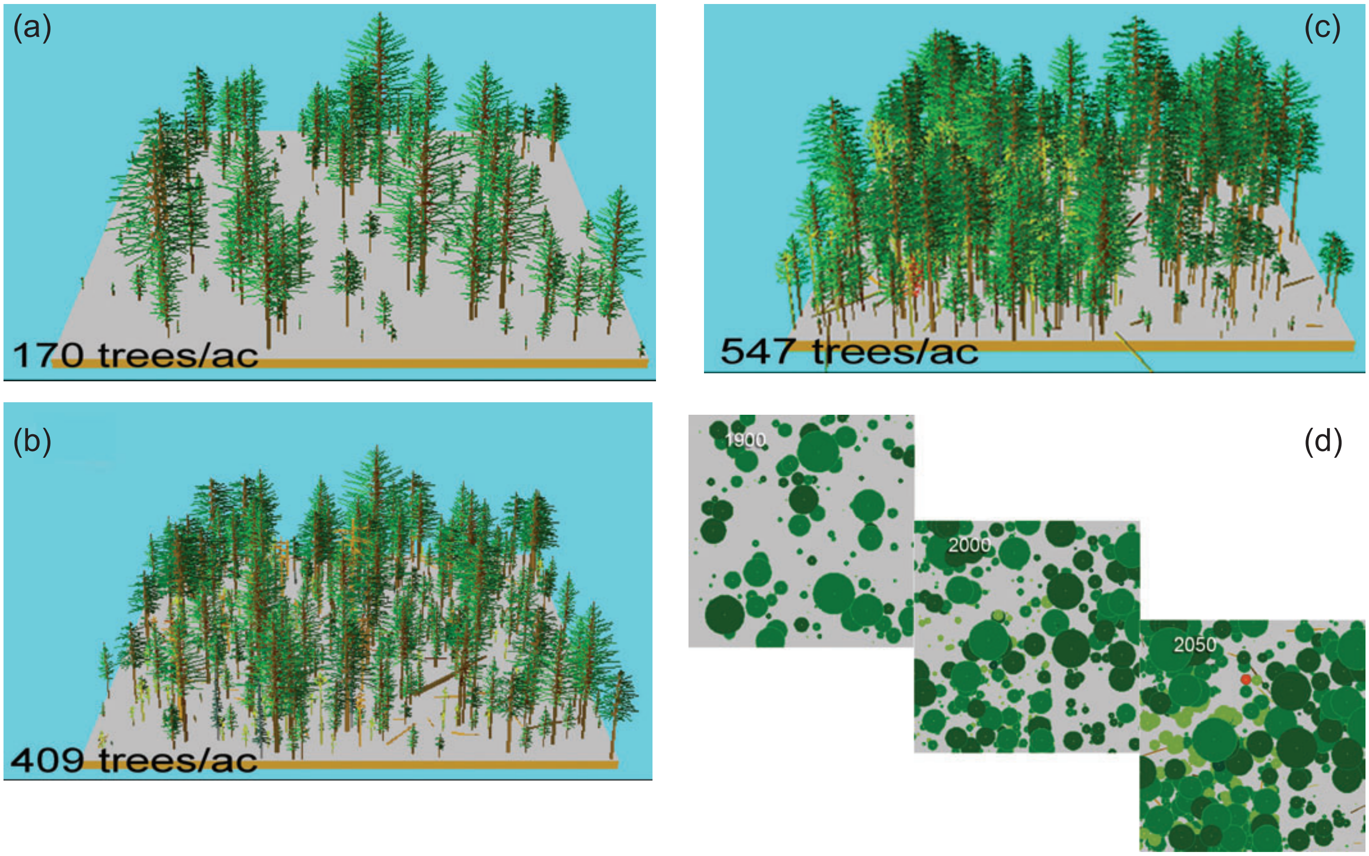

Figure 2-13—Fuel continuity. Increasing stand density on a site as a function of natural succession leading to an increase in horizontal and vertical fuel continuity. Illustrated are 170 trees per acre (420 trees per hectare) in 1900 (a), 409 trees per acre (1010 trees per hectare) in 2000 (b), 547 trees per acre (1351 trees per hectare) in 2050 (c), and horizontal fuel continuity from an overhead view of frames a-c (d). Crown cover is expected to increases to 80 percent by 2050 leading to a significant increase in crown fire potential (from Smith and others 2000). Simulations were done using FFE-FVS (Crookston and others 2000, i.e., prior to the 2002 Hayman Fire) with data from Cheesman Reservoir, Pike National Forest, Colorado.

advanced state of curing. Stands with high vertical and horizontal fuel continuity are less likely to burn because of the typically moister microenvironment, but such stands have the highest crown fire potential when fires burn under drought, low relative humidity, or high wind conditions (Alexander 1998; Cruz and Alexander 2010; Finney 1998, 1999; Scott 1998; Scott and Reinhardt 2001; Van Wagner 1977, 1993). The availability of fuels varies not only in space, but also in time with changes in weather (principally relative humidity, temperature, and drought) (Bessie and Johnson 1995; Flannigan and Wotton 2001; Johnson 1992; Schroeder and Buck 1970). Spatial variation in the fire environment leads to varying fire severities and burn mosaics as fire spreads across the landscape.

Ignition: How Fuel is Ignited Affects Fire Behavior and Effects—Taken collectively, the vegetation structure, weather, and terrain constitute the biophysical fire environment (DeBano and others 1998; Pyne and others 1996) (fig. 2-6a), which describes the potential fire behavior and effects. Actual fire behavior varies with how the specific area is burned. Independent of the biophysical environment in which the fire is burning, major differences in fire behavior are associated with the location on the fire's perimeter, that is, whether an area is burned by a heading, flanking, or backing fire (Catchpole and others 1982, 1992; Cheney and Sullivan 2008; Ryan 2002) (figs. 2-3, 2-6b). The heading portion of the fire burns with the wind or upslope. The backing fire burns into the wind or down slope. The flanking fire burns perpendicular to the wind's or slope's axis. The direction of fire spread is a function of the slope and wind vectors, with the latter dominating except at low wind speeds (Albini 1976; Finney 1998; Rothermel 1972). The intensity of both heading and backing fires are dependent on the strength of the wind and steepness of a slope. Commonly, fireline intensity in a backing fire is on the order of 0.1 to 0.2 times that of a heading fire in a given biophysical environment, while flanking fires are about 0.4 to 0.6 times the head-fire intensity (Catchpole and others 1992). Variations in the fire environment and location on the fire perimeter lead to significant variations in the fire behavior and effects (fig. 2-6b). For example, it is common to see fires spread across a slope running with the wind when the vegetation structure is not sufficient and continuous enough for the fire to carry up the slope. Thus the ignition pattern that is used in a restoration burn can also be expected to affect the pattern of fire behavior and the resulting effects.

In summary, fires burn in varying combinations of ground, surface, and crown depending on the local conditions at the specific time a fire passes a point. Changes in surface and ground fire behavior occur in response to subtle changes in the microenvironment, stand structure, and weather leading to a mosaic of fire treatments at multiple scales in the ground, surface and, canopy strata. Crown fires are of high intensity (energy release rate) and of short duration. Ground fires are of low intensity and long duration. Surface fires are intermediate to crown and ground fires and cover a wide range of intensities and duration depending on the amount of available fuel loading and its particle size distribution. Heavy concentrations of coarse woody debris can result in long duration high intensity heating of the soil. However, such concentrations typically cover only a small proportion of the surface of the ground (Albini 1976; Brown and others 2003; Peterson and Ryan 1986). In most forests, either duff or peat covers a much greater proportion of the surface than FWD and CWD combined. The burnout of these organic soil horizons by smoldering combustion is the primary source of mineral soil heating. During crown and surface fires the majority of heat released by combustion is transferred to the atmosphere and surrounding exposed surfaces by radiation and convection. During ground fires, much of the heat that is released is transferred into the soil by conduction. When crown fires or intense surface fires occur over dry organic soil horizons these layers can continue to burn for several hours after the passage of the flaming front leading to high heat release both above and below ground (fig. 2-14). The practical significance of ground, surface, and canopy fires to cultural resource management will be discussed in subsequent sections.

Fire Intensity, Depth of Burn, and Fire Severity

Fire intensity and fire severity are terms that are often used in fire literature; however, there is considerable confusion about their use (see Keeley 2009 for discussion). Part of the confusion in their use stems from the fact that the terms may be used both informally, as a normal matter of discourse, or they may be used formally as terms defined by the user. Definitions vary somewhat depending on the scale of the fire being investigated.

Fire Intensity

Fire intensity is used by researchers in the United States and Canada to describe the amount of energy released in a given area during the passage of a fire front (Alexander 1982; DeBano and others 1998; Kaufmann and others 2007; Pyne and others 1996; Rothermel and Deeming 1980; Van Wagtendonk 2006; Wotton and others 2009). This measurement relates the length and depth of a fire front to the amount of heat energy being released (Byram 1959) (Equation 2, and fig. 2-6). In turn, these values are used to understand

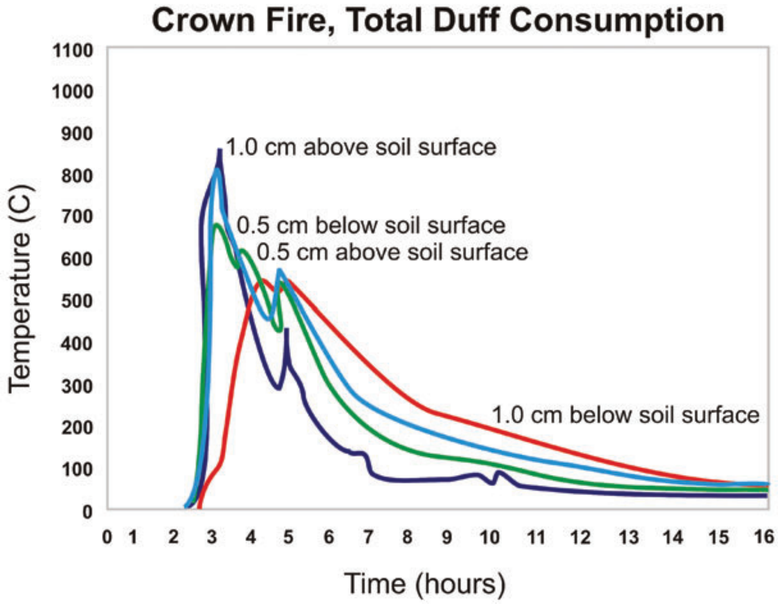

Figure 2-14—Temperatures associated with a high intensity, long duration fire in a whitebark pine (*Pinus albicaulis*) stand, Clearwater National Forest, Idaho. Passive crowning (torching) was followed by sustained flaming in a cluster of logs.

fire potential and level of fire suppression difficulty (Alexander and Lanoville 1989; Andrews and others 2011). Byram's (1959) definition of fireline intensity has become a standard quantifiable measure of intensity (Agee 1993; Alexander 1982; DeBano and others 1998; Johnson 1992; Rothermel and Deeming 1980; Van Wagner 1983; Van Wagtendonk 2006). Fireline intensity is the product of the fuel value (i.e., the fuel's heat content, the mass of fuel consumed, and the rate of spread (m/s)) (Byram 1959). It is a measure of the rate of energy release per unit width of the flaming front of the spreading fire. It does not address the residual secondary flaming behind the front nor subsequent smoldering combustion (fig. 2-2a) (Alexander 1982; Albini and Reinhardt 1995, 1997; Johnson and Miyanishi 2001; Rothermel and Deeming 1980). Fireline intensity can be written as a simple equation:

$$I = HWR \qquad [2]$$

where

I is Byram's (1959) fireline intensity (kW/m/sec or BTU/ft/sec),

H is the heat content of the fuel (kW/kg or BTU/lb or of fuel),

W is the weight of available fuel burned in the active flaming (spreading) fire front (kW/kg of fuel or BTU/lb), and

R is the forward rate of spread (m/sec or ft/sec).

Byram's fireline intensity is usually calculated from empirical observations of the rate of spread (R), weight of fuel consumed (W) and the heat content (H), which is normally taken from typical published approximate values, or it is predicted by fire behavior models (Albini 1976; Alexander 1982; Rothermel 1972; Rothermel and Deeming 1980). The challenge in managing fire is to determine how much, and what type of fuel will burn, and by what type of combustion. In Byram's (1959) equation (eqn. 2), the value of W is the weight of fuel consumed in the active flaming phase of the fire. W approaches the value for available fuel in fires where only fine dead fuels are consumed (such as the grass fire mentioned above) (fig. 2-11), or when coarser fuels are too sparse or wet to be ignited by the passing flame front. When these conditions are not satisfied, a portion of the available fuel is consumed in the secondary flaming and smoldering combustion phase. The burnout of these residual fuels does not contribute to the forward propagation of the fire (R in equation 2), but is often important for predicting fire effects related to soil heating (Busse and others 2005; Hartford and Frandsen 1992; Hungerford and others 1991; Monsanto and Agee 2008; Odion and Davis 2000). Figure 2-15 illustrates the total consumption of 1-, 10-, and 100-hour time-lag fuels as a function of fuel moisture content. In practice, because all combustion phases occur simultaneously (Urbanski and others 2009), it can be difficult to clearly identify which portion of the available fuel is burned in the

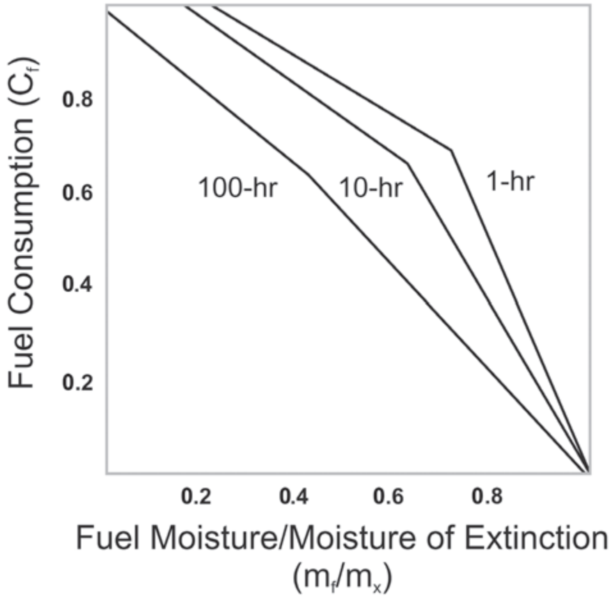

Figure 2-15—Fuel consumption and a function of the fuel's fractional fuel moisture content (M_f) and the fractional moisture content beyond which fuels typically no longer sustain combustion (M_x) except at very high packing ratios. The ratio m_f/m_x for 1-, 10-, and 100-hour fuels is 0.73, 0.51, and 0.38, respectively (from Peterson and Ryan 1985).

active flaming vs. residual secondary flaming and smoldering, but fuel consumption (Albini and Reinhardt 1995, 1997; Albini and others 1995) and smoke production (Bytnerowicz and others 2008; Sandberg and others 2002; Urbanski and others 2009) programs can be used as a guide. Alternatively some field studies measure flame length (Finney and Martin 1992; Deeming 1980; Rothermel and Deeming 1980; Ryan 1981; Simard and others 1989) to estimate fireline intensity (Albini 1981a; Byram 1959; Fernandes and others 2009; Nelson 1980). Flame length (fig. 2-2) is proportional to fireline intensity in a spreading fire and is a useful measure of the potential to cause damage to aboveground structures (Alexander 1982; Ryan and Noste 1985; Van Wagner 1973). Actual field measurement of fireline intensity requires sophisticated instrumentation (Butler and Dickinson 2010; Butler and others 2004; Kremens and others 2010). Thus field observers often calculate fireline intensity from ocular estimates of flame length, simple flame height sensors (Finney and Martin 1992; Ryan 1981; Simard and others 1989), or vegetation damage indicators (Norum 1977; Ryan and Noste 1985) and use known relationships between fireline intensity and flame length (Albini 1981a; Byram 1959; Fernandes and others 2009; Nelson 1980). The appendix contains photographic examples of a range of flame lengths associated with fire intensity classes (table A-1, fig. A-1.1 to A-1.5, appendix) (Ryan 2002).

Rothermel (1972) defined a somewhat different measure of fire intensity, the Reaction Intensity, which is the heat per unit area. This is commonly used in fire danger rating (Deeming and others 1977) and fire behavior prediction (Albini 1976; Andrews 1986; Scott 1998; Scott and Reinhardt 2001) in the United States. In contrast, the Canadian forest fire danger rating system (Stocks and others 1989) and the Canadian Forest Fire Behavior Prediction (FBP) System (Hirsch 1996; Taylor and others 1996; Wotton and others 2009) calculate the intensity of surface fires using Byram's (1959) equation.

Depth of Burn

Although infrequent, fire is capable of burning independent of surface fuels. When it moves through the crown alone (independent crown fire), there is often little surface and subsurface effect because of the short burning duration of canopy fuels. More commonly, crown fires and torching are associated with active or running surface fires (appendix table A-1). If the duff is dry, it is ignited by the passage of a surface fire. Then, duff greater than about 4 cm deep (1.6 in) can burn independently without continued flaming in surface fuels (Frandsen 1997; Lawson and others 1997a; Urbanski and others 2009) (fig. 2-16). During

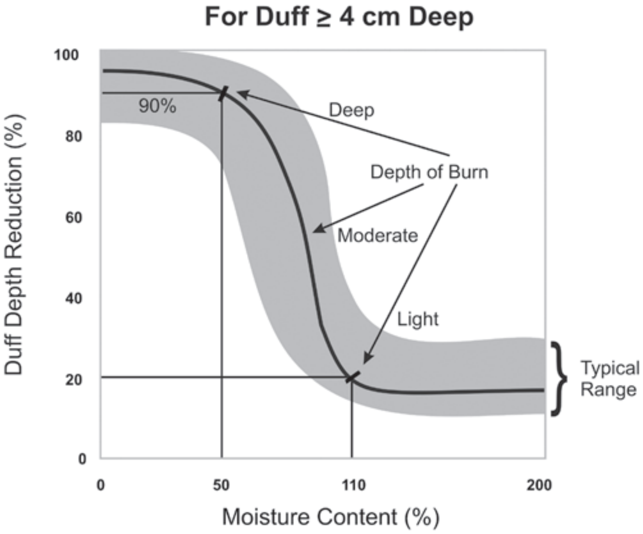

Figure 2-16—Illustration of duff consumption, percent of total duff available (%), as a function of lower duff (humus) moisture content for common forest conditions where duff is greater than 4 centimeters deep and able to burn independent of a surface fire if dry enough to burn. Shaded area represents the range of consumptions found in the literature. Deeper layers and those with less mineral content tend toward greater consumption for given moisture content.

glowing and smoldering combustion of surface and ground fuels, residence time is prolonged. The duration of smoldering can range from as little as 2 hours to more than 30 hours in deep organic soil horizons (Grishin and others 2009; Hungerford and others 1995; Reardon and others 2007, 2009; Rein and others 2008) (fig. 2-8). Given longer durations, heat may penetrate deeply into the soil profile. The term commonly used to describe the degree to which surface and ground fuels are consumed is "depth of burn."

Ryan and Noste (1985) summarized literature on depth of burn and charring of plant materials and developed descriptive characteristics. Their original descriptions were revised to reflect subsequent work (DeBano and others 1998; Feller 1998; Moreno and Oechel 1989; Pérez and Moreno 1998; Ryan 2002) and were published in the Rainbow volume on the *Effects of Fire on Soil and Water* (Neary and others 2005). A description of the characteristics that they developed is provided for clarification of subsequent discussion of fire effects. The appendix includes several examples of depth of burn classes.

> **Unburned:** Plant parts are green and unaltered; there is no direct effect from heat.
>
> **Scorched:** Fire did not burn the area but radiated or convected heat caused visible damage. Mosses and leaves are brown or yellow but species characteristics are still identifiable. Soil heating is negligible.
>
> **Light:** In forests, the surface litter, mosses, and herbaceous plants are charred to consumed but the underlying forest duff or organic soil is unaltered. Fine dead twigs are charred or consumed but larger branches remain. Logs may be blackened but are not deeply charred except where two logs cross. Leaves of understory shrubs and trees are charred or consumed but fine twigs and branches remain. In non-forest vegetation, plants are similarly charred or consumed; herbaceous plant bases are not deeply burned and are still identifiable, and charring of the mineral soil is limited to a few millimeters (fractions of an inch).
>
> **Moderate:** In forests, the surface litter, mosses, and herbaceous plants are consumed. Shallow duff layers are completely consumed and charring occurs in the top centimeter (0.4 in.) of the mineral soil. Deep duff layers or organic soils are deeply burned to completely consumed, resulting in deep charcoal and ash deposits but the texture and structure of the underlying mineral soil are not visibly altered. Deep ash deposits are sometimes confused with oxidized mineral soil. Ash is fine and powdery when dry, slick and greasy when wet, whereas oxidized soil retains pebbles and granularity and feels gritty. Trees of later successional, shallow-rooted species often topple or are left on root pedestals. Fine dead twigs are completely consumed, larger branches and rotten logs are mostly consumed, and logs are deeply charred. Burned-out stump holes and rodent middens are common. Leaves of understory shrubs and trees are completely consumed. Fine twigs and branches of shrubs are mostly consumed (this effect decreases with height above the ground), and only the larger stems remain. Stems of these plants frequently burn off at the base during the ground fire phase, leaving residual aerial stems that were not consumed in the flaming phase lying on the ground. In non-forest vegetation, plants are similarly consumed; herbaceous plant bases are deeply burned and unidentifiable. In shrublands, charring of the mineral soil is on the order of 1.0 centimeter (0.4 in.) but soil texture and structure are not clearly altered.
>
> **Deep:** In forests growing on mineral soil, the surface litter, mosses, herbaceous plants, shrubs, and woody branches are completely consumed. Sound logs are consumed or deeply charred. Rotten logs and stumps are consumed. The top layer of the mineral soil is visibly oxidized, reddish to yellow. Surface soil texture is altered and, in extreme cases, fusion of particles occurs. A black band of charred organic matter 1 to 2 centimeters (0.4 to 0.8 inches) thick occurs at variable depths below the surface. The depth of this band is an indication of the duration of extreme heating. The temperatures associated with oxidized mineral soil are associated with flaming rather than smoldering. Thus, deep depth of burn typically only occurs where woody fuels burn for extended duration, such as beneath individual logs or in concentrations of woody debris. In areas with deep organic soils, deep depth-of-burn occurs when ground fires consume the root-mat or burn beneath the root-mat. Trees often topple in the direction from which the smoldering fire front approached.

Fire Severity

Fire behavior refers to the manner in which a specific fire burns the fuel bed (fuel complex) in a given terrain with the prevailing weather conditions at the time. Fire behavior prediction is concerned primarily with the characteristics contributing to the advance of a free-burning fire. This issue is more directly related to fireline intensity (Alexander 1982; Byram 1959; Ryan and Noste 1985). One problem with applying fireline intensity in ecological studies is that it does not predict all of the combustion or quantify all of the energy released during a fire (Johnson and Miyanishi 2001; Ryan 2002; Keeley 2009). In contrast, **fire**

severity is concerned with both the characteristics of the free burning fire as it spreads across an area and the characteristics of the stationary fire as it resides at a site (i.e., duration of burning), because it is the latter's characteristics that primarily determine how deep into the soil profile fire and heat can penetrate (Frandsen and Ryan 1986; Hartford and Frandsen 1992; Ryan 2002). Fire severity is a construct that describes the change in site properties/conditions due to fire. Fire severity describes the outcome rather than the process and is thus useful for understanding the ecological effects of fire on an ecosystem: the amount of organic matter lost from a location, vegetation mortality, and soil transformations (Feller 1998; Jain and others 2008; Kaufmann and others 2007; Keeley 2002; Ryan 2002). The same principles apply when considering the impacts of fire on cultural resources found within the soil profile.

Following a fire, researchers are able to better understand fire dynamics by quantifying fire intensity and duration (Neary and others 2005; Ryan 2002; Ryan and Noste 1985). Several authors have quantified the depth of burning into the ground (DeBano and others 1998; Feller 1998; Jain and Graham 2007; Jain and others 2008; Morgan and Neuenschwander 1988; Ryan and Noste 1985), and consumption (fig. 2-15) and depth of char in FWD and CWD (Albini and Reinhardt 1995, 1997; Costa and Sandberg 2004). When depth of burn/char measurements are coupled with estimates of flame length and fire spread direction, it is possible to recreate a fire's movement through a stand. By combining flame length and depth of burn/char measurements, researchers are able to create a two-dimensional matrix of fire severity, which may be a useful classification of the level of fire treatment for comparative analysis of fire effects within and between fires. For example, Ryan and Noste (1985) (appendix table A-3) assessed the effects of fire on tree crowns and ground fuels by visiting burned sites and measuring scorch heights and using them to back-calculate fireline intensity using Van Wagner's (1973, 1977) crown scorch model. Depth of burn/char measurements can be used to estimate residence time in surface fuels and soils. Wildland fuels are poor conductors of heat. Due to heat transfer constraints, fuels burn at relatively constant rates (Anderson 1969; Frandsen 1991a,b). A fire can be very intense, as exhibited by long flame lengths, but its duration within the forest strata most determines the depth of burn/char. Readers are referred to the recent review by Keeley (2009) for further discussion on the topic of fire intensity versus fire severity. A more in-depth discussion of the differences between fire intensity and fire severity can be found in the *Effects of Fire on Soil and Water* volume (Neary and others 2005), and Ryan 2002. Field guidance on determining fire severity may also be found in the appendix.

Integrating Fire Severity With Cultural Resources

In short fire return forests where duff accumulation is restricted, the burnout of CWD is the primary source of deep soil heating (Monsanto and Agee 2008). In forests with long fire return intervals, the buildup of duff covers most of the forest floor surface. Logs, even at high fuel loadings, rarely cover more than 10 percent of the soil surface area (Albini 1976; Brown and others 2003; Peterson and Ryan 1986). Thus, the most common source of deep soil heating is the burnout of the duff. Equations exist to predict duff consumption in the United States (Brown and others 1985, 1991; Ottmar and others 1993, 2005; Reinhardt 2003) and Canada (Chrosciewicz 1968, 1978a,b; de Groot and others 2009; Muraro 1975; Van Wagner 1972). Predictions are available using both actual measured moisture contents (fig. 2-16) or more readily available fire danger rating indices (figs. 2-17, 2-18). Users are referred to equations in the CONSUME (Ottmar and others 1993, 2005, accessed November 13, 2009) and FOFEM (Reinhardt 2003) publications as a means of predicting expected duff, FWD, and CWD consumption in wildfires or prescribed fires.

In addition to the burnout of duff and woody fuels, there are a number of other means by which buried cultural resources can be heated. One of the most common is the burnout of stumps and dead roots. Commonly at cultural sites, logs and building materials are buried

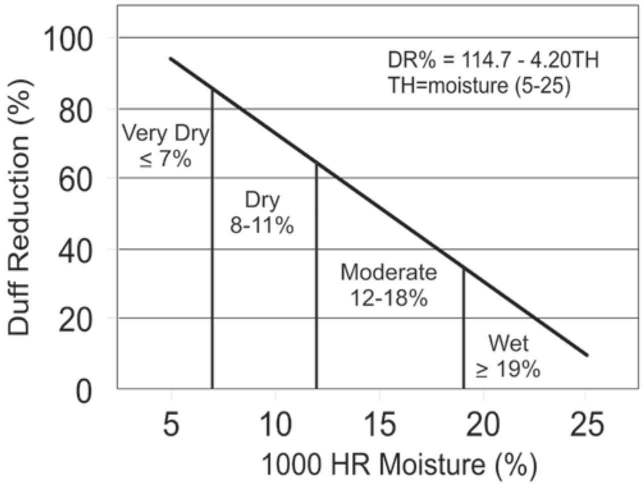

Figure 2-17—Illustration of duff consumption, percent of total duff available (%), as a function of U.S. National Fire Danger Rating System (NFDRS) (Deeming and others 1977) thousand hour moisture content for common forest conditions where duff is greater that 4 centimeters deep and able to burn independent of a surface fire if dry enough to burn (equation from Brown and others1985).

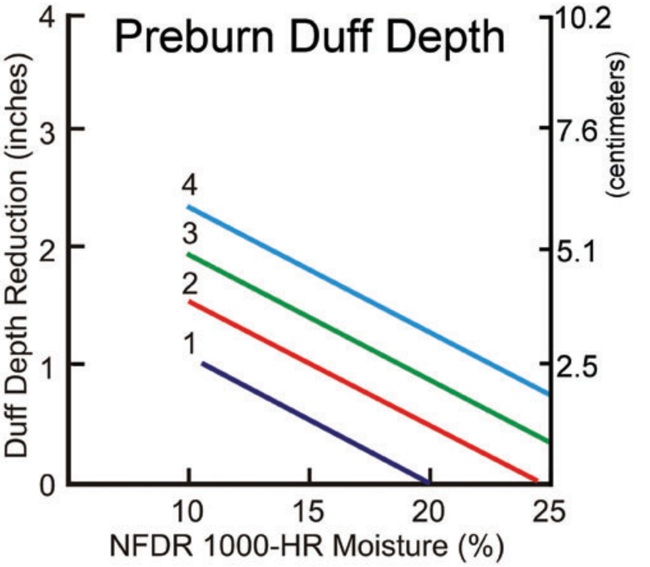

Figure 2-18—Illustration of duff depth reduction (in.) as a function of varying initial duff depths (in.) and U.S. National Fire Danger Rating System (NFDRS) (Deeming and others 1977) thousand hour moisture content based on Brown and others 1985. (1 in. = 2.54 cm.)

or partially buried. Once ignited these burn slowly, deeply heating lower layers in the soil profile. Another mode of subsurface heating is when soil is interspersed with organic material in old middens and dump sites where fire can freely move throughout the strata. For further discussion of these unique fire environments see chapters 6, 7 and 9.

The conceptual model of fire severity developed by Ryan and Noste (1985) defines severity as the union of the heat pulse above the site and the heat pulse in the ground (heat pulse up – heat pulse down) (appendix table A-3). As the mass of fine fuel increases, so does the potential for a high intensity surface fire or crown fire. The primary weather factors that determine how intensely that fine fuel mass will burn are the wind speed and short-term drying (i.e., low relative humidity). Canopy fuels readily torch at relative humidity less than 20 percent. As fire intensity increases, so does the above-ground heat pulse. Likewise, the potential for fire to damage surface and above-ground cultural resources also increases. The increased radiant flux associated with large flames more effectively heats surfaces at greater distances than is possible with small flames (see sidebar 2-1). Also, as fire intensity increases, fires become more uniformly severe as more surface and canopy fuel is consumed. As the depth of burn increases the potential to damage surface and sub surface resources increases. With greater depth of burn, more heat is released for a longer period of time and the distance between the combustion zone and a buried artifact is reduced as organic soil horizons are consumed. The primary factors determining the depth of burn are long-term drying and the depth of organic material available on the site (fig. 2-19). The primary factor determining the temperatures reached in the soil is the depth of burn whether resulting from increased duff consumption (fig. 2-20) or increased burnout of coarse woody debris (fig. 2-21). The depth of burn and the temperatures reached in the soil determine the damage to subsurface cultural resources.

In their work on classifying fire severity, Ryan and Noste (1985), Ryan (2002), and Neary and others (2005) stressed the concept that one needs to look independently at the heat pulse above the fire as well as the heat pulse in the ground. For practical reasons, it is often impossible to adequately instrument a site in order to get definitive measures of the energy release characteristics or temperature history across a burned area of interest. The spatial variability of fuels and fire behavior within most fires precludes actual quantification in most cases. Classification of the level of fire treatment has considerable pragmatic utility. While remote sensing of fire characteristics is becoming increasingly common (Kremens and others 2010; Lentile and others 2006, 2007, 2009) and real-time monitoring from remote platforms such as aircraft or satellites shows great promise for the future, most cultural resource specialists will have to rely on proxy data to reconstruct and classify the level of fire treatment associated with observed fire effects. In the case of unplanned fires, *ex post facto* measures are all that is available to ecologists and archaeologists alike. The fire severity matrix (appendix table A-3) describes a classification of fires in a 6 by 4 matrix with six classes of heat pulse above the ground and four classes of depth of burn including the unburned case. In addition, figures 2-16 through 2-21 can help inform burning prescriptions designed to manage the effects of fire on cultural resources during fuel reduction and ecosystem restoration treatments. Buenger (2003) presented data and synthesis of the effects of high temperatures on various archaeological and historically significant materials. Data are also presented on temperature effects on ceramics (chapter 3), lithics (chapter 4), and historic era materials (chapter 6) in this publication. Ryan (2010) summarized these temperatures and discussed the importance of the duration of exposure to high temperatures (sidebar 2-2). These temperatures can be compared to representative temperature histories of fires (e.g., figs. 2-8, 2-10, 2-11, 2-12, 2-14, 2-19, and 2-20) to bound expected fire effects when planning prescribed burns or post wildfire rehabilitation and stabilization.

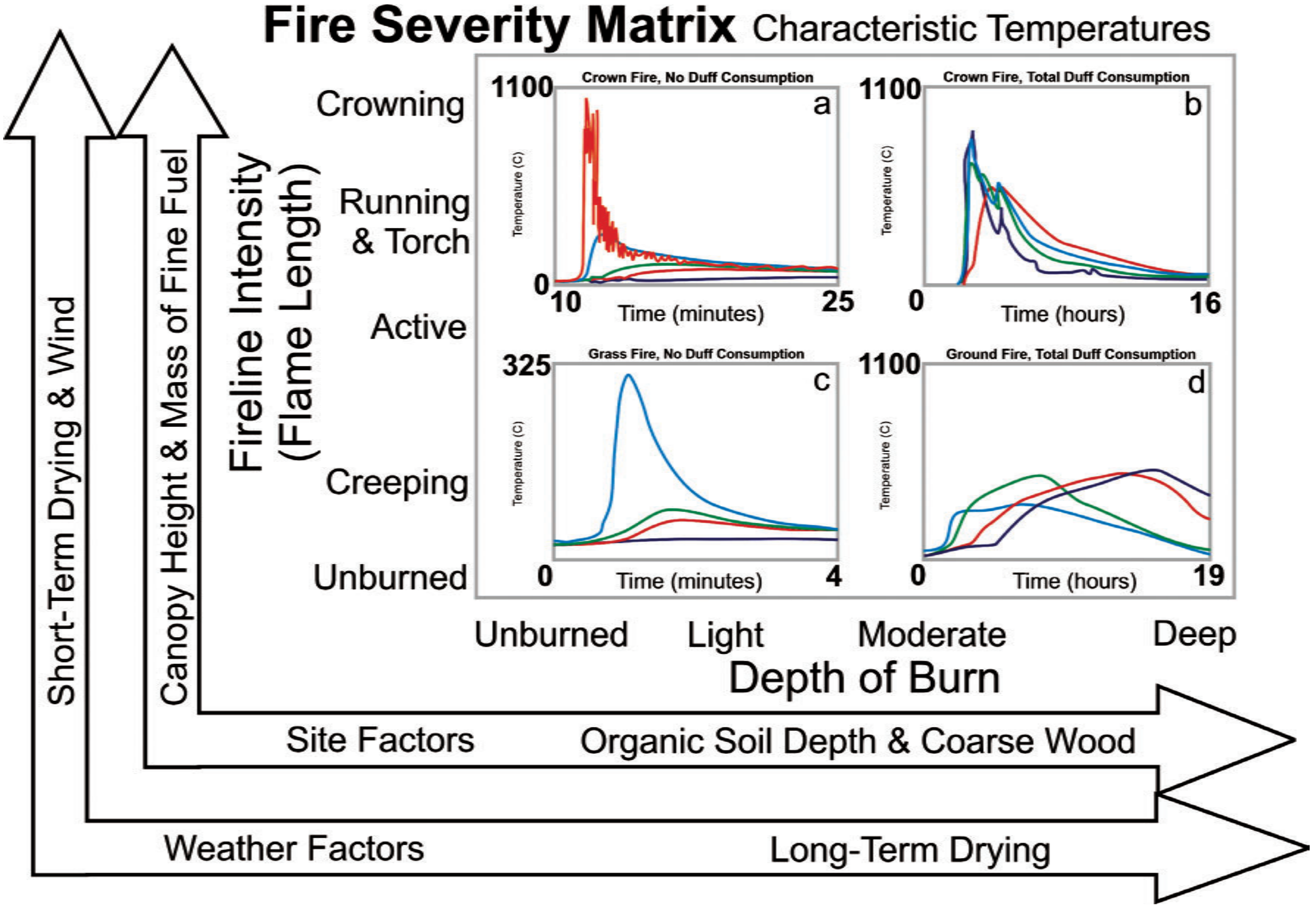

Figure 2-19—Representative temperature histories for fires of varying severity: (a) crownfire/low depth of burn (DOB), (b) crownfire/moderate DOB, (c) active surface fire/low DOB, (d) creeping surface fire/moderate DOB. (See text and appendix for fire intensity and DOB descriptions.) Differing combinations of high temperature and duration of heating lead to fires of different severity. Changes in site variables, including terrain and vegetative structure, and weather variables lead to fires of differing peak temperature and duration. Broad arrows indicate increasing site and weather potential. Both site and weather conditions must be met to affect fire severity (adapted from Ryan 2002).

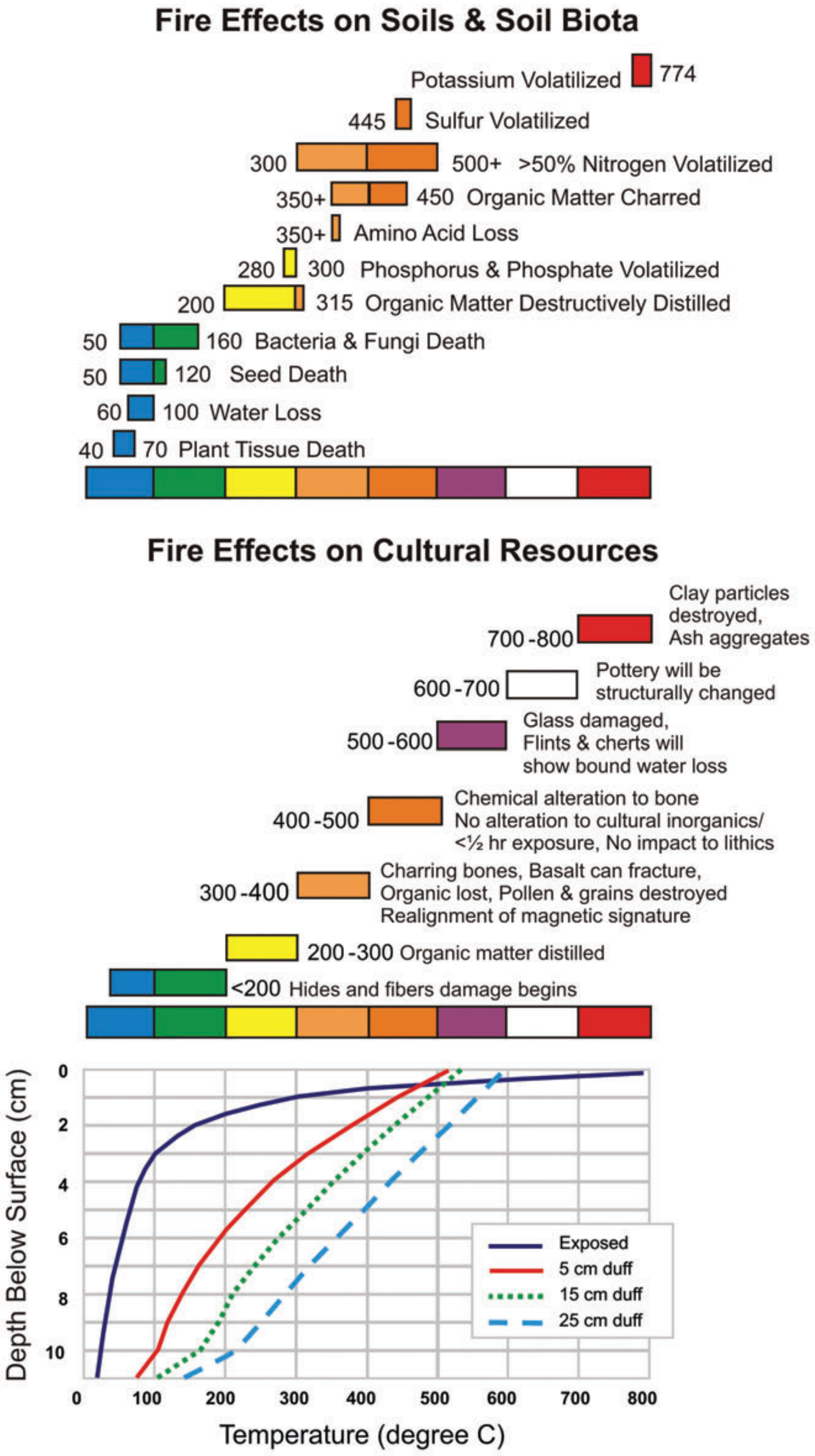

Figure 2-20—Temperature ranges associated with various biophysical fire effects (top) (modified from Hungerford and others 1991) and cultural resource fire effects (center) compared to the depth of heat penetration into mineral soil (bottom) for a crown fire over exposed mineral soil (observed in jack pine *Pinus banksiana* in the Canadian Northwest Territories) or for ground fire burning in 5-, 15-, and 25-cm of duff (predicted by Campbell and others1994, 1995). Conditions are for coarse dry soil, which provides the best conduction (i.e., a worst-case scenario) (adapted from Ryan 2002).

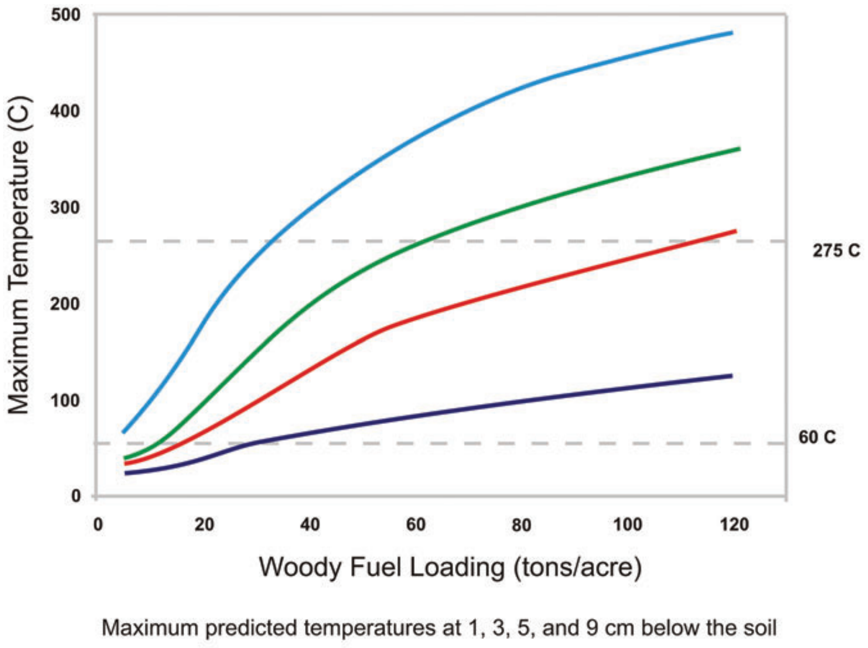

Figure 2-21—Maximum soil temperatures predicted by the soil heating model in the First Order Fire Effects Model (FOFEM) (Reinhardt and others 2005) for varying loadings of coarse woody debris (CWD (from Brown and others 2003). Solid lines depicting 1, 3, 5, and 9 cm below the soil starting from top to bottom.

Fire Regime

In current fire management, the highest spatial and temporal fire scale of interest is described by the fire regime (fig. 2-1). Scott (2000) refers to the paleo-fire triangle—an even higher scale represented by atmosphere, vegetation, and climate—which recognizes that terrain and atmospheric chemistry are variable over geologic time frames. This longer term perspective may not seem too relevant to fire managers; however, in the study of climate-vegetation-fire relationships that affected ancient cultures, it is germane to many reconstructions of archaeological information. Understanding climate-vegetation-fire interactions is likely to become of greater importance in formulating future fuels treatment and restoration policies under climate change scenarios (Lovejoy and Hannah 2005).

Fire regime concepts emerged in the fire ecology literature with the early work of Heinselman (1978, 1981) and Kilgore (1981). In recent years there has been considerable refinement in fire regime concepts as ecologists have investigated more ecosystems and have developed a greater appreciation for how fire regimes vary over time. At the same time, ecological theory has matured to recognize the importance of periodic disturbance to the maintenance of ecological integrity (Agee 1993; Hardy and others 2001; Morgan and others 2001; Sugihara and others 2006). In the United States, the use of fire regime concepts has increasingly been used in the fire ecology and management communities, particularly in the context of the Coarse-Scale Assessment of Fire Regime Condition Class (FRCC) (Schmidt and others 2002) (table 2-4) and because its use is mandated under the Healthy Forests Restoration Act of 2003 (H.R. 1904). Fire regime refers to the general nature of the type of fire that most commonly occurred over long time periods (Agee 1993; Brown 2000; Hardy and others 1998; Sugihara and others 2006).

Table 2-4—Historical natural fire regimes from Coarse-Scale Assessment of Fire Regime Condition Class (Schmidt and others 2001).

Code	Description
I	0-35 year frequency[a], low severity[b]
II	0-35 year frequency, stand replacement severity
III	35-100+ year frequency, mixed severity
IV	35-100+ year frequency, stand replacement severity
V	200+ year frequency, stand replacement severity

[a] Fire frequency is the average number of years between fires.
[b] Severity is the effect of the fire on the dominant overstory vegetation.

Sidebar 2-2—Impact of Temperature and Duration of Heating on Lithics

It is common knowledge that many material transitions occur as complex functions of temperature and duration of exposure. Such functions are often described by Arrhenius functions (fig. S-2.1) (Ryan 2010). Few time-temperature data are available (e.g., Bennett and Kunzman 1985; Buenger 2003), and those that do exist are not robust enough to calculate actual Arrhenius functions but they are adequate to illustrate their potential use. The following example uses data from Bennett and Kunzman (1985) to illustrate the principle. (Bennett and Kunzman's work is unpublished but widely cited and sometimes misinterpreted because the results of laboratory muffle furnace results are difficult to extrapolate to field burning situations.)

General Information:

- Type of research: Laboratory experiment
- Purpose: Heating experiment was designed to mimic a range of wildland fire situations
- Experimental heating of artifacts conducted by Bennett and Kunzman, Western Archeological and Conservation Center, National Park Service, Tucson, Arizona
- Heating description:
  - Temperature range: 200 to 800 °C (392 to 1472 °F)
  - Duration: 3,000,000 degree-minutes for temperatures between 200 and 600 °C (392 and 1112 °F); 1,345,000 and 1,400,000 degree-minutes for two trial runs of 800 °C (1472 °F) max temperature.
- Equipment used:
  - Electric thermolyne-type 1400 muffle furnace; temperature measured by a Weelco controller
  - Temperatures of heated specimens measured by 36 gauge iron-constantan (type J) thermocouples
  - Perkin Elmer 599 infra-red spectrometer used to measure bound water loss

Procedures:

Peter Bennett and Michael Kunzmann (1985) conducted experimental heating of artifacts in the materials and ecological testing laboratory of the Western Archeological and Conservation Center in Tucson, Arizona. They used a muffle furnace to assess potential damage to artifacts heated at prescribed burn temperatures. In their experiments, Bennet and Kunzman examined specimens of chert, flint, chalcedony, obsidian, prehistoric earthenware, and historic to modern bone, glass and enameled tinware. Separate samples of specimens were heated in the furnace to different maximum temperatures. Duration of heating was measured in degree-minutes. Degree-minutes of heating were equal to the maximum temperature reached minus 100 °C (212 °F) multiplied by the time in minutes: (max. temp. – 100 °C (212 °F)) (minutes heated). Duration of heating in degree-minutes was generally kept standard.

Color change and other visual alterations to the surface of items were recorded. Heating effects to artifact structure were identified in terms of chemically bound water loss and weight loss due to causes other than evaporation of free water. Free water evaporation was measured by heating specimens in a drying oven at 100 °C (212 °F). Loss of chemically bound water was determined with the use of an infrared spectrometer on ground-up pieces of specimens before and after furnace heating. Weight loss not accounted for by free or bound water loss was attributed to other causes.

Specimens were also heated and plunged into cold water to test for thermal shock. The rate of cooling in water was judged to be greater than 500 °C (932 °F) per minute. Although this test was not carefully controlled, a minimal amount of observed cracking and spalling led Bennett and Kunzman to conclude that thermal shock was not a major concern in prescribed burns.

Given estimates of the Arrhenius functions for various cultural materials provide a means to compare expected temperatures and durations of fires to assess the likelihood of CR damage. Such assessments require applying knowledge of the CR material type and its location (for example, exposed above ground versus insulated by unburnable mineral soil), the combustion characteristics of nearby fuels, and the heat transfer mechanisms coupling fire behavior to the CR. In practice, many cultural materials including lithics are composed of various elements, often in layers, and each with their own thermal properties. Rapid heating or cooling can create internal stresses that cause materials to fracture (e.g., potlidding, spalling). Such mechanical failures are difficult to explain with Arrhenius functions; however, time-temperature relationships help to explain why an artifact of a given material type might display similar damage over a range of fire behaviors. Likewise, they help explain why two different material types might display very different effects from a given fire behavior.

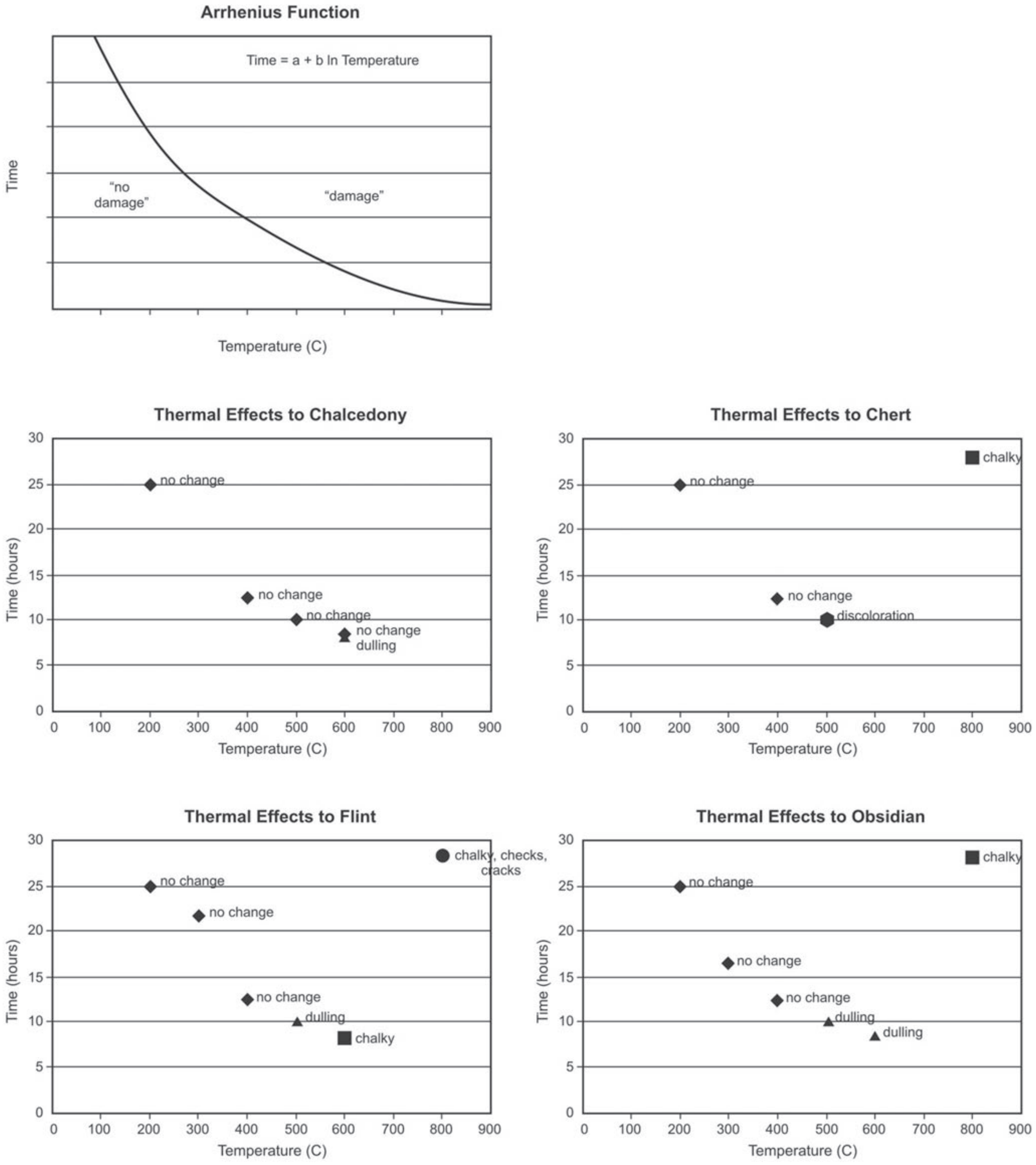

Figure S2.1. Time-temperature relationships for four lithic materials (from Bennett and Kunzman 1985).

The actual terms used and the concepts they describe vary somewhat and this can result in confusion. Fire regimes include descriptions of the frequency and severity of the fire. Older literature often referred to the effects of the fire as **intensity** but common usage in current North American literature favors the term **fire severity** as a description of the effects of fire (Agee 1993; Brown 2000; Hardy and others 1998; Keeley 2009; Neary and others 2005; Ryan 2002). Readers are referred to the *Effects of Fire on Flora* (Brown 2000) for a description of various early uses of the fire regime concept. There is a large body of more recent fire regime-related literature, the review of which is beyond the scope of this chapter. Interested readers are invited to type the words "fire regime" into their favorite internet search engine.

The following terms are commonly encountered in the fire regime literature. **Understory fire regime**, **surface fire regime**, **low severity fire regime**, and **non-lethal fire regime** are terms used to describe fires that are generally non-lethal to the dominant vegetation and do not substantially change the structure of the dominant vegetation (Brown 2000). Such descriptions apply to forests and woodlands. As originally defined by Brown (2000), approximately 80 percent or more of the dominant vegetation must survive to be deemed non-lethal. In the FRCC field methods used by Federal land management agencies in the United States, the cut-off is 75 percent or more (Hann and Bunnell 2001). In either case, most of the dominant arboreal vegetation survives. A **stand replacement fire** or **lethal regime** is one that either consumes or kills 80 percent or more of the above-ground dominant vegetation (Brown 2000), or 75 percent or more according to FRCC field methods (http://www.frcc.gov) (Hann and Bunnell 2001). Stand replacement fire regimes apply to forests, woodlands, shrublands, and grasslands (Brown 2000). In the case of grasslands, the post-fire community often recovers quickly from surviving meristematic tissues, such as rhizomes and bulbs. Intermediate regimes, or those between understory and stand replacement fire regimes, are generally referred to as **mixed severity fire regimes.** Mixed severity fire regimes can occur due to variation in space or time. However, some forest types tend to go through cycles wherein the series of low severity fires is periodically punctuated with stand replacement fires as long-term climate trends oscillate between warm-dry and cool-moist climate periods. Brown (2000) and several other authors also recognize a non-fire regime where there is little or no occurrence of natural fire. This description may be useful in discussions of vegetation types where fire is rare. However, upon close inspection, evidence of past fires is found in virtually all non-marine vegetation types (Andreae 1991; Bond and others 2005; Clark and others 1997; Delacourt and Delacourt 1997; Levine 1991; Levine and others 1995, 1996a,b; Power and others 2008). Determining whether or not these fires are natural or were started by aboriginal people is often problematic (Anderson 2005; Barrett and Arno 1982; Bonnicksen 2000; Boyd 1999; Denevan 1992; Vale 2002). Throughout the period of human occupation of North America, aboriginal people are widely believed to have extensively burned the landscape (Bonnicksen 2000; Boyd 1999; Delacourt and Delacourt 1997; Delacourt and others 1998; Erickson 2008; Gavin and others 2007; Hallett and others 2003; Jurney and others 2004; Kay 1994, 1998, 2007a,b; Keeley 2002; Leenhouts 1998; Lewis 1989; Moore 1972; Nevle and Bird 2008; Pausas and Keeley 2009; Stewart 1956, 1982; Williams 2000). Use of fire by aboriginal people was pervasive (Anderson 2005; Barrett and Arno 1982; Boyd 1999; Kay 1994; Denevan 1992; Kay and Simmons 2002; Williams 2000). Infrequent fires can have long-lasting effects on species composition and stand structure (Brown and others 1999; Frost 1998; Kaufmann and others 2000, 2004).

Fire Planning

The careful planning and implementation of fuel treatment or restoration projects can go a long way toward minimizing the potential impacts on cultural resources (see chapter 9). Well executed projects can greatly reduce the impacts of subsequent wildfires. Also integrating fire behavior and effects concepts with an understanding of how cultural resources are impacted by fire (fig. 2-20) can aid in the planning and implementation of post-fire restoration and monitoring.

Planning fuels treatments, restoration projects, or suppression activities requires that cultural resource specialists collaboratively plan activities with fire management personnel (see chapter 9). In addition to the graphical aids in this chapter (figs. 2-15 through 2-21), there are numerous software decision support tools, databases, and syntheses available to resource professionals. There are a number of agency-developed software programs that can be used to predict fire behavior and to project probable effects at both the site and landscape levels. These predictive tools, used by managers to support planning and decisions, vary in their inputs, outputs, and uses. The following discussion identifies a few commonly used by the fire management community. For more information please visit http://fire.org, the Fire Research and Management Exchange System (FRAMES, http://frames.nbii.gov/portal/server.pt), or use an internet search engine to search each program individually. Additional resources are listed in table 2-5.

Table 2-5—Annotated list of fire effects resources for planning and evaluating fuel treatment and restoration projects and surveying and monitoring wildland fire management activities (adapted and modified from Kelly Pohl, TNC Global Fire Initiative, LANDFIRE Program).

		Type of tool		
Resource/Tool	**Description**	**Fire ecology resource**	**Resource search**	**Monitoring/ Modeling**
Smith, J.K., ed. 2000. **Wildland fire in ecosystems: effects of fire on fauna**. http://www.treesearch.fs.fed.us/pubs/4553	A volume from the Rainbow Series that outlines the effects of fire on North American fauna.	X		
Brown, J.K.; Smith, J.K., eds. 2000. **Wildland fire in ecosystems: effects of fire on flora**. http://www.treesearch.fs.fed.us/pubs/4554	A volume of the Rainbow Series that outlines historical and current fire regimes and fire effects organized by Kuchler Natural Potential Vegetation Types.	X		
Neary, D.G.; Ryan, K.C.; DeBano, L.F., eds. 2005. **Wildland fire in ecosystems: effects of fire on soil and water**. http://www.treesearch.fs.fed.us/pubs/20912	A volume from the Rainbow Series that outlines the effects of soil and water. The volume: 1) defines fire severity as it affects soil and water resources, 2) synthesizes the state of knowledge on the effects of fire on the physical, chemical and biological properties of soil; and water quality; and 3) summarizes erosion models and burned area rehabilitation practices	X		
Sandberg, D.V.; Ottmar, R.D.; Peterson, J.C.; Core, J. 2002. **Wildland fire in ecosystems: the effects of fire on air**. http://www.treesearch.fs.fed.us/pubs/5247	A volume from the Rainbow Series that outlines the effects of fire on air quality to assist managers with smoke planning.	X		
Zouhar, K.; Smith, J.K.; Sutherland, S.; Brooks, M.L. 2008. **Wildland fire in ecosystems: fire and non-native invasive plants**. http://www.treesearch.fs.fed.us/pubs/30622	A volume from the Rainbow Series that outlines the effects of fire on exotic and invasive weeds	X		
Grissino-Mayer, H.D. 2003. **Dendrochronology Literature Database** http://www.waldwissen.net/themen/wald_gesellschaft/forstgeschichte/wsl_jahrringforschung_datenbank_EN	A searchable database of tree-ring literature, including many fire history studies. This literature can provide information about fire effects, fire history, fire regimes, and disturbance interactions, among other topics.		X	
ESSA Technologies Ltd. **TELSA: Tool for Exploratory Landscape Scenario Analysis.** http://www.essa.com/tools/telsa/index.html	A spatially explicit, landscape-level model of forest dynamics to help assess the consequences of alternative management scenarios. Used with VDDT and ArcView 3.X. Software and training are available upon request.			X
ESSA Technologies Ltd. **VDDT: Vegetation Dynamics Development Tool.** http://www.essa.com/tools/vddt/index.html	Public domain state-transition modeling software that provides functions for natural vegetation succession and natural and human disturbances. Resulting models can help create estimates of percent cover for different vegetation types (states) and important drivers in landscape change (transitions). Models are not spatially explicit and do not account for biophysical constraints.			X

Table 2-5—Continued

Resource/Tool	Description	Type of tool		
		Fire ecology resource	Resource search	Monitoring/ Modeling
U.S. Department of Agriculture **Fire Effects Information System (FEIS)** http://www.fs.fed.us/database/feis/	A complete database of the effects of fire on plant and wildlife species and communities in North America, searchable by species or Kuchler Potential Natural Vegetation Type. Contains sections on distribution, botanical and ecological characteristics, succession, fire ecology and effects, management considerations, and case studies.	X		
U.S. Department of Agriculture **Fire Effects Information System (FEIS) Citation Reference System (CRS)** http://www.feis-crs.org/	A searchable database of all of the references cited in the Fire Effects Information System (FEIS). Searchable by subject, year, author, or any combination thereof. A complete fire history literature database!		X	
U.S. Department of Agriculture & The Nature Conservancy **Fire Regime Condition Class Guidebook and Reference Conditions** http://www.frcc.gov	A standardized, interagency protocol for assessing the departure of current conditions from historical reference conditions. Information and methodology are available at the web address listed. National training events are held regularly. Reference Conditions for potential natural vegetation groups across the U.S. are described, including reference mean fire intervals and successional stages.	X		X
The Northwest and Alaska Fire Research Clearinghouse. **FIREhouse** http://depts.washington.edu/nwfire/	A web-based data center providing documentation and data on fire science and technology relevant to Washington, Oregon, Idaho, and Alaska.		X	
Fire Sciences Laboratory **FIREMON: Fire Effects Monitoring Protocol** http://frames.nbii.gov/firemon	Sampling protocol, sources, and forms for determining current conditions. Methodologies can be used directly or serve as templates.			X
FRAMES: Fire Research and Management Exchange System http://frames.nbii.gov/portal/server.pt	A suite of software developed for fire management professionals, including modeling programs like BEHAVE and FARSITE. Also an information exchange with bulletin boards and notice pages that facilitate collaboration among fire management professionals.			X
Interagency Research Partnership **Joint Fire Sciences Program** http://www.firescience.gov/	The Joint Fire Science Program (JFSP) funds research and development projects focused on improving the knowledge available for management and policy decisions to support federal, tribal, state, and local agencies and their partners. JFSP provides access to reports of past projects and links to related sites.	X	X	
U.S. Department of Agriculture, U.S. Geological Society, The Nature Conservancy, U.S. Department of the Interior **LANDFIRE** http://www.landfire.gov	LANDFIRE is a wildland fire, ecosystem, and fuel assessment-mapping project designed to generate consistent, comprehensive, landscape-scale maps of vegetation, fire, and fuel characteristics for the United States.	X		X

Table 2-5—Continued

Resource/Tool	Description	Type of tool		
		Fire ecology resource	Resource search	Monitoring/ Modeling
Systems for Environmental Management **Fire.org: Public Domain Software for the Wildland Fire Community** http://www.fire.org/	Systems for Environmental Management provides downloadable versions of public domain software for predicting fire weather, behavior, and effects ass well as links to other sources of fire information.			X
Schmidt, K.M.; Menakis, J.P.; Hardy, C.C.; Hann, W.J.; Bunnell, D.L. 2002. **Development of coarse-scale spatial data for wildland fire and fuel management.** http://www.treesearch.fs.fed.us/pubs/4590	A national-scale mapping of fire regime data, including potential natural vegetation groups, current cover types, and historical and current fire regime condition classes. GIS data layers are available. Note that this data is at ecoregional scales and not suitable for project scale.	X		
Tall Timbers Research Station and Land Conservancy **Tall Timbers Library** http://www.talltimbers.org/info-library.html	A searchable database of literature on fire ecology, prescribed fire use, and control of fires. Has an international scope with a focus on the southeastern U.S.		X	
The Nature Conservancy **Global Fire Initiative** http://www.tncfire.org/training_landfire_techTransfer.htm	A resources site that describes how to use the ESSA VVDT successional models in the LANDFIRE Vegetation Model Library, and contains many other fire resources designed to help land managers.	X	X	X
Forest Service Research and Development **Treesearch** http://www.treesearch.fs.fed.us/	A searchable database of all USDA Forest Service publications online. Searchable by author, year, and region.		X	
USDA Natural Resources Conservation Service **The PLANTS Database** http://plants.usda.gov/index.html	A comprehensive database that provides standardized information on the vascular plants, mosses, liverworts, hornworts, and lichens of the US and its territories. PLANTS includes names, photos, checklists, and automated tools.			X
USDI National Park Service **National Park Service Fire Monitoring Handbook** http://www.nps.gov/fire/download/fir_eco_FEMHandbook2003.pdf	Outlining the National Park Service's standardized fire effects monitoring protocol, including setting goals and objectives, designing pre- and post-burn sampling, and data analysis. Also includes useful field forms, checklists, and additional reading lists.			X
Wildland Fire Lessons Learned Center http://www.wildfirelessons.net/	A web-based clearinghouse of information, case studies, and lessons learned to improve performance, safety, efficiency, and organizational learning in the interagency wildland fire community.		X	
Gassaway, L. **Fire Archaeology** http://web.mac.com/linnog/Fire_Arch/Home.html	A site designed to "disseminate information on the effects of fire to cultural resources, both historic and prehistoric." Includes information on protection, policy, and management.	X		
Federal Preservation Institute **Historic Preservation Learning Portal** https://www.historicpreservation.gov/web/guest/home	Portal with information in the field of historic preservation that covers and allows users to search for laws, policies, literature, news, case studies, training, and best practices.	X	X	

Fire Planning Software

Behave-Plus, v 5.0 (Andrews 2008; Heinsch and Andrews 2010) predicts wildland fire behavior for fire management purposes. Behave-Plus is used for real-time fire prediction of fire behavior on a specific site for a specific set of burning conditions, and as a treatment planning tool. This software uses the minimum amount of site-specific input data to predict fire for a given point in time and space. Behave-Plus is useful for gaming a proposed treatment by allowing users to quickly test the effect of changes in fuel moisture, wind, and fuel loading on predicted fire behavior and effects, thereby allowing the user to hone in on a favorable prescription window.

FARSITE (Finney 1998) is a landscape-level fire growth simulation model for forecasting fire growth and intensity and requires the input of topography, fuels, and weather and wind files. This software incorporates existing models for surface fire, crown fire, spotting, post-frontal combustion, and fire acceleration in a two-dimensional fire growth model. It was developed initially as a tool for managing fires in wilderness areas where fire often burns for several weeks. FARSITE was developed to predict how far a fire could spread over long periods of time under changing fire environment (fuels, terrain, and weather). Thus it requires landscape maps of fuels and terrain along with predicted weather over the simulation period. In the modeling framework, fuels are digital representations of fuel-bed properties using either the Anderson 13 fire behavior fuel models (Anderson 1982), the 40 Scott and Burgan fuel models (Scott and Burgan 2005), or user-defined custom fuel models (Burgan and Rothermel 1984). While FARSITE does not explicitly require fuels data at any particular spatial resolution, analyses are typically at 30-meter pixel (900 m^2) (0.22 acre). This spatial resolution is based on analysis of readily available LANDSAT TM-7 data. In the United States, FARSITE fuel and vegetation inputs are freely available through the standardized LANDFIRE national data product (www.landfire.gov) (Rollins 2009; Reeves and others 2009; Rollins and others 2006; Ryan and others 2006). Digital terrain is routinely available from a variety of sources (e.g., USGS), including LANDFIRE. Weather input is provided by the user either from predicted weather or historic climate/weather data. FARSITE is spatially explicit and predicts fire spread and intensity for every place on the perimeter at every time step. Thus, as fires grow in size the model becomes increasingly computationally intensive. Guidance for inputting fuels data and analyzing potential fire behavior are contained in Stratton (2006).

FlamMap is a related model that looks at the spatial pattern of fire potential under static, user-defined weather conditions. Thus it is useful for determining the fire potential in the vicinity of infrastructure (Cohen 2000), natural resources, and cultural resource sites. FlamMap creates raster maps of potential fire behavior characteristics (spread rate, flame length, and crown fire activity) and environmental conditions (dead fuel moisture, mid-flame wind speeds, and solar irradiance) over the entire landscape. Unlike FARSITE, there is no temporal component in FlamMap although they use the same spatial and tabular data as input. This input includes a landscape file, initial fuel moistures, custom fuel models, as well as optional conversion weather and wind files. Many fire behavior models are incorporated into FlamMap ranging from Rothermel's 1972 surface fire spread model to Nelson's 2000 fuel moisture model. In addition to technical knowledge of fire, FARSITE and FlamMap may require geographic information system analyst assistance to obtain spatial landscape information for input to the program.

FireFamily Plus, v.4 (http://www.firemodels.org/index.php/national-systems/firefamilyplus, accessed May 5, 2011) is a software package that quickly summarizes historic weather patterns for local management planning in the United States. Fire Family Plus combines fire climatology and occurrence analysis capabilities of the PCFIRDAT, PCSEASON, FIRES and CLIMATOLOGY programs into a single package with a graphical user interface. This software package is valuable for designing burning prescriptions that are operationally feasible by letting the user determine the frequency and timing of suitable burning weather. In particular, users can analyze historic drying trends critical for achieving cultural resource objectives in prescribed burns.

NEXUS, v. 2.0 (Scott and Reinhardt 2001) is crown fire hazard analysis software that links to separate models of surface and crown fire behavior to compute relative crown fire potential. This software is used to compare crown fire potential for different stands and compare the effects of alternative fuel treatments on crown fire potential. NEXUS updated its previous model from an Excel spreadsheet to a stand-alone program in 2003. The information may be combined with other program output in the future to better understand crown fire development and behavior. Operators of this program should be familiar with BehavePlus (Andrews 2008; Heinsch and Andrews 2010) and be familiar with crown modeling techniques to fully comprehend the simulations in NEXUS and their respective meanings.

Behave Plus, FARSITE, and FlamMap are all meant for users trained in fire planning, behavior, and effects. This group of users should be familiar with fuels, weather, topography, wildfire situations, and associated concepts and terminology. Use of these programs is strictly intended to provide information to trained professionals to make educated land and fire management decisions.

Prometheus, v. 5.3 (http://www.firegrowthmodel.com/) is a deterministic fire growth simulation model (Tymstra and others 2010). It uses spatial fire behavior input data on topography (slope, aspect, and elevation) and Canadian Forest Fire Behavior Prediction (FBP) System fuel types, along with weather stream and FBP fuel type lookup table files. Prometheus uses the simple ellipse as the underlying template to shape fire growth, and simulates fire growth using the Canadian Forest Fire Danger Rating System (CFFDRS)—Fire Weather Index (FWI) and Fire FBP Sub-Systems—to model fire behavior outputs. It uses Grid ASCII, Generate files, and Shapefiles. Prometheus is a national interagency project endorsed by the Canadian Interagency Forest Fire Centre (CIFFC) and its members.

The Canadian Forest Fire Behavior Prediction (FBP) System (http://cwfis.cfs.nrcan.gc.ca/en_CA/background/summary/fbp, accessed February 5, 2010) (Hirsch 1996) provides quantitative estimates of potential head fire spread rate (ROS), total fuel consumption, and fire intensity. With the aid of the Prometheus elliptical fire growth model, it gives estimates of fire area, perimeter, perimeter growth rate, and flank and back fire behavior. Descriptions of the primary outputs follow:

1. **Rate of Spread** (**ROS**) is the predicted speed of the fire at the front or head of the fire (where the fire moves fastest). It takes into account both crowning and spotting and is measured in meters per minute based on the Fuel Type (FT), Initial Spread Index (ISI), Buildup Index (BUI), and several fuel-specific parameters, such as phenological state (leafless or green) in deciduous trees, crown base height in coniferous trees, and percent curing in grasses.
2. **Total Fuel Consumption (TFC)** is the predicted weight of fuel consumed by the fire both on the forest floor and in the crowns of the trees. It is measured in kilograms per square meter of ground surface and is based on Foliar Moisture Content (FMC), Surface Fuel Consumption (SFC), and ROS.
3. **Head Fire Intensity (HFI)** is the predicted intensity, or energy output, of the fire at the front or head of the fire. This is one of the standard gauges by which fire managers estimate the difficulty of controlling a fire and select appropriate suppression methods. It is measured in kilowatts per meter of fire front and is based on the ROS and TFC.
4. **Crown Fraction Burned (CFB)** is the predicted fraction of the tree crowns consumed by the fire based on BUI, FMC, SFC, and ROS.
5. **Fire Type (FT)** is a general description of the fire based on the CFB.

The First Order Fire Effects Model (FOFEM) (http://frames.nacse.org/0/939.html, accessed May 5, 2011) (Reinhardt 2003) is used by managers and planners to predict and plan for fire effects. FOFEM is used for impact assessment and for long range planning and policy development; it helps quantify predictions needed for planning prescribed fires that best accomplish resource needs. FOFEM inputs are divided into four geographic regions of the United States, thereby adding resolution through built-in forest cover types. Outputs include tree mortality; smoke emissions; consumption of duff, FWD, and CWD; mineral soil exposure; and soil heating. Users refer to FOFEM output to set upper and lower fuel moisture limits when writing prescriptions for conducting prescribed burns to manage vegetation injury and particulate emissions from a projected fire area. FOFEM can also be used to assess the effects of wildfire. This information is potentially valuable for designing post-fire surveys and rehabilitation projects. The list of output variables are (1) fuel consumption (percent consumption for these components: fine woody, coarse woody, and duff); (2) smoke (kg km^2 for these emission classes: PM2.5, CO^2, CH_4, and NO_x); (3) tree mortality (% mortality); and (4) soil heating (e.g., depth in cm at which temperature is 60 °C (140 °F) for 1 min (lethal) or 275 °C (527 °F) (irreversible damage to organics)).

Consume, v. 3.1 (http://www.fs.fed.us/pnw/fera/research/smoke/consume/consume30_users_guide.pdf, assessed May 5, 2011), (Ottmar and others 2007) predicts the amount of fuel consumption and emissions from burning logged units, piled debris, and natural fuels. The required inputs include weather data, the amount and moisture content of fuels, and other factors. Resource managers can accurately determine when and where to conduct prescribed burns to achieve desired objectives while reducing impacts on other resources. This software may be used for most forests, shrubs and grasslands in North America (adapted from abstract from Consume 2.0 user guide).

Weather is the most variable element in the fire environment. While antecedent and current weather are the primary considerations for predicting or documenting the direct effects of a specific fire on cultural resources, climate analyses are important for planning fuel treatment and restoration projects (Cerdà and Robichaud 2009; Neary and others 2005; Pannkuk and others 2000; Robichaud and others 2007) as well as in assessing the potential impacts of a fire on subsequent erosion (Johnson 2004a,b). Post-fire erosion often poses a greater threat to cultural resources than the direct effects of heat and smoke. The potential for post-fire erosion increases with increasing fire severity (Cerdà and Robichaud 2009; Neary and others 2005; Robichaud and others 2007) (fig. 2-22).

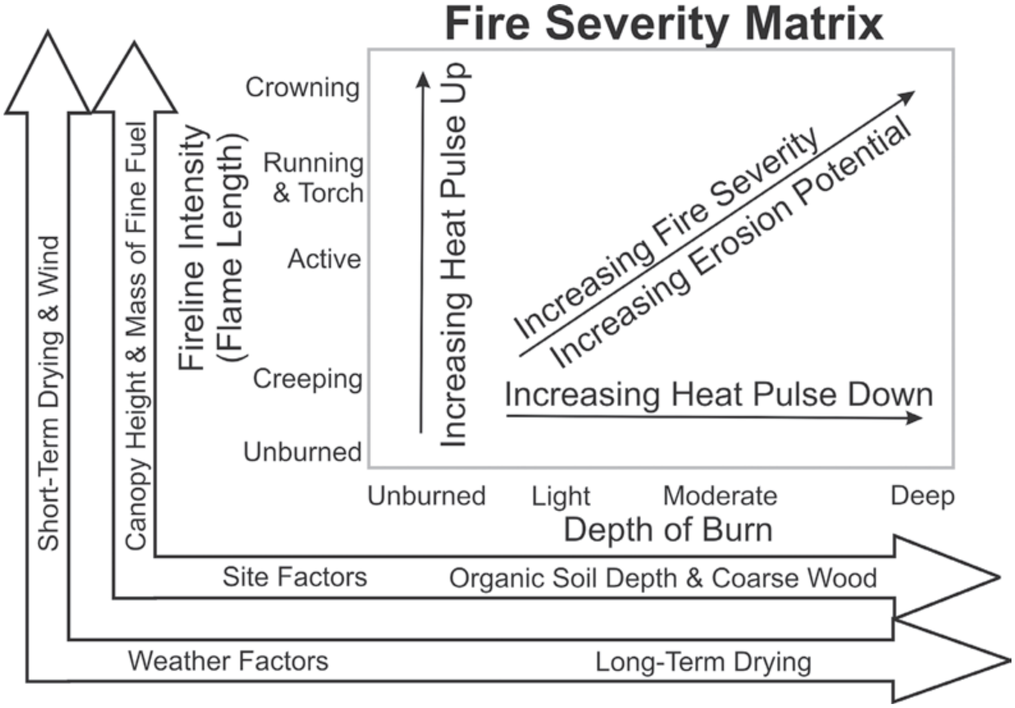

Figure 2-22—Site and weather factors associated with increasing fire severity and erosion potential. Increasing erosion potential increases the risk of damage to cultural resources (from Neary and others 2005).

Basic knowledge of climate, particularly seasonal patterns, can be used within shorter term weather forecasting to refine management prescriptions (Bowman and others 2009; Brown and others 2005; Heyerdahl and others 2008; Kitzberger and others 2007; Littell and others 2009; Morgan and others 2008; Preisler and Westerling 2007; Skinner and others 2006; Swetnam and Betancourt 1990, 1998; Trouet and others 2009; Wang and others 2010; Westerling and others 2006). Climate models are used for a variety of purposes, from study of the dynamics of the weather and climate system to projections of future climate.

Major recognized weather patterns include the North Atlantic Oscillation (NAO) (Ambaum and others 2001); the Northern Annular Mode (NAM) (McAfee and Russell 2008), (http://www.atmos.colostate.edu/ao/introduction.html, assessed May 5, 2011); the Arctic Oscillation (AO); Madden-Julian 30 to 60 Day Intra-seasonal Oscillation (MJO); The Indian Ocean Dipole (IOD), which is linked to the 3- to 7-year El Niño-Southern Oscillation (ENSO) (Izumo and others 2010; Kurtzman and Scanlon 2007); the Pacific Decadal Oscillation (PDO) with a 20- to 30-year oscillation (MantuPachauria 2002); a 20- to 40-year Atlantic Multi-decadal Oscillation (AMO); and the Interdecadal Pacific Oscillation (IPO) with a 15- to 30-year cycle. As climatologists improve our understanding of global circulation patterns, recognized patterns emerge. These patterns, referred to as teleconnections (Dixon and others 2008; Heyerdahl and others 2008), identify lags between ocean and atmospheric measurements and subsequent probable weather in various parts of the globe. These teleconnections are improving our ability to predict fire potential for fire planning purposes.

Climate, vegetation/fuels, and fire are dynamically coupled (fig. 2-1); any change in one will lead to changes in the others (Ryan 1991) with numerous inherent feedbacks (Running 2008). There is near universal agreement in the science community that anthropogenic activities—principally the burning of fossil fuels—is changing atmospheric chemistry (Pachauri and Reisinger 2007). These changes are expected to result in numerous climate-vegetation-disturbance changes with complex and incompletely understood interactions (Grulke 2008; Running 2008) including increased tree mortality (Allen and others 2010; McKenzie and others 2008), major shifts in fire regimes (Flannigan and others 2009; Krawchuk and others 2009a,b; Le Goff and others 2009; Liu and others 2010; Wotton and others 2010), and complex social reactions.

The activities of man are strongly tied to regional climatology. Throughout the development of civilization, the people inhabiting the land have responded to climate-vegetation shifts by changing land practices and migrating as productivity and disturbance patterns changed (Carto and others 2009; Dillehay 2009; Gupta and others 2006; Tipping and others 2008). Evidence suggests that human activities have strongly influenced vegetation (Anderson 2005; Betancourt and Van Devender 1981; Bond and others 2005; Moore 1972; Stewart 1956, 1982; Vale 2002) and likely climate (Ruddiman 2003, 2007), and populations and burning practices have ebbed and flowed (Carcaillet and others 2002, Nevle and Bird 2008; Ruddiman 2003, 2007; Ruddiman and Ellis 2009) over the millennia. Humans are dynamically coupled to their environment, climate, and vegetation. Fire is man's first tool. As we move forward, cultural resource specialists and fire managers will need to plan and adapt to meet the challenge to manage fire and protect cultural resources.

Conclusions

Vegetation/fuels, climate, and disturbance processes are dynamically coupled. Any change in one has feedbacks to the others. The vegetation/fuels on a site reflect the history of climate and terrain influences as well as past disturbances. The character of vegetation/fuels affects the potential occurrence and severity of future fires. Vegetation has developed throughout time with fire as a periodic disturbance agent, and fires will continue to occur, likely at an increased rate under a warming climate. The human family has developed through time closely coupled to the climate and vegetation. Humans have affected vegetation/fuels through use of fire as a land management tool. Fires have impacted cultures for millennia and fire will continue to impact contemporary cultures as well as the remnants of past cultures. The challenge is to manage vegetation/fuels to minimize damage to contemporary cultures as well as the cultural resources left by those who once lived on this land. Fires are highly variable both spatially and temporally, but the principles that govern fire are well known. Application of these principles can help to minimize the negative impacts of fuels treatment and restoration activities as well as inform post-fire inventory, monitoring, stabilization and rehabilitation plans. Critical to achieving this is the application of good local, site-specific knowledge about the combustion and fire environments juxtaposed to cultural resources. Currently, the application of fire principles to the wise management of cultural resources in fire prone environments is largely qualitative. We can bound the conditions where problems are more versus less likely to occur but we cannot predict them with accuracy because of the wide variation in field conditions. Research is needed to improve our ability to predict energy release and temperature histories associated with burning of various fuel beds. Improved fire science, when coupled with knowledge about the location and material characteristics of cultural resources, will lead to refined predictions and improved guidance for management of cultural resources.

Appendix 2-1—A Field Guide to Fire Severity Terminology and Classification

Fire Characteristics: Fire Intensity Classes

Fires burn throughout a continuum of energy release rates (table A-1) (Artsybashev 1983; Rothermel 1991; Rowe 1983; Van Wagner 1983). Ground fires burn in compact fermentation and humus layers and in organic muck and peat soils where they spread predominantly by smoldering (glowing) combustion and typically burn for hours to weeks. Forward rates of spread in ground fires range on the order of several inches (decimeters) to yards (meters) per day. Temperatures are commonly in excess of 300 °C (572 °F) for several hours (Agee 1993; Frandsen and Ryan 1986; Hartford and Frandsen 1992; Ryan and Frandsen 1991). The conditions necessary for ground fires are organic soil horizons greater than about 4 to 6 cm (1.6 to 2.4 in) deep and extended drying (Brown and others 1985; Miyanishi 2001; Reinhardt and others 1997). Surface fires spread by flaming combustion in loose litter, woody debris, herbaceous plants and shrubs, and trees roughly less than 2 m (6 ft) tall. Under marginal burning conditions, surface fires creep along the ground at rates of <1 m/hr with flames less than 0.5 m high (table A-1; fig. A-1.1). As fuel, weather, and terrain conditions become more favorable for burning, surface fires become progressively more active with spread rates ranging on the order of tens of meters (yards) to kilometers (miles) per day. The duration of surface fires is on the order of one to a few minutes (Frandsen and Ryan 1986; Hartford and Frandsen 1992; Vasander and Lindholm 1985) except where extended residual burning occurs beneath logs or in concentrations of heavy woody debris. Here flaming combustion may last a few hours resulting in substantial soil heating (Hartford and Frandsen 1992). However, the surface area occupied by long-burning woody fuels is typically small, less than 10 percent and often much less (Albini 1976; Albini and Reinhardt 1995; Dyrness and Youngberg 1957; Ryan and Noste 1985; Tarrant 1956). If canopy fuels are plentiful and sufficiently dry, surface fires begin to transition into crown fires (Scott and Reinhardt 2001; Van Wagner 1977). Crown fires burn in the foliage, twigs, and epiphytes of the forest or shrub canopy located above the surface fuels. Such fires exhibit the maximum energy release rate but are typically of short duration, 30 to 80 seconds. Fires burn in varying combinations of ground, surface, and crown fuels depending on the local conditions at the specific time a fire passes a given point. Ground fires burn independently from surface and crown fires and often occur some hours after passage of the flaming front (Artsybashev 1983; Hungerford and others 1995; Rowe 1983; Van Wagner 1983). Changes in surface and ground fire behavior occur in response to subtle changes in the microenvironment, stand structure, and weather, leading to a mosaic of fire treatments at multiple scales in the ground, surface and, canopy strata (Ryan 2002).

Table A-1—Representative ranges for fire behavior characteristics for ground, surface, and crown fires (from Ryan 2002).

Fire type	Dominant combustion phase	General description	Rate of spread (meters/minutes)	Flame length (meters)	Fireline intensity (kW/meter)
Ground	Smoldering	Creeping	3.3E-4 to 1.6E-2	0.0	<10
Surface	Flaming	Creeping	<3.0E-1	0.1-0.5	1.7E0-5.8E1
		Active/Spreading	3.0E-1 to 8.3E0	0.5-1.5	5.8E1-6.3E2
		Intense/ Running	8.3E0-5.0E1	1.5 to 3.0	6.3E2 to 2.8E3
Transition	Flaming	Passive crowning	Variable[a]	3.0 to 10.0	Variable[a]
Crowning	Flaming	Active crowning	1.5E1 to 1.0E2	5.0 to 15[b]	1.0E4 to 1.0E5
		Independent crowning	Up to ca. 2.0E2	Up to ca.70[b]	Up to ca. 2.7E6

[a] Rates of spread, flame length and fireline intensity vary widely in transitional fires. In subalpine and boreal fuels it is common for surface fires to creep slowly until they encounter conifer branches near the ground, then individual trees or clumps of trees torch sending embers ahead of the main fire. These embers start new fires, which creep until they encounter trees, which then torch. In contrast, as surface fires become more intense, torching commonly occurs prior to onset of active crowning. SI units to English units conversions: meters/minute x 3.28 = feet/minute, meters x 3.28 = feet, kW/meter x 0.2891 = BTU/ft.-s.

[b] Flame lengths are highly variable in crown fires. They commonly range from 0.5 to 2 times canopy height. Fire managers commonly report much higher flames but these are difficult to verify or model. Such extreme fires are unlikely to result in additional fire effects within a stand but are commonly associated with large patches of continuous severe burning.

A number of authors have broken the fire intensity continuum into classes typically for purposes of clear communication in the context of fire suppression activities (Alexander and Cole 1994; Alexander and de Groot 1989; Andrews and Rothermel 1982; Rothermel and Reinhardt 1983; Roussopoulos and Johnson 1975; Van Wagner 1982). For similar reasons it is useful to break the fire intensity continuum into classes for documenting and communicating the effects of fire on ecosystem components (Ryan 2002) and cultural resources. Table A-1 provides a descriptive classification of fire intensity. Figures A-1.1 to A-1.5 provide a visual reference for intensity classes. As with all classifications, it is important to recognize that there is some subjectivity when placing fires into a class, particularly near class boundaries. Also, it is important to recognize that there can be considerable variation in fire intensity across small spatial distances as elements in the fire environment change or multiple fire fronts converge. The appropriate use of a classification depends on the spatial and temporal scale of concern (fig. 2-1). The first-order effects on an artifact or feature depend on the intensity and depth of burn immediately adjacent to the artifact or feature. The first-order effects to a site depend more on the modal fire intensity and depth of burn in the general area. The second-order effects depend not only on the intensity and depth of burn at the site (i.e., first-order drivers) but also the modal condition of the surrounding landscape (e.g., erosion potential) (fig. 2-22).

Figure A-1.1—Fire intensity class 1: Creeping surface fires. Examples include: A. aspen, B. longleaf pine, C. ponderosa pine, D. black spruce (note: fires often creep in black spruce forests igniting and torching trees leading to localized higher intensity and spotting but the area is burned predominantly by creeping surface fires until the fire environment becomes dryer or windier).

Figure A-1.1 (Continued)

Figure A-1.2—Fire intensity class 2: Active/Spreading Surface Fires. Examples include: A. southern pine – oak, B. ponderosa pine, C. jack pine, and D. mixed conifer (Douglas-fir – ponderosa pine).

Figure A-1.2 (Continued)

C

D

Figure A-1.3—Fire intensity class 3: Intense/Running Surface Fires. Examples include: A. lodgepole pine, B. mountain big sagebrush, C. Southern pine – oak, and D. pocosin – pond pine woodland.

Figure A-1.3 (Continued)

A

B

Figure A-1.4—Fire intensity class 4: Passive Crowning/Torching. Examples include: A. black spruce, B. mixed conifer (lodgepole pine, ponderosa pine, Douglas-fir), C. individual lodgepole pine tree torching, and D. clump of ponderosa pine and Douglas-fir trees torching.

Figure A-1.4 (Continued)

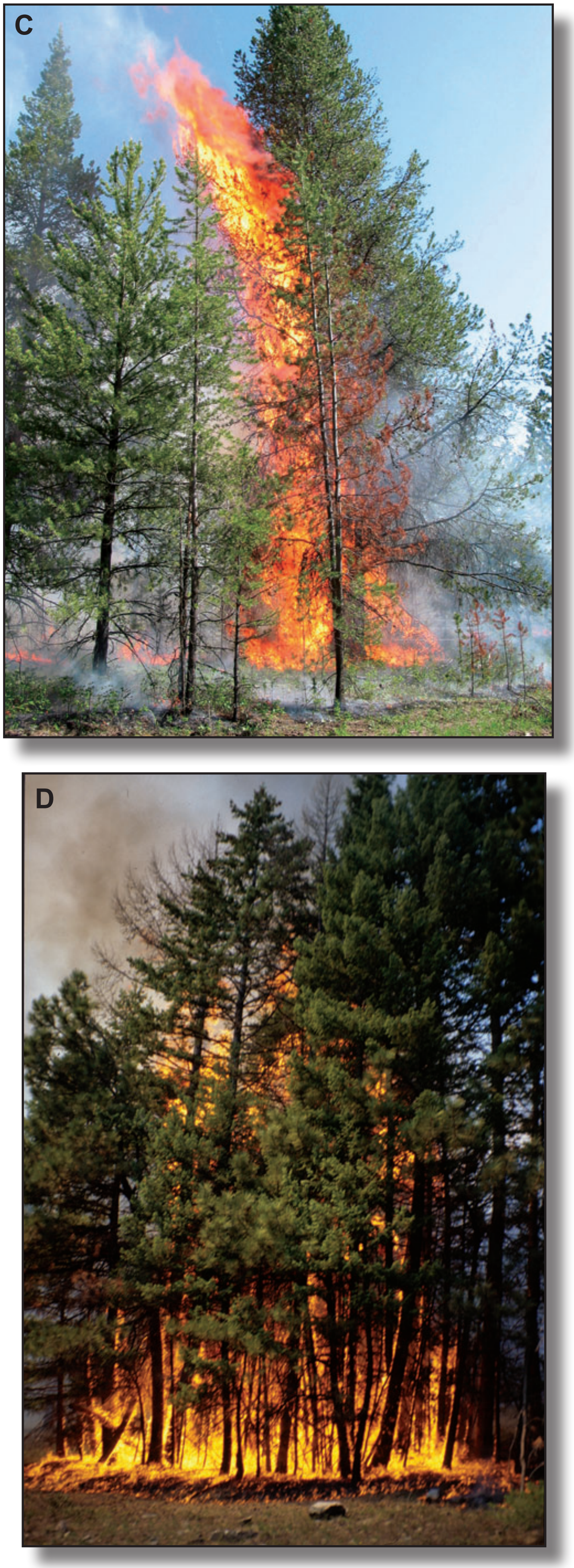

Figure A-1.5—Fire intensity class 5:Active Crowning. Examples include A. Douglas-fir, B. jack pine/black spruce, C. crown-fire in heavy chaparral, and D. black spruce – white spruce.

Figure A-1.5 (Continued)

C

D

Fire Characteristics: Depth of Burn Classes

Numerous authors have used measures of the depth of burn into the organic soil horizons or visual observation of the degree of charring and consumption of plant materials to define fire severity for interpreting the effects of fire on soils, plants, and early succession (Conrad and Poulton 1966; DeBano and others 1998; Dyrness and Norum 1983; Feller 1998; Johnson 1998; Miller 1977; Morgan and Neuenschwander 1988; Ohmann and Grigal 1981; Rowe 1983; Ryan and Noste 1985; Schimmel and Granström 1996;Viereck and Dyrness 1979; Viereck and Schandelmeier 1980; Zasada and others 1983). Depth of burn (DOB) is directly related to the duration of burning in woody fuels (Albini and Reinhardt 1995; Anderson 1969) and duff (Frandsen 1991a, b; Johnson and Miyanishi 2001). In heterogeneous fuels, depth of burn can vary substantially over short distances (e.g. beneath a shrub or tree canopy vs. the inter-canopy area, or beneath a log vs. not) (Ryan and Frandsen 1991; Tunstall and others 1976). At the spatial scale of a sample plot within a given fire, depth of burn can be classified on the basis of visual observation of the degree of fuel consumption and charring on residual plant and soil surfaces (Ryan 2002; Ryan and Noste 1985).

Ryan and Noste (1985) summarized literature on the relationships between depth of burn and the charring of plant materials. An adaptation of their table 2, updated to reflect subsequent literature (DeBano and others 1998; Feller 1998; Moreno and Oechel 1989; Pérez and Moreno 1998) and experience, particularly in peat and muck soils, is presented in table A-2. This table can be used as a field guide to classifying depth of burn on small plots (e.g., quadrats). The larger the plot area being described by a single class, the more the rating will approach the modal condition for the area and the less it will reflect finer scale variation, which may be important for understanding the fire treatment effects on a particular cultural feature. A brief description of depth of burn characteristics is provided for clarification of subsequent discussion of fire effects:

- *Unburned:* Plant parts are green and unaltered; there is no direct effect from heat. The extent of unburned patches (mosaics) varies considerably within and between burns as the fire environment (fuels, weather, and terrain) varies. Unburned patches are important rufugia for many species and are a source of plants and animals for recolonization of adjacent burned areas. Soil organic matter, structure, and infiltration rate are unchanged.
- *Scorched:* Fire did not burn the area, but radiated or convected heat from adjacent burned areas caused visible damage. Mosses and leaves are brown or yellow but species characteristics are still identifiable. Soil heating is negligible. Scorched areas occur to varying degrees along the edges of more severely burned areas. As it occurs on edges, the area within the scorched class is typically small (Dyrness and Norum 1983). Soil effects are typically similar to those in unburned areas. The scorched class may, however, have utility in studies of micro-variation of fire effects.
- *Light:* In forests, the surface litter, mosses, and herbaceous plants are charred-to-consumed but the underlying forest duff or organic soil is unaltered. Fine dead twigs up to 0.6 cm (0.2 in) are charred or consumed but larger branches remain. Logs may be blackened but are not deeply charred except where two logs cross. Leaves of understory shrubs and trees are charred or consumed but fine twigs and branches remain. In non-forest vegetation, plants are similarly charred or consumed; herbaceous plant bases are not deeply burned and are still identifiable. Charring of the mineral soil is negligible. Light DOB is associated with short duration fires either because of light fuel loads (i.e., low fuel mass per unit area), high winds, moist fuels, or a combination of these three factors. Typical forest-floor moisture contents associated with light DOB are litter (O_i) 15-25 percent and duff (O_e+O_a) greater than 125 percent. Impacts on infiltration and runoff are typically minimal. Reduction in leaf area may decrease interception and evapotranspiration but, as most soil-stored seeds, rhizomes, and other underground plant structures survive (Miller 2000; Ryan 2000), hydrologic recovery is typically rapid. Other names associated with this class include low depth of burn and low soil burn severity. Figure A-2.1 illustrates light depth of burn characteristics.
- *Moderate:* In forests, the surface litter, mosses, and herbaceous plants are consumed. Shallow duff layers are completely consumed and charring occurs in the top 1.2 cm (0.5 in) of the mineral soil. Where deep duff layers or organic soils occur, they are deeply burned to completely consumed resulting in deep char and ash deposits but the texture and structure of the underlying mineral soil are not visibly altered. In uplands, trees of late-successional, shallow-rooted species often topple or are left on root pedestals. Fine dead twigs are completely consumed, larger branches and rotten logs are mostly consumed, and logs are deeply charred. Burned-out stump holes and rodent middens are common. Leaves of understory shrubs and trees are completely consumed.

Table A-2—Visual characteristics of depth of burn in forests, shrublands, and grasslands from observations of ground surface characteristics, charring, and fuel consumption for unburned and light (Part A), moderate (Part B) and deep (Part C) classes (modified from Ryan and Noste 1985; Ryan 2002; Neary and others 2005).

	Vegetation type		
Depth of burn Class	**Forests**	**Shrublands**	**Grasslands**
Unburned			
Surface characteristics	Fire did not burn on the surface.		
Fuel characteristics	Some vegetation injury may occur from radiated or convected heat resulting in an increase in dead fuel mass.		
Occurrence:	A wide range exists in the percent unburned in natural fuels. Under marginal surface fire conditions, the area may be >50%. Under severe burning conditions, <5% is unburned. Commonly, 10-20% of the area in slash burns is unburned. Unburned patches provide refugia for flora and fauna.		
Light			
Surface characteristics	Leaf litter charred or consumed. Upper duff charred but full depth not altered. Gray ash soon becomes inconspicuous leaving a surface that appears lightly charred to black.	Leaf litter charred or consumed, but some leaf structure is discernable. Leaf mold beneath shrubs is scorched to lightly charred but not altered over its entire depth. Where leaf mold is lacking, charring is limited to <0.2 cm (0.1 in) into mineral soil. Some gray ash may be present but soon becomes inconspicuous leaving a blackened surface beneath shrubs.	Leaf litter is charred or consumed but some plant parts are discernable. Herbaceous stubble extends above the soil surface. Some plant parts may still be standing, bases not deeply burned, and still recognizable Surface is black after fire but this soon becomes inconspicuous. Charring is limited to <0.2 cm (0.1) into the soil.
Fuel characteristics	Herbaceous plants and foliage and fine twigs of woody shrubs and trees are charred to consumed but twigs and branches >0.6cm (0.2 in) remain. Coarser branches and woody debris are scorched to lightly charred but not consumed. Logs are scorched to blackened but not deeply charred. Rotten wood is scorched to partially burned.	Typically, some leaves and twigs remain on plants and <60% of brush canopy is consumed. Foliage is largely consumed whereas fine twigs and branches >0.5 cm (0.2 in) remain.	Typically, 50 to 90% of herbaceous fuels are consumed and much of the remaining fuel is charred.
Occurrence	Light DOB commonly occurs on 10-100 percent of the burned area in natural fuels and 45-75% in slash fuels. Low values are associated with marginal availability of fine fuels whereas high values are associated with continuous fine fuels or wind-driven fires.	In shrublands where fine fuels are continuous, light DOB occurs on 10-100% depending on fine fuel moisture and wind. Where fine fuels are limited, burns are irregular and spotty at low wind speeds. Moderate to high winds are required for continuous burns.	Burns are spotty to uniform, depending on grass continuity. Light DOB occurs in grasslands when soil moisture is high, fuels are sparse, or fires burn under high wind. This is the dominant type of burning in most upland grasslands.
Moderate			
Surface characteristics	In upland forests, litter is consumed and duff deeply charred or consumed, mineral soil not visibly altered but soil organic matter has been partially pyrolyzed (charred) to a depth >1.0cm (0.4 in). Grey or white ash persists until leached by rain or redistributed by rain or wind. In forests growing on organic soils, moderate DOB fires partially burn the root-mat but not the underlying peat or muck.	In upland shrublands, litter is consumed. Where present, leaf mold deeply charred or consumed. Charring 1 cm (0.4 in) into mineral soil, otherwise soil not altered. Gray or white ash quickly disappears. In shrub-scrub wetlands growing on organic soils, moderate DOB fires partially burn the root-mat but not the underlying peat or muck.	In upland grasslands, litter is consumed. Charring extends to <0.5 cm (0.2 in) into mineral soil, otherwise soil not altered. Gray or white ash quickly disappears. In grasslands, sedge meadows and prairies growing on organic soils moderate DOB fires partially burn the root-mat but not the underlying peat or muck.

Table A-2—Continued

	Vegetation type		
Depth of burn Class	**Forests**	**Shrublands**	**Grasslands**
Fuel characteristics	Herbaceous plants, low woody shrubs, foliage and woody debris <2.5 cm (1 in) diameter consumed. Branch-wood 2.5 to 7.5 cm (1-3 in) 90+ percent consumed. Skeletons of larger shrubs persist. Logs are deeply charred. Shallow-rooted, late successional trees and woody shrubs typically topple or are left on pedestals . Burned-out stump holes are common.	Herbaceous plants are consumed to the ground-line. Foliage and branches of shrubs are mostly consumed. Stems <1 cm (0.4 in) diameter are mostly consumed. Stems >1 cm (0.4 in) mostly remain.	Herbaceous plants are consumed to the ground-line.
Occurrence	Moderate DOB occurs on 0-100% of natural burned areas and typically 10-75% on slash burns. High variability is due to variability in distributions of duff depth and woody debris.	Moderate DOB varies with shrub cover, age, and dryness. It typically occurs beneath larger shrubs and increases with shrub cover. Typically, burns are more uniform than in light DOB fires.	Moderate DOB tends to occur when soil moisture is low and fuels are continuous. Then burns tend to be uniform. In discontinuous fuels high winds are required for high coverage in moderate DOB.
Deep			
Surface characteristics	In forests growing on mineral soil, the litter and duff are completely consumed. The top layer of mineral soil visibly altered. Surface mineral soil structure and texture are altered and soil is oxidized (reddish to yellow depending on parent material). Below oxidized zone, >1 cm (0.4 cm) 2of mineral soil appears black due to charred or deposited organic material. Fusion of soil may occur under heavy woody fuel concentrations. In forests growing on organic soils, deep DOB fires burn the root-mat and the underlying peat or muck to depths that vary with the water table.	In shrublands growing on mineral soil, the litter is completely consumed leaving a fluffy white ash surface that soon disappears. Organic matter is consumed to depths of 2-3 cm (0.8-1.2 in). Colloidal structure of surface mineral soil is altered. In shrub-scrub wetlands growing on organic soils deep DOB fires burn the root-mat and the underlying peat or muck to depths that vary with the water table.	In grasslands growing on mineral soil, the litter is completely consumed leaving a fluffy white ash surface that soon disappears. Charring to depth of 1 cm (0.4 in) in mineral soil. Soil structure is slightly altered. In grasslands growing on organic soils, deep DOB fires burn the root-mat and the underlying peat or muck to depths that vary with the water table.
Fuel characteristics	In uplands, twigs and small branches are completely consumed. Few large, deeply charred branches remain. Sound logs are deeply charred and rotten logs are completely consumed. In wetlands twigs, branches, and stems not burned in the surface fire may remain even after subsequent passage of a ground fire.	In uplands, twigs and small branches are completely consumed. Large branches and stems are mostly consumed. In wetlands twigs, branches, and stems not burned in the surface fire may remain even after subsequent passage of a ground fire.	All above ground fuel is consumed to charcoal and ash.

Figure A-2.1—Light depth of burn. A. sagebrush-grass (mixture of light depth-of-burn (DOB) beneath sagebrush and unburned grass), Beaverhead-Deerlodge National Forest, Montana; B. ninebark mountain shrub community (mixture of light with some moderate under denser shrubs), Lolo National Forest, Montana; C. pocosin – pond pine woodland, Dare County Bombing Range, North Carolina; D. feather moss, Tetlan National Wildlife Refuge, Alaska (transitions to moderate DOB on left); E. glacier lilies growing from just beneath lightly charred lodgepole pine duff, Yellowstone National Park, Wyoming (lethal heat penetration into soil <5 mm (0.2 in.) as evidenced by tissue regrowth); F. sagebrush – grass, Bridger-Teton National Forest, Wyoming; G. ponderosa pine (note litter charred but underlying fermentation uncharred; H. following crown fire in jack pine-black spruce in Northwest Territories, Canada (note logs not charred on bottom, surface needles blackened but not consumed); I. light logging slash, Mt. Hood National Forest, Oregon (note logs and surface litter blackened but not deeply charred, much fine woody debris was unconsumed).

Figure A-2.1 (Continued)

C

D

Figure A-2.1 (Continued)

E

F

Figure A-2.1 (Continued)

G

H

Figure A-2.1 (Continued)

I

Fine twigs and branches of shrubs are mostly consumed (this effect decreases with height above the ground), and only the larger stems remain. Shrub stems frequently burn off at the base during the ground fire phase leaving residual aerial stems that were not consumed in the flaming phase lying on the ground. In non-forest vegetation, plants are similarly consumed, herbaceous plant bases are deeply burned and unidentifiable. In shrublands, average char-depth of the mineral soil is on the order of less than 1 cm (0.4 in) but soil texture and structure are not noticeably altered. Charring may extend 2 to 3 cm (0.8 to 1.2 in) beneath shrubs where deep litter and duff were consumed. Typical forest-floor moisture contents associated with moderate DOB are litter (O_i) 10 to 20 percent and duff (O_e+O_a) less than 75 percent. The depth at which plant tissues are killed and hydrophobic layers are formed increases with the depth of the organic horizon, or log diameter, consumed. Ash depth also increases with depth of duff consumed. Figure A-2.2 illustrates moderate depth of burn characteristics.

- *Deep:* In forests growing on mineral soil, the surface litter, mosses, herbaceous plants, shrubs, and woody branches are completely consumed. Sound logs are consumed or deeply charred. Rotten logs and stumps are consumed. The top layer of the mineral soil is visibly oxidized, reddish to yellow. Surface soil texture is altered and, in extreme cases, fusion of particles occurs. A black band of charred organic matter 1 to 2 cm (0.4 to 0.8 in) thick occurs at variable depths below the surface. The depth of this band increases with the duration of extreme heating. The temperatures associated with oxidized mineral soil are typical of those associated with flaming >500 °C (>932 °F) rather than smoldering <500 °C (<932 °F). Thus, deep depth of burn typically only occurs where woody fuels burn for extended duration such as beneath individual logs or concentrations of woody debris, and in harvester ant mounds and litter-filled burned-out stump holes. Moisture content of logs >3 in (7.6 cm) diameter is typically <10 percent. Representative forest-floor moisture contents associated with deep depth of burn are litter (O_i) less than 15 percent and duff (O_e+O_a) less than 30 percent. In areas with deep organic soils, deep depth-of-burn occurs when ground fires consume the root-mat or burn beneath the root-mat. Trees often topple in the direction from which the smoldering fire front approached (Artsybashev 1983; Hungerford and others 1995; Wein 1983). Other names associated with this class include high depth of burn, severe burn, and high soil burn severity. We prefer the term "deep" as it better reflects the physical process of heat penetration into the soil. Figure A-2.3 illustrates deep depth of burn classes.

The moderate depth of burn class is a broad class. Some investigators have chosen to divide the class into two classes (c.f. Feller 1998). In practice we have found it difficult to do so on the basis of post-hoc examination of the mineral soil alone, but rely on the preponderance of the evidence, which includes reconstructing the prefire vegetative structure. The depth-of-burn characteristics are appropriate for quadrat-level descriptions. At higher spatial scales, logic needs to be developed for defining fire severity on the basis of the distribution of depth of burn classes (c.f. DeBano and others 1998; Ryan and Noste 1985).

Fire Severity Matrix

Ryan and Noste (1985) combined fire intensity classes with depth of burn (char) classes to develop a two-dimensional matrix approach to defining fire severity. The basis for these characteristics is that fire-intensity classes qualify the relative energy release rate for a fire, whereas depth-of-burn classes qualify the relative duration of burning. Their concept focuses on the ecological work performed by fire both above ground and below ground. The matrix provides an approach to classifying the level of fire treatment or severity for ecological studies at the scale of the individual and the community. The approach has been used to interpret differences in plant survival and regeneration (Smith and Fischer 1997; Willard and others 1995) and to field-validate satellite-based maps of burned areas (White and others 1996). The matrix has been used to develop a conceptual model of post-fire regeneration potential (Ryan 2002) and potential impacts on soils and watersheds (Neary and others 2005). The Ryan and Noste (1985) conceptual model of fire severity can also be used and as a means of documenting the level of fire treatment in prescribed fires and wildfires for the purposes of evaluating the effects of fire on cultural resources (table A-3). Other investigators have developed similar classifications (c.f., DeBano and others 1998; Jane and others 2009) with somewhat different class definitions. However, they all employ similar logic in that the rate of organic matter consumption (represented by rate of energy release in fire intensity classes) and the magnitude of organic matter consumption (represented in depth of burn classes) affect numerous ecosystem states and processes.

A

Figure A-2.2—Moderate depth of burn. A. complete duff consumption aspen-mixed conifer Bridger-Teton National Forest, Wyoming; B. complete duff consumption aspen, Caribou National Forest, Idaho; C. complete duff consumption beneath white ash, light DOB in blackened areas, Douglas-fir, Lubrecht Experimental Forest, Montana; D. Sagebrush – grass Yellowstone National Park, Wyoming (moderate DOB mid ground, elsewhere lite DOB and unburned); E-F. following a crown-fire in jack pine – black spruce Northwest Territories, Canada (note litter consumed to white ash but underlying fermentation and humus not altered (light DOB) except where residual burning of crossed logs (E) resulted in moderate DOB (F) where duff and logs were completely consumed at their intersection; G. moderate depth of burn on an extremely fragile high elevation site (obsidian-derived soil, no vascular plants survived or colonized 1 year after 1988 North Fork Fire, a crown-fire/moderate depth-of-burn fire, Moose Creek Research Natural Area, Targee, National Forest, Idaho); H. Douglas-fir duff mostly consumed but underlying mineral soil not visibly altered and logs charred, Willamette National Forest, Oregon.

Figure A-2.2 (Continued)

Figure A-2.2 (Continued)

D

E

Figure A-2.2 (Continued)

F

G

Figure A-2.2 (Continued)

H

A

Figure A-2.3—Deep depth of burn class. A. charred, black layer beneath oxidized soil and ash; B. charred, black layer beneath oxidized soil and ash plus deeply charred log; C. charred, black layer beneath oxidized soil; D. 20 cm (8 in.) duff pin (nail) documented duff consumption next to a partially rotten log that burned out. Deep ash deposits are occasionally mistaken for oxidized mineral soil. Ash is fine and powdery when dry and slick and greasy when wet whereas oxidized soil retains pebbles and granularity. The black zone corresponds roughly with the depth at which 250 °C (482 °F) was maintained in the soil profile. E. deeply burned soil and western larch stem resulting from burnout of heavy concentration of coarse woody debris, Lolo, National Forest, Montana; F. reburned forest (note: second fire consumed logs created by first fire leading to deep DOB (light color) whereas intervening areas had little residual fuel and less soil heating (dark color); G. ponderosa pine stump-hole and log burn-out (note: localized deep DOB where stump and log burned out, otherwise light DOB and unburned except moderate DOB where duff mounds burned-out beneath old pine (not shown).

Figure A-2.3 (Continued)

B

C

Figure A-2.3 (Continued)

D

E

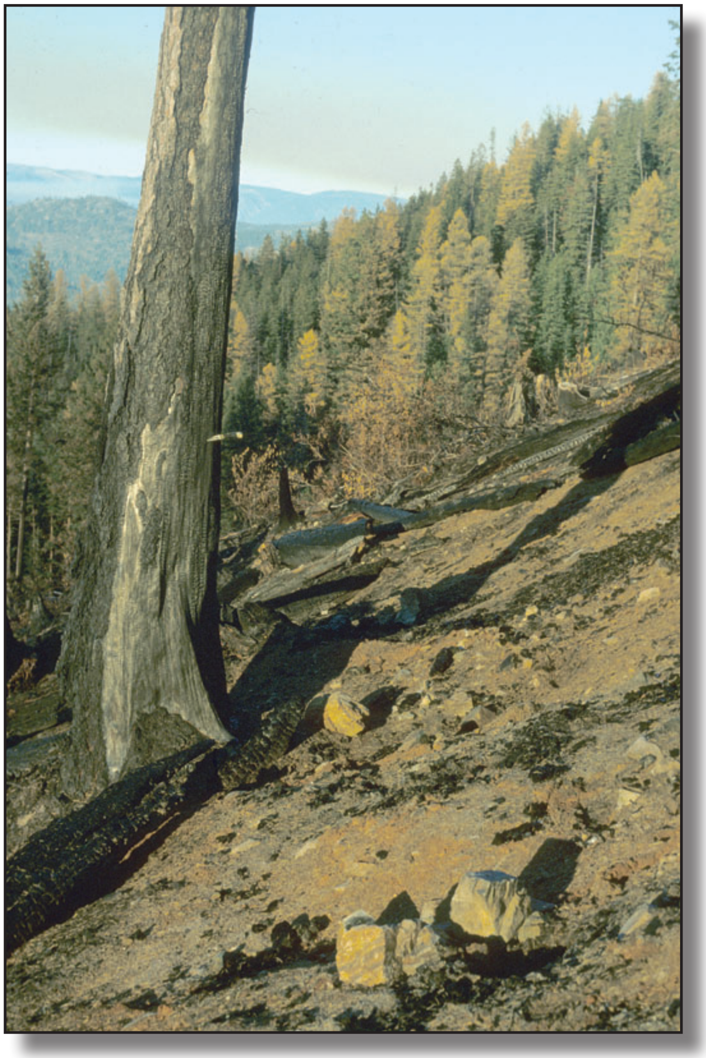

Figure A-2.3 (Continued)

F

G

Table A-3—Fire severity matrix for evaluating and documenting the effects of fire on cultural resources. Fire intensity classes relate to the heat pulse up and the potential to damage above ground cultural resources (artifacts) and those exposed on the pre-fire surface of the ground. Depth of burn classes relate to the heat pulse down and the potential to damage cultural resources in the soil.[a]

Fire severity matrix for cultural resources				
	Depth of burn class			
Fire intensity class	**Unburned**	**Light**	**Moderate**	**Deep**
Crowning	Limited to transition zone between burned and unburned. Above ground resources may be damaged by radiant heat or combustion deposits (tar, soot, etc.).	Common occurrence in early-season fires when humus is wet (>120%), in undisturbed wetlands with high water table, and in areas with exposed mineral soil. Above-ground and surface CR exposed to high temperatures for short duration and combustion deposits. Damage restricted to exposed CR and top 1 cm (0.4 in) in soil.	Common occurrence in forests with moderate duff depths (5 to 10 cm [2-3.9 in]) and duff moisture <50%. Above-ground CR exposed to high temperatures for short duration and combustion deposits. Severe damage is common to all exposed CR and artifacts in top 5 cm (2 in) of the ground.	Common in forests with deep duff (>10cm [3.9 in]) or heavy CWD. High energy release rate and long residence time associated with deep depth of burn leads to maximum potential damage to both above and below ground CR. Available fuel approximately equals total fuel. Damage may extend to artifacts in top 10 cm (3.9 in) of mineral soil. Loss of canopy interception, deep soil heating, and heavy ash increase potential for post-fire erosion.
Torching	See above	See above. The primary distinction is in the spatial scale uniformity of heating to exposed CR.	See above. The primary distinction is in the spatial scale uniformity of heating to exposed CR.	See above. The primary distinction is in the spatial scale uniformity of heating to exposed CR.
Intense running surface fire	See above. Damaging distance from burned edge is less due to lower intensity.	Common in fire environments where heavy surface fuel loadings burn under low humidity and moderate to strong winds and when duff is shallow (<5 cm [2 in]) or moist (>120%) and where over-story stratum is sparse or vertical fuel continuity is poor due to high crown base height. Effect of CR similar to above except that height of thermal damage restricted to < 5 meters (16 feet) above ground. Damage restricted to exposed CR and top 1 cm in soil.	Common in fire environments where heavy surface fuel loadings burn under low humidity and moderate to strong winds and where duff is moderately deep (5 to 10 cm [2-3.9 in]) and dry (duff moisture <50 %). Often occurs in head-fires and on the flanks of crown fires. Damage common to exposed CR <5 m (16 ft) above the ground and artifacts in top 5 cm of mineral soil.	Common in fire environments where heavy surface fuel loadings burn under low humidity and moderate to strong winds and where duff is deep (>10 cm [3.9 in]) and dry (duff moisture <80 %, once ignited peat soil and deep organic soils may burn up to 120% moisture content), and beneath rotten logs. Often occurs in head-fires and on the flanks of crown fires. Damage common to exposed CR <5 m (16 ft) above the ground and artifacts in top 10 cm (3.9 in) of mineral soil.

Table A-3—Continued

Fire severity matrix for cultural resources				
	Depth of burn class			
Fire intensity class	**Unburned**	**Light**	**Moderate**	**Deep**
Actively spreading surface fire	Edge effect intermediate between above and below	Common in numerous fire environments where surface fuels support active burning. Effects on CR intermediate to above and below. Less thermal effects than above, residue deposits possible to exposed CR at the surface or <4 meters (13 feet). Thermal damage restricted to exposed CR near the surface (<2 meters [6.5 feet] above ground) and top 1 cm (0.4 in) in soil.	Common in numerous fire environments where surface fuels support active burning. Effects on CR intermediate to above and below. Less thermal effects than above, residue deposits possible to exposed CR at the surface or <4 meters (13 feet). Thermal damage restricted to exposed CR near the surface (<2 meters [6 feet] above ground) and top 5 cm (2 in) in soil.	Common in numerous fire environments where surface fuels support active burning and duff is deep (5-to-10 cm deep (>10 cm [3.9 in]) and moderately dry (<80% once ignited peat soil and deep organic soils may burn up to 120% moisture content), and beneath rotten logs. Thermal damage common to exposed CR near the surface (<2meters [6 feet] above ground) and artifacts in top 10 cm (3.9 in) of mineral soil.
Creeping surface fire	Edge effect on exposed surface artifacts limited to a few millimeters.	Common under marginal burning conditions due to sparse fine fuels or high humidity, and in backing fires. Thermal damage restricted to exposed CR near the surface and top 1 cm in soil.	Common under marginal burning conditions due to sparse fine fuels or high humidity, and in backing fires where duff is intermediate (5-to 10 cm deep [2-3.9 in]) and dry (<50%). Thermal damage common to exposed CR near the surface and artifacts in top 5 cm (2 in) of soil.	Common under marginal burning conditions due to sparse fine fuels or high humidity, and in backing fires where duff is >10 cm (3.9 in) deep and moderately dry (<80%), and beneath rotten logs. Thermal damage common to exposed CR near the surface and artifacts in top 10 cm of mineral soil.
Unburned	No direct effect of fire on CR at the fine scale. Isolates unaffected. The burn mosaic may alter the visual character and experience of the cultural landscape	NA	NA	NA

[a] Typically, the burn- no-burn boundary is mineral soil surface in upland forests, woodlands, shrublands, and grasslands. In wetlands and temperate old-growth forests with deep organic soils, fires may burn vertically until they reach a moisture limit around 100% on an oven dry basis.

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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 Propper 1990; Switzer 1974).

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

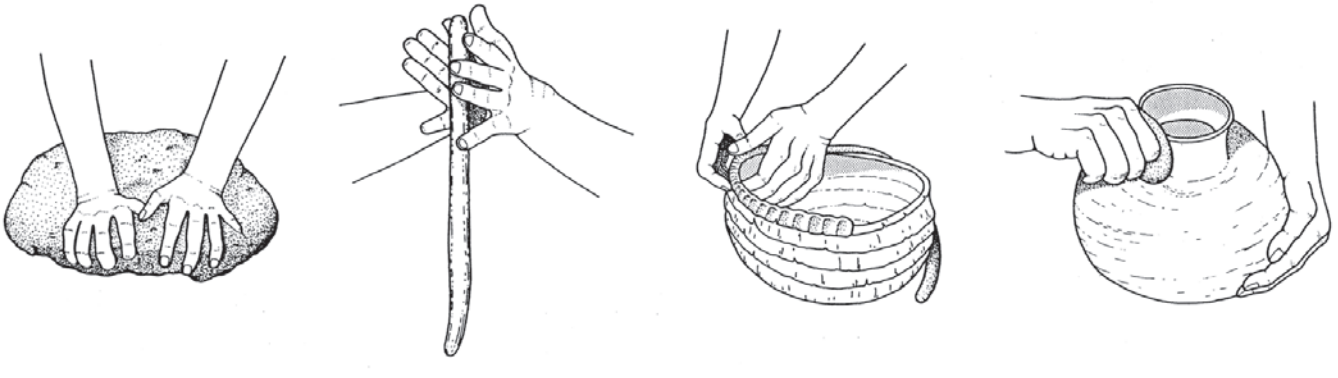

Figure 3-4—Schematic illustrating the making of a clay pot from ribbons.

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; couldtheoretically 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)

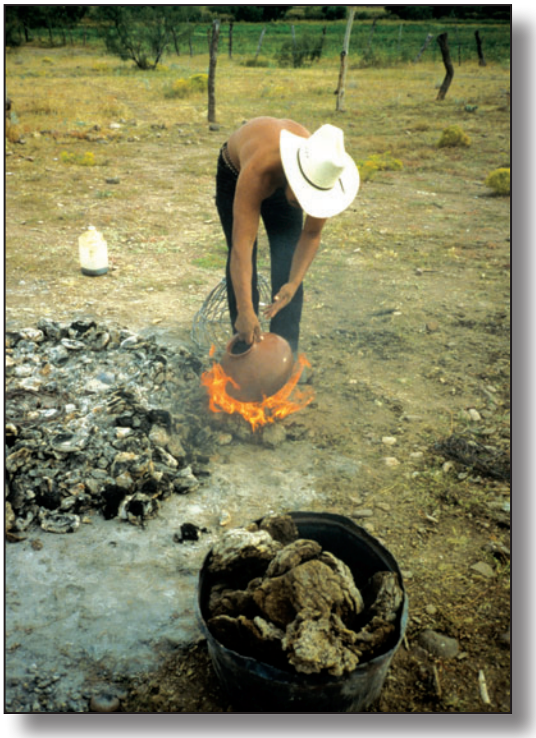

Figure 3-5—Firing of a clay pot over an open fire.

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 km^2 (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 identifiable 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.

Krista Deal

Chapter 4:

Fire Effects on Flaked Stone, Ground Stone, and Other Stone Artifacts

> *Although the action of fire upon building stones is well understood by engineers and insurance specialists, it is commonly supposed that its effect upon rocks in nature is only of minor consequence... on the contrary, fire is in some regions very important; and, under suitable conditions, it overshadows all the other factors [of weathering] combined (Eliot Blackwelder 1927).*

Introduction

Lithic artifacts can be divided into two broad classes, flaked stone and ground stone, that overlap depending on the defining criteria. For this discussion, *flaked stone* is used to describe objects that cut, scrape, pierce, saw, hack, etch, drill, or perforate, and the debris (debitage) created when these items are manufactured. Objects made of flaked stone include projectile points, knives, drills, scrapers, planes, burins, gravers, spokeshaves, choppers, saws, cores, flakes, fish hooks, hoes, and hand axes, among others. These were commonly made from chert, flint, chalcedony, petrified and opalized wood, slate, siltsone, mudstone, quartz, quartzite, obsidian, basalt, metamorphic rocks, and vitrified and welded tuff.

Ground stone distinguishes items used to pound, mash, crack, pulverize, grind or abrade minerals or plant and animal products, and includes such objects as metates, millingstones, manos or handstones, pestles, portable mortars, abraders, hammerstones, mullers, polishing stones, and paint palletes. Ground stone was often fashioned of granite, diorite, gabbro, gneiss, basalt, andesite, rhyolite, greywacke, steatite, dolomite, limestone, slate, shale, sandstone, schist and quartzite, among other types of rock.

All other stone artifacts, including a wide range of ornamental and utilitarian items made from numerous material types, are grouped and discussed separately from flaked and ground stone.

Data and research potentials associated with flaked stone objects include information related to technology, subsistence, economic exchange, and site chronology. Obsidian, basalt, tuff and chert can be subjected to geochemical analysis to identify their geographic source of origin, thus yielding information on material acquisition, economic exchange and trade networks. Obsidian and chert artifacts can also be dated, providing manufacturing and site occupation dates. The presence of particular artifact types or the selection and/or relative frequency of certain stone material types may reflect social stratification, or ethnic, linguistic, and tribal affiliations. Plant and animal residues on stone tools may yield information about tool function, food processing and consumption. It has also been speculated that some data resident in lithic artifacts may be useful in landscape reconstructions, fire histories, and determining past fuel loads.

Lithic Artifacts and Fire

Artifacts made of stone are generally the best preserved of all material types in the archaeological record, often providing the only evidence of where people lived and worked in the past. Despite its durability, stone can be affected by fire, as well as by efforts to suppress wildfires and to rehabilitate burned areas following fires.

Reported fire effects on stone artifacts include breakage, spalling, crenulating, crazing, potlidding, microfracturing, pitting, bubbling, bloating, smudging, discoloration, adhesions, altered hydration, altered protein residue, and weight and density loss. Surface artifacts tend to be altered more than those located in subsurface contexts, with protection often afforded by even a few centimeters of soil. Fewer negative effects are noted in light fuels, with increasing effects in moderately and heavily fueled fires, or at specific locations within fires where fuels are heavy, such as near or under logs. Most researchers suggest that effects in heavier fuels are a result of the increased amount of time artifacts are exposed to heat (see, for instance, Benson 2002; Buenger 2003; Deal 2002; Gaunt and others 1996; Linderman 1992). In general, the higher the temperature and the more severely charred the ground surface, the greater the reported effect.

Some Caveats

Despite the long list of effects that can occur to stone artifacts in fires, it should be noted that not all effects are adverse, nor does a single effect, even if adverse, necessarily limit the recovery of all data resident in the artifacts. For example, discoloration may hinder identification of material type, but have little impact on the recognition of artifact type or other macroscopic information, such as manufacturing technique. Likewise, few or no visible effects to artifacts may be present, but microscopic data associated with these objects, such as plant protein, blood residue or hydration rinds, may be altered or destroyed. Some effects can be both adverse and beneficial—for instance, the increased visibility afforded after fires can lead to vandalism and illegal collecting, although for archaeologists, this condition often allows more accurate recording of site features and constituents (Biswell 1989; Blakensop and others 1999; Davis and others 1992b; Hester 1989; Likins, personal communication, 1999; Moskowitz 1998; Pilles 1982 and 1984; Racine and Racine 1979; Romme and others 1993; Silvermoon 1987; Switzer 1974).

Overall, relatively little is known or reported in the literature about thermal effects on most types of stone artifacts, primarily because most research has been conducted in the aftermath of wildfires. Without pre-fire information on the material affected, or collection of standardized data concerning the fire environment, fire history, fire behavior, temperature, burn intensity, or ground charring, no inferences may be made about fire-caused damage to artifacts. This lack of information makes it difficult to compare or meaningfully summarize effects. The data on effects that is available is heavily weighted to flaked stone, and primarily to obsidian and chert.

Another difficulty in assessing fire effects on stone tools results from reports lacking explicit descriptions of criteria used to measure effects. Many articles lacked methodology of both temperature collection and how specimens were heated, making it difficult to assess if reported temperatures could be comparable. Other reports clearly indicated techniques, but were lacking important fire related information, such as weather conditions and fuel type. Yet another problem is the variability of methods used to collect temperature data. Sayler and others (1989), and Picha and others (1991) used a suite of temperature sensitive crayons, which change color according to the maximum temperature. Some researchers have used temperature sensitive pellets, lacquers and pyrometric cones (Halford 2002; Kelly and Mayberry 1980; Solomon 2002) and others used no temperature measurement at all. Pellets, lacquers, and crayons generally provide few temperatures per measured plot, present no timeframe of when the maximum temperature was reached, or fire residence time within a site. Another problem with pellets is related to their placement and where the pellets should be placed to appropriately measure temperature affecting cultural materials. In Solomon (2002), pellets were placed below the artifact; whether the pellet measured the temperature of the artifact's underside, the heat flux surrounding the artifact or the soil surface temperature is unknown. In Bennett and Kunzmann (1985), the team heated artifacts in a muffle furnace, a controlled and consistent environment where temperature change is gradual. Several others (Biswell 1989; Hemry 1995; Solomon 1999) placed artifacts within a prescribed fire management area, where heating is rapid, uneven, and temporally variable. These researchers measured pre- and post-fire conditions of the pieces and the incongruence between studies was likely due to burn location, seasonal weather patterns, fuel composition, and fuel loading differences. Buenger (2003) assessed effects using a combination of field-based and laboratory experimentation, combined with a sampling of burned-over archaeological sites. Buenger's prescribed burn experiments were conducted in a variety of fuel types, and his lab experiments were conducted by heating artifacts in a muffle furnace, and in wildland fire simulations within a large combustion chamber/wind tunnel. Buenger's wildland fire simulations, conducted at the USDA Rocky Mountain Research Station's Fire Sciences Laboratory in Missoula, Montana, are especially relevant, as he was able to simulate fires of variable intensities, while recording both time and temperature data, as well as heat flux data. In addition, Buenger placed thermocouples, set to record temperatures every second, on the upper and lower surfaces of artifacts in order to assess temperature differences on artifacts as they were burned over (2003). Buenger's study and others using thermocouples and data loggers indicate that this is at present the best method of temperature assessment. Temperatures are collected periodically during heating and provide maximum, average, and minimum temperatures and duration of heating. The collection of data is systematic and different studies may be compared to show variability of effects between sites and artifacts.

Even when the data collection criteria are stated, results can be misinterpreted. For instance, one widely referenced source (Bennett and Kunzmann 1985) states "severe alteration of inorganic materials is not to be expected at temperatures below 400 to 500 °C (752 to 932 °F)." This temperature range has been cited in training documents and prescribed burn plans as a critical temperature threshold below which few, if any, effects are expected. Bennett's and Kunzmann's (1985) primary criterion for determining effect was a change in weight, and they qualified their statement with "if [burned for] less than 1/2 hour." Reported "critical threshold temperatures" for inorganic materials vary widely, ranging from a relatively cool 200 °C (392 °F) (Silvermoon 1987), to 300 °C (572 °F) (Hemry 1995; Lissoway and Propper 1988), to 400 °C (752 °F) (Biswell 1989), to between 400 and 500 °C (752 to 932 °F) (Bennett and Kunzmann 1985), to 426 °C (800 °F) (Linderman 1992), to a hotter range of 500 to 600 °C (932 to 112 °F) (Kelly 1981).

In addition to the wide range of temperatures reported, another problem with using the "critical temperature" approach is that it implies that temperature alone accounts for the effects, without consideration of other critical elements, such as heating methods, temperature measurement mechanisms, burning conditions, fuel loading, or residence time. In fact, if the duration of heat is extended, some effects can occur at dramatically lower temperatures, similar to those occurring at more extreme temperatures in shorter periods of time.

Further, many reports cite the critical temperature threshold for effects without defining exactly what it is that is being critically altered. For instance, these reports often lump all lithic items together, and often without discussions of "artifact-stored information" (Bennett and Kunzmann 1985), such as obsidian hydration, pigments or protein residues. In these instances, effects statements are based on visual observations alone, without attempts to discern whether other data potentials have been affected. In addition, few studies have looked at the effects of slow versus rapid cooling.

Flaked Stone

Much of the research and available data on thermal effects on flaked stone has been categorized by toolstone type, with most research focused primarily on chert and obsidian.

Chert: Flint, Jasper, Chalcedony, and Related Silicates

Chert was sometimes deliberately heated during the prehistoric manufacture of tools in order to improve its flaking characteristics. Researchers have found that slowly heating chert can improve flaking characteristics and enhance workability. Replicative studies of heat-treating techniques have provided substantial data relating temperatures and duration of heating to changes in chert (Bleed and Meier 1980; Griffiths and others 1987; Luedtke 1992; Rick 1978). The temperature range that improves flaking characteristics for most chert is from 250 °C to 450 °C (482 °F to 842 °F) when heated and cooled slowly, with the length of exposure to heat varying from 30 minutes to as long as 72 hours (Luedtke 1992). Several researchers report similar effects from heating chert at lower temperatures for an extended period of time, or from heating at higher temperatures for a shorter amount of time (Griffiths and others 1987; Rick 1978). Chert has a temperature range below which there will be no improvement to flaking, no matter how long it is exposed to heat, and above which the chert becomes unworkable, probably due to impurities, water content, and grain size (Luedtke 1992). Compositionally dissimilar chert will react differently to heat.

The most obvious changes to heat-treated cherts are in color and internal luster. In areas where chert sources vary by visible characteristics such as color (see Luedtke 1992), external color change can make visual source determinations difficult or impossible (Perkins 1985), or lead to misidentification as another type of toolstone (Anderson and Origer 1997). Although not all cherts change color when heated, most will change luster on the *interior*, often going unnoticed until a flake is removed after heat treatment. Temperatures at which color and luster are altered vary by chert source. Color changes have been noted between 240 °C (464 °F) and as high as 800 °C (1472 °F), and luster between 121 °C (249.8 °F) and 400 °C (752 °F) (Mandeville 1971; Perkins 1985; Picha and others 1991; Purdy 1974; Purdy and Brooks 1971).

Internal change in luster is often the best indication that artifacts have been thermally altered, although distinguishing between deliberate cultural heat treatment and the effects of fires can prove difficult (Luedtke 1992; Rogers and Francis 1988; Rondeau 1995). When heated, the external surfaces of cherts tend to become optically dull (that is, non-reflective of light). Bennett and Kunzmann (1985) found this occurred at temperatures of 600 °C to 800 °C (1112 °F to 1472 °F), whereas Buenger (2003) first noted this effect at 300 °C (572 °F). Perkins (1985) suggested the presence of lustrous and relict dull flake scars on the same piece is a good indication the object was deliberately heat-treated, and not subsequently altered in a fire. Complete artifacts displaying all optically dull surfaces, combined with potlidding and crazing, are likely to have been subjected to a post-manufacturing fire.

Chert from different sources will fracture at different temperatures, although most reportedly fracture between 350 °C and 550 °C (662 °F and 1022 °F) (Buenger 2003; Luedtke 1992; Purdy 1974; Rick 1978; Schindler and others 1982). At temperatures between 350 °C and 400 °C (662 °F and 752 °F), chert can become distorted or brittle in as little as 20 minutes (Luedtke 1992; Purdy 1974). Some chert will explode when raised to these temperatures rapidly, but not when temperatures are elevated slowly (Luedtke 1992; Purdy 1974). Impurities in chert can result in alterations at temperatures as low as 150 °C (302° F), or as high as 650 °C (1202 °F), with recrystallization causing chert to coarsen, appear foliated, and take on a sugary appearance (Luedtke 1992).

Heating or cooling chert rapidly or unequally can cause fracturing and breakage from thermal shock (Buenger 2003; Luedtke 1992). Thin flakes are less susceptible than bulkier cores and cobbles to thermal shock (Bennett and Kunzmann 1985; Buenger 2003; Perkins 1985; Picha and others 1991). Once heated, rapidly cooled chert will break (Luedtke 1992). Fine-grained cherts become altered at lower temperatures and suffer more thermal shock than coarse-grained ones (Mandeville 1971). Chert protected from direct heat, even if insulated by as little as one to two centimeters of sand or other material, is less susceptible to thermal shock than unprotected pieces (Flenniken and Garrison 1975; Perkins 1985). Buenger found that chert nodules were prone to thermal fracturing "when the upper surfaces are precipitously heated to approximately 550 °C [(1022 °F)] for 20 seconds, and when the temperature between the upper and lower surfaces approaches or exceeds 60 percent" (2003). After direct contact with flames, chert can become calcinated to the point of being easily crushed (Luedtke 1992; Weymouth and Williamson 1951).

Cherts altered in wildland and prescribed fires have suffered external color changes, patination, cracking, crenulated breaks, potlidding, fracturing, exploding, shattering, crazing, reddening, blackening, sooting, smudging, and vitrification (see fig. 4-1) (Ahler 1983; Bayer 1979; Benson 1999; Buenger 2003; Eisler and others 1978; Gaunt and others 1996; Katz 1999; Lentz and others1996; Likins, personal communication,1999; Lissoway and Propper 1998; Patterson 1995; Picha and others 1991; Tremaine and Jackson 1995). These modifications have occurred in low to high intensity fires of varying duration, temperature, and ground surface damage severities. In general, the longer and/or hotter fire burns, the greater the reported damage. Leudtke (1992) reports that the most common type of thermal damage to chert is fracture, either in blocky, angular chunks

Figure 4-1—Potlidding, crazing and cracking on chert thermally damaged during a heat-treatment replication experiment (sample courtesy of Rob Jackson).

with no bulbs of percussion, or more distinctively, in "pot lid" fractures, which are small, circular, convex fragments that have popped off flat surfaces (table 4-1).

Other data associated with chert artifacts can be extracted using laboratory techniques such as protein residue analysis, sourcing through macroscopic fossil content and trace element analysis, and dating via thermoluminescence (TL) or electron spin resonance (ESR) spectroscopy (Julig 1994; Luedtke 1992; Newman 1994). Fire impacts some artifacts to the point where these laboratory techniques cannot be used, or the data gathered using these techniques is suspect. TL and ESR spectroscopy have been used to determine if chert has been previously heated (Luedtke 1992; Melcher and Zimmerman 1977; Robins and others 1978). Unfortunately, we do not yet know at what temperature the ability to use these analytic techniques on chert from different sources are lost.

Obsidian

Obsidian from distinct volcanic flows has unique chemical compositions, allowing researchers to determine the source of obsidian tools and debris left on sites in prehistoric contexts (Bowman and others 1973). Few studies analyzed whether fires affect the sourcing potential of obsidian, but several studies used X-ray fluorescence and were successful in obtaining source information from surface samples subject to intense fires (Davis and others 1992b; Keefe and others 1998; Skinner and others 1995, 1997; Steffen 2002; Tremaine and Jackson 1995). However, Shackley and Dillian (2002) reported potential problems with sourcing thermally altered obsidian artifacts, noting that bonding of melted sand to the obsidian surface could create sourcing errors. Steffen (2002) observed a slight increase in trace elemental values with heating, although none to the extent that sourcing was affected. Skinner and others (1997) noted problems using X-ray fluorescence on fire-affected obsidians that had a dark patina believed to be a silica-based encrustation. Anderson and Origer (1997) reported the exterior surface of some obsidian was altered enough to make sourcing via macroscopic attributes difficult one year after a wildland fire.

The temperatures and duration of heating reported to affect obsidian varies widely. It has been suggested that some component of the fire environment (such as wood ash, soil chemistries, or soil moistures) may be contributing to observed changes (Deal 2002; Nakazawa 2002; Steffen 2002; Trembour 1979). Variation in heating within respective fires (chapter 2) may explain some of the differences in reported effects. Differences in water content in obsidian might be causing divergent heat effects (Steffen 2002). Some apparent inconsistencies may be due to observer technique, or the result of various source materials reacting differently to thermal environments because of unique chemical compositions (although Steffen 2002 documented variations in heat effects on obsidian from the same source).

Obsidian is thermally affected at varying temperatures and at differing lengths of exposure to heat. In field and lab fire experiments, obsidian has been reported to fracture, crack, craze, potlid, exfoliate, shatter, oxidize, pit, bubble, bloat, melt, become smudged, discolored, covered with residue, or rendered essentially unrecognizable (see fig. 4-2) (Anderson and Origer 1997; Bayer 1979; Buenger 2003; Davis and others 1992b; Deal 2002; Eisler and others 1978; Gaunt and Lentz 1996; Hull 1991; Johnson and Lippincott 1989; Kelly and Mayberry 1979; Lentz and others1996; Likins, personal communication, 1999; Lissoway and Propper 1988; Nakazawa 1999, 2002; Origer 1996; Pilles 1984; Rogers and Francis 1988; Skinner and others 1997; Steffen 1999, 2002; Steffen and others 1997; Stevenson and others 1985; Traylor and others 1983; Trembour 1979). Buenger (2003) found that some of these effects could be produced when temperatures peaked between 500 and 600 °C (932 and 1112 °F) within 40 to 50 seconds, and when the temperatures were sustained within 100 °C (212 °F) for as little as 5 to 32 seconds. Steffen (2002)

Table 4-1—Some reported thermal effects on chert.

Temperature (°C)	Temperature (°F)	Effect [a]
150	302	Impurities may result in fractures
121 - 400	249.8 - 752	Change in interior luster
240 - 800	464 - 1472	Change in color on external surface
350 - 400	662 - 752	Becomes distorted, brittle, or explosive
350 - 550	662 - 1022	Fractures
600 - 800	1112 - 1472	Optical dulling of external surface

a Note: Cherts from different sources react differently to heat. Some effects can occur at lower temperatures if duration of heat is long enough. Not all cherts change color or luster when heated. Temperatures for other effects summarized in text are unknown, or variable from Luedtke (1992).

Figure 4-2—Obsidian flake altered in a prescribed fire experiment displaying adhesions, smudging, and light surface pitting.

noted the need for a standardized set of definitions to describe heat effects to obsidian, and offered (in part) the following:

> *Matte finish*: A dulling of the surface resembling weathering or a lusterless patina;
>
> *Surface sheen*: A metallic-like luster, with a reported "gun-metal" sheen attributed to organic buildup on the surface of obsidian, and a "silvery, reflective" sheen attributed to shallow microscopic crazing and the formation of small bubbles;
>
> *Fine crazing*: A delicate network of very shallow surface cracks (similar to, but contrasted with, the internal crazing observable on fire altered chert) that form a network of closed polygons, probably caused by differential thermal expansion and/or cooling;
>
> *Deep surface cracking*: Shallow crevices splitting the surface, probably due to the continued expansion and stretching of finely-crazed surfaces;
>
> *Fire fracture*: Fracture initiating from within the object, resembling deliberate reduction, but lacking bulbs of percussion, and often resulting in the complete fracture of the artifact;
>
> *Incipient bubbles*: Individual bubbles developing below the surface; and
>
> *Vesiculation*: Abundant, interconnected bubbles on the surface and interior resulting in the "puffing up" of thermally altered obsidian; in its extreme form, vesiculation can transform artifacts into a frothy, Styrofoam-like mass.

Sidebar 4-1—Stone Artifacts

Yellowstone Fires, Yellowstone National Park, 1988
References: Ayers (1988); Connor and Cannon (1991); Connor and others (1989); Davis and others (1992b)

General Information:

- Elevation: about 1,830 m (6003.9 ft) above sea level
- Vegetation: mostly forested areas of mixed lodgepole pine and Douglas Fir
- Topography: mountainous
- Type of study: post-burn assessment

Fire Description:

- Temperature range: 32.2 °C (90 °F)+ temperatures on June 24 and July 21, 25, 26, 30.
- Relative humidity: dry
- Fuel: high fuel load
- Type of fire: wildland (about 8 separate fires)
- Energy Release Component (ERC): July, August, and early September saw ratings of 22 and 23.
- Burning Index (BI): values in July and August reached 90-105

Discussion

In the summer of 1988, a series of wildfires burned approximately 6070 km^2 (1.5 million acres) of Yellowstone National Park and surrounding forestland. The high intensity wildfires created a mosaic burn pattern of severely burned areas and spots of land that had not been affected (Connor and Cannon 1991; Connor and others 1989).

After the Yellowstone fires, researchers from the Midwest Archeological Center of the National Park Service excavated archaeological sites in the burned area and assessed fire effects to the soil matrix (Connor and Cannon 1991; Connor and others 1989). Fire was found to have burned the surface layer of duff, leaving a 5-10 cm (2-3.9 in) thickness of burned material. The soil beneath this burned material was generally unaffected. The researchers also observed heavily oxidized soil beneath deadfall trees. They noted that similar lenses of burned and oxidized soil were found in the local archaeological record and interpreted as cultural features.

In 1989, Montana State University researchers, under a contract with the National Park Service, conducted fieldwork at Obsidian Cliff lithic procurement site (Davis and others 1992b). Two thirds of this lava flow had been burned severely during the 1988 fires. The researchers recorded information necessary to nominate the site as a National Historic Landmark, taking advantage of the increased ground visibility to record 59 obsidian procurement loci. The researchers observed site erosion caused by vegetation loss and noted that soil loss had caused trees to fall and upturn several cubic meters of sediment. They also described visual fire effects to obsidian and compared geochemical analyses of obsidian collected before and after the fire (Davis and others 1992b).

Minor vesiculation has been reported on obsidian heated for one hour to 700 °C (1292 °F) (Shackley and Dillian 2002). Obsidian has melted at 760 °C (1400 °F) (Trembour 1979), or suffered extreme vesiculation between 815 °C and 875 °C (1499 °F and 1607 °F) (Steffen 2001, 2002) to 1000 °C (1832 °F) (Buenger 2003) (figs. 4-3, 4-4). Extreme vesiculation has been noted in a backfire, a prescribed fire, and a campfire (Steffen 2002). Some of the most severe fire effects have been noted at quarry sites and source areas, such as those reported from the Dome Fire in New Mexico (Steffen 1999, 2001, 2002).

Figure 4-3—Bloated and melted obsidian, oven heated to 800 °C (1472 °F) (sample courtesy of Anastasia Steffen).

Obsidian is particularly valued for its dating potential. Over time, freshly exposed surfaces on obsidian absorb atmospheric moisture, creating distinct hydration bands (Evans and Meggers 1960; Friedman and Smith 1960; Michels and Tsong 1980). After certain variables such as the obsidian source, soil moistures, soil pH, and temperatures have been accounted for, the thickness of the hydration band can indicate how long a surface on a piece of obsidian has been exposed to atmospheric moisture, offering a means for establishing prehistoric site chronologies and depositional integrity. A major factor influencing the integrity of hydration bands is elevated temperature, which forces resident moisture within the hydrated layer further into, as well as out of, the obsidian, creating wide, diffuse bands with unreadable or blurred margins (Jackson, personal communication 1997; Trembour 1979, 1990).

The percentage of obsidian with measurable bands recovered after wildland fires varies widely, from a low of only 9 percent to as high as 71 percent (Jackson and others 1994b; Pilles 1984; Skinner and others 1995, 1997; Trembour 1990). Obsidian located in lightly

Figure 4-4—On right: Extreme vesiculation in obsidian oven heated to 800 °C (1472 °F); sample also suffered severe weight and density loss. On left: Unheated obsidian from same source (samples courtesy of Anastasia Steffen).

fueled areas is more likely to retain hydration than those burned under moderate or heavy fuels (Benson 2002; Deal 2002; Green and others 1997; Linderman 1992; Origer 1996). Obsidian located on the ground surface is more likely to be altered, although Skinner and others (1997) reported that hydration was erased on obsidian at depths of 6 cm (2.4 in.) in one high intensity fire.

Preliminary results of lab and prescribed fire experiments indicate, even at very low temperatures, extended exposure to heat can alter hydration bands (Benson 2002; Deal 2002; Linderman 1992; Solomon 2002). Hydration bands can become too diffused to accurately measure after 2 hours at 200 °C (392 °F) and after 1 hour at 300 °C (572 °F) (Solomon 2002). Hydration bands have been erased completely after 12 hours at 200 °C (392 °F), and after 1 hour at 400 °C (752 °F) and 432 °C (809.6 °F) (Skinner and others 1997; Solomon 2002).

As part of a post-fire hydration study, Skinner with others (1997) conducted an experiment to determine heat effects to hydration on obsidian from a single source. Skinner and others (1997) used a single flake of obsidian cut into six pieces, with each piece heated for one hour at temperatures of 100 °C to 600 °C (212 °F to 1112 °F), in 100 °C (212 °F) increments. At 100 °C (212 °F), the hydration bands were still distinct. At 200 °C (392 °F), band width had increased slightly, but was still visible and measurable. At 300 °C (572 °F), the band was difficult to measure, due to diffuse and indistinct diffusion fronts. At 400 °C (752 °F), the diffusion front was gone and the band was not measurable, but a slight bluish tint marked where the band had been. At 500 °C and 600 °C (932 °F and 1112 °F), there was no sign of a hydration band. Skinner and others (1997) concluded, in dating obsidian, interpretation problems may occur in cases of lower temperature exposures when band width is not completely erased, and the hydration age may be misread indicating an artifact is older than it really is. Conversely, with high temperature exposures, the band may be read to date an artifact as younger than it is. Similar interpretive problems have been reported by Trembour (1979, 1990) and Stevenson and others (1989b).

Steffen (2002) demonstrated that intact hydration could exist on portions of fire-affected obsidian artifacts where hydration was erased from other areas of the artifacts, when objects were partially buried during a fire, or various surfaces experienced differential exposure to intense heat. She suggests that better recognition of fire effects to obsidian could aid in selecting specific surfaces of artifacts on which to focus hydration analysis. For instance, Steffen (2002) notes that the surface of artifacts displaying crazing or vesiculation may have been exposed to heat sufficient to alter measurable hydration (table 4-2).

Since high temperatures and smoldering fires of extended duration can destroy hydration bands, Deal (2002) speculated that intact obsidian hydration data could be used as an indicator of the absence of fire or heavy fuel loads in past landscapes. Many areas of the continent bear evidence of past fire return intervals shorter than those expected from lightning (Abrams 2000; Agee 1993; Anderson 1993, 1999; Anderson and Moratto 1996; Barrett 1980; Barrett and Arno 1999; Blackburn and Anderson 1993; Bonnicksen 2000; Boyd 1999; DeVivo 1990; Hicks 2000; Johnson 1999; Kay 2000; Komarek 1968; Lewis 1973, 1980; MacLeery 1994; Pyne 1982; Olson 1995, 1999; Turner 1999; Van Lear and Waldrop 1989; Yarnell 1998). In landscapes with frequent, periodic fires, such as areas that Native Americans were managing with fire, fuels would have been reduced to the point that areas burned at fairly low temperatures with very restricted fire residence times (Deal 2002). When obsidian is found in these areas, the presence of numerous hydration readings from surface settings could help support fire history reconstructions based on ethnographic accounts of deliberate burning (Deal 2002). However, if further research indicates hydration is re-establishing relatively quickly on fire altered obsidian (see Anderson and Origer 1997), the potential to use obsidian hydration to date past fires or to indicate prior fuel conditions may be compromised.

Table 4-2—Thermally altered hydration bands on obsidian from a single source; subjected to varying temperatures for 1 hour (source: Skinner and others 1997).

Temperature °C	Temperature °F	Change to hydration band[a]
100	212	Band still distinct
200	392	Band width increased slightly, but still measurable
300	572	Band diffuse and difficult to read
400	752	Band no longer visible; faint blue tint present where band was
500+	932+	No sign of hydration band

[a] Note: Changes in hydration bands can occur at lower temperatures if exposure time is long enough. For instance, hydration bands have been erased after heating for 12 hours at 200 °C (Solomon 2002).

Several researchers have suggested past fire events are discernible on obsidian through retained alterations such as surface crazing, bubbling, partial vesiculation, diffused hydration bands (Friedman and Trembour 1983; Steffen 2002), or re-established hydration bands (Green 1999; Linderman 1992; Trembour 1979, 1990). Some obsidian samples sent to labs for hydration studies display wide, unreadable, diffuse bands, with a second distinct, readable band retained on the surface of the sample (Jackson, personal communication 1997; Origer, personal communication 1997), suggesting that the bands may have rehydrated after fires. Labs usually note the presence of diffused bands, and provide a micron reading on the intact, thinner, secondary hydration band, if one is present (Jackson, personal communication 1997). This micron reading may prove to mark a past high intensity fire event, rather than a past cultural (manufacturing) event, as has often been assumed. If one could use data from rehydrated obsidian to determine a site had been previously subjected to a fire, this could help explain why other data (pigments, protein residues, organic material) were missing.

Steffen (2002) makes the intriguing suggestion that multiple hydration rim measurements from single specimens may provide the heat exposure history of the specimen, allowing for reconstructions of fire histories. Researchers in northeastern California are plotting the distribution of what are believed to be rehydrated Archaic points as an indicator of where fires may have occurred in the past, and are using this data to reconstruct landscape-level fire histories (Green 1999). Should it prove possible to secure dates for past fires from obsidian rehydration, these approaches could potentially extend fire history data well beyond the limit of several centuries reached when dating fires from tree cores.

Basalt

Lentz (1996a) noted sooting, potlidding, oxidation, reduction, crazing, luster changes, and adhesions on lithic material, including basalt that had been in a wildfire. Eisler and others (1978) found basalt to be covered with a shiny, smooth, tar-like, brittle residue, with basalt boulders fractured into angular chunks, possibly due to rapid cooling. Tremaine and Jackson (1995) reported thermal fractures on basalt bifaces. Tremaine and Jackson (1995) were able to secure sourcing information on basalts using X-ray fluorescence after a high intensity fire (see also Skinner and others 1995 for similar results from another moderate to severe wildland fire). Blood residue analysis has been successful on basalt artifacts burnt at high intensities (Newman 1994; Tremaine and Jackson 1995). Pilles (1984) noted that thermoluminescence dates from basalt could be as much as 24 percent more recent than expected, due to fires (see also Rowlett and Johannessen 1990).

In lab experiments, Blackwelder (1927) reported 12 periods of rapid heating and cooling of a small piece of basalt resulted in no effects, although a similar piece, heated to 300 °C (572 °F) showing no visible effects, fractured after being rapidly cooled in cold water only twice. Another specimen was heated to 300 °C (572 °F) for 30 minutes with no visible changes, but when the temperature was raised to 325 °C (617 °F), the basalt lost “a few thin flakes... from the sides” (Blackwelder 1927). After heating basalt pieces to 375 °C (707 °F) for 30 minutes, a fourth sample “broke violently into a considerable number of pieces while still in the oven” (Blackwelder 1927). A block of basalt (presumably a cube about 7.6 cm (3 in) to a side) was heated to 150 °C (302 °F), with no visible changes. The temperature was then raised to 400 °C (752 °F), and after 10 minutes, flakes began to spall off, continuing “until the block was almost wholly reduced to fragments.” Another 7.6 cm (3 in) basalt cube was placed in a furnace at 600 °C (1112 °F), resulting in “small scales” breaking off after 3 minutes, and continuing for another 10 minutes (Blackwelder 1927). Blackwelder’s experiments suggest that basalt may be extremely susceptible to thermal damage in fires.

Quartz, Quartzite, Mudstone, Rhyolite, Siltstone, Slate, and Vitrified and Welded Tuff

Very little data is available on other kinds of toolstone. Quartz is an excellent thermal conductor and expands first in one direction, then another, which adds stress to the rock and leads to fractures (Luedke 1992). Thermal expansion in quartz crystals, compared as a percent increase from the volume recorded at 20 °C (68 °F), is noted as a 0.36 percent increase at 100 °C (212 °F), 0.78 percent at 200 °C (392 °F), 1.9 percent at 400 °C (752 °F) and 4.5 percent at 600 °C (1112 °F) (Dane 1942). Quartz undergoes changes in crystalline structure at 573 °C (1064 °F), and liquifies beyond the range of temperatures experienced in wildland fires, at 1723 °C (3133.4 °F) (Luedtke 1992). In lab experiments, Bennett and Kunzmann (1987) detected no weight loss to cryptocrystalline quartz at temperatures of less than 500 °C (932 °F), and Purdy (1974) found only 0.01 percent weight loss in a quartz crystal after 24 hours at 350 °C (662 °F). In areas with moderate to severe ground charring within one fire in the Sierra Nevada Mountains, milky and crystalline quartz was often covered with a black, shiny residue on all surfaces except those in contact with the ground, making it extremely difficult to identify material type during post-fire archaeological investigations (Deal 1995, 2001; Tremaine and Jackson 1995). In less severe cases, quartz was blackened and discolored.

Lentz (1996a) reported wildland fire effects (sooting, potlidding, oxidation, reduction, crazing, luster changes, and adhesions) to several different toolstone materials, including rhyolite, quartz, and quartzite sandstone. Most of these effects occurred on sites that experienced moderate and heavy charring. Fracturing, spalling, sooting, discoloration or oxidation has been reported on mudstone, quartzite, rhyolite and vitric tuff (Buenger 2003; Deal 1995; Hemry 1995; Lentz and others 1996). Surface-collected vitric tuff artifacts from a high intensity fire were successfully sourced using X-ray fluorescence (Jackson and others 1994b), and were found to retain immunological data in the form of protein residues (Newman 1994).

Ground Stone

As discussed in the introduction, ground stone objects were used to pound, mash, crack, pulverize, grind or abrade minerals or plant and animal products. Little information regarding thermal effects to ground stone artifacts or the effects of fire on use-wear patterns is available in the literature (Adams 2002), although field observations and experiments indicate that objects manufactured of different materials will react differently to heating and cooling. For instance, Pilles (1984) reported sandstone manos that were severely cracked in wildfires, where basalt manos were only blackened. Lentz (1996) indicated that all five metates in a wildfire were affected by sooting, spalling, discoloration and/or adhesions, but the single mano was not altered. Portable mortars were rendered nearly unrecognizable due to extreme fracturing in one severe wildfire (Likins, personal communication, 1999), and in another, trough metates were broken in half (Jones and Euler 1986). Effects noted to pestles have included spalling, and blackening and discoloration to the point of obscuring material type identification (Deal 1995, 2001; Foster 1980; Tremaine and Jackson 1995). See figures 4-5 and 4-6 for illustrations of a fire-affected mano and millingstone. Buenger's experiments showed sandstone blocks exhibiting color change and minor surface spalling at 200 °C (392 °F), with spalling becoming more extensive in the 400 to 500 °C (752 to 932 °F) temperature range (2003).

Figure 4-5—Granitic mano partially buried in soil within an area of intense ground charring from a wildland fire. Upper portion of mano is covered with a black, baked-on residue.

Outcrops and boulders containing mortars and milling features have been blackened, sooted, cracked, spalled, and exfoliated as a result of wildland fires (figs. 4-7, 4-8, 4-9) (Deal 1995, 2001). High fuel loading around boulders and rock walls has been reported to

Figure 4-6—Millingstone altered in a wildland fire; note discolored areas and potlidded milling surface.

Figure 4-7—White granitic bedrock mortar outcrop showing discoloration and spalling following a wildland fire. Spalling can be severe at rock outcrops where the fuels are heavy and allowed to radiate heat for extended lengths of time. This is graphically illustrated by the damage underneath the 24-inch dbh ponderosa pine that fell and smoldered on this bedrock mortar outcrop.

Figure 4-8—Note that the burning in the thicker butt-end of the log shown in figure 4-7 caused the most damage.

contribute to extensive damage (Blakensop and others 1999; Hester 1989). In one fire, major impacts on mortar outcrops resulted in the exfoliation of large sheets of rock from the intense heat (Deal 1995). Blackening of mortar rock outcrops often hampered positive identification of the material type, although soil in mortar cups protected the grinding features from damage (Deal 1995, 2001). Additional effects expected at bedrock milling features would probably be similar to those reported elsewhere for boulders and cliff faces (Blakensop and others 1999; Eisler and others 1978; Gaunt and others 1996; Hester 1989; Johnson and Lippincott 1989; Noxon and Marcus 1983; Roger 1999; Romme and others 1993; Switzer 1974). Rock faces at petroglyph and pictograph panels can also be extensively damaged by spalling in fires. Removing fuels near rock outcrops and rock art panels can help limit these types of effects.

Figure 4-9—(a) Heavy brush (manzanita) growing at the base of this granite face resulted in severe localized spalling. (b) Spalled fragments remaining attached to this granite face were easily removed by the touch of a finger.

Thermal shock, reportedly from as little heat as that generated by sunlight, and particularly when coupled with the freezing of water in cracks and pores of rock, can lead to fracturing, exfoliating and degrading of granite, basalt and limestone (Schiffer 1987). Based on field observations and experiments, Blackwelder (1927) concluded that in many forested areas of the western United States, fire was the primary agent of fracturing, spalling, and weathering in boulders and rock outcrops, rather than diurnal changes in temperature. Blackwelder defined fire weathering features at boulders and outcrops as resembling curved wedges, plates or scales, 1 to 5 cm (0.4-2 in) thick, which often taper to a thin edge (1927). Based on experiments, Blackwelder (1927) reported many igneous rocks (basalt, andesite, porphyry) will withstand rapid heating and cooling up to 200 °C (392 °F) without any damage, but will begin breaking and fracturing when cooled after being heated to higher temperatures, while granites and quartzites tolerate slow temperature changes to as high as 800 °C (1472 °F).

Pollen, phytolyths, starches, ochre and other pigments, and protein residues from plants and the blood of small mammals have been detected on ground stone (Johnson 1993; Mikkelsen 1985; Traylor and others 1983; Yohe and others 1991). These remains can be used to infer tool function, as well as the time of year a site was occupied. Fire and fire retardant can be expected to negatively impact these data types, although Tremaine and Jackson (1995) retrieved a granitic handstone from the surface of a severely burned site that yielded positive residue reactions for cat and acorn. Several other ground stone objects from this fire tested positive for acorn, deer, and rabbit (Newman 1994). Animal proteins can survive temperatures to at least 800 °C (1472 °F) (Thoms 1995). Pollen is destroyed at temperatures over 300 °C (572 °F) (see Lentz and others 1996; Romme and others 1993; Timmons 1996).

Thermal Effects on Rock Used as Heating or Cooking Stones

Stone slabs were sometimes placed over fires or hearths and used for cooking. The slabs were often shaped, and sometimes prepared by the application of oil onto the cooking surface (Adams 2002). With use, cooking slabs became oxidized and blackened; with repeated heating and cooling, some slabs became friable and sloughed off on the underside (Adams 2002). Adams (2002) reports that the oil-saturated surfaces are sometimes the only part of these cooking stones recovered in archaeological sites. Stone pot rests used to support cooking vessels in fires and hearths also became blackened and fractured from heat (Adams 2002).

Occasionally, ground stone was used as cooking stones in stone-boiling, which often led to discoloring, cracking or fracturing (although some pieces may have already been broken and only served a second career as a cooking stone; Johnson 1993). Conditions for stone-boiling are similar to burning situations in wildland or prescribed fires where fuels are heavy, the duration of heat is extended, and cold water, foam or retardant is dropped on heated stone. Post-fire studies in Mesa Verde National Park (Corbeil 2002) have shown that surfaces on porous rock like sandstone are vulnerable to damage from retardant and gel; phosphates in retardant can penetrate the rock and crystallize, turning the surface into a fine powder, and gel can dry and peel grains off of rock surfaces. In addition, retardant and gel entrap or absorb water, which can contribute to spalling. Distinguishing stone that has been fractured by wildland or prescribed fires from those previously fractured during stone-boiling or cooking hearths has proved problematic (Lentz and others 1996; Tremaine and Jackson 1995). Several researchers have suggested ways to differentiate between cultural heating and natural burning based on fracture patterns, location within particular fuel loading situations, analysis of organic residue, or luminescence analysis of mineral constituents (Hemry 1995; Kritzer 1995; Picha and others 1991; Rapp and others 1999; Seabloom and others 1991).

Experiments with rock types used in stone-boiling, roasting and oven pits, hearths, and sweat lodges have produced information concerning how various stone behaves when subjected to heat (Brink and others 1986; Kritzer 1995; McDowell-Loudan 1983; Pierce 1983, 1984; Wilson and DeLyria 1999;). Topping (1999) found that granitic rocks used to line fire pits "cracked along the axis parallel to the fire," while those embedded in the soil did not crack. Of the rocks that cracked, those with multiple breaks were "subjected to the most violent temperature shock," whereas those "subjected to the least amount of temperature shock" were only cracked roughly "in half" (1999). Blackwelder (1927) reported that a 2.7 kg (6 lbs) cobble of andesite, rapidly heated to 200 °C (392 °F) in an electric furnace, then rapidly cooled nine separate times, suffered no visible effects. A greywacke river pebble 7.6 cm (3 in) thick had "thin slabs split off along almost imperceptible planes of stratification" while still in the oven at 350 °C (662 °F) (Blackwelder 1927). Heating a piece of fine-grained granite slowly for 2 hours to a temperature of 880 °C (1616 °F), and then cooling it slowly for 10 hours, resulted in a darkening of its pink shade, and a single small crack on the surface (Blackwelder 1927).

Wilson and DeLyria (1999) determined that andesite and basalt rocks were more durable than quartzite in replicative studies with camas ovens/roasting pits.

During three successive firings, several rocks exploded within the first hour at temperatures between 150 °C and 425 °C (302 °F and 797 °F). Most damage to the rock occurred during the initial firing, with each successive firing resulting in additional damage. Rocks in the oven were fractured by spalling off thin flat potlids, or by breaking into blocky chunks, with block breakage more common to quartzite than to igneous rocks, probably due to bedding planes in quartzite.

How certain rock reacted to different rates of heating and cooling was undoubtedly well known by people in the past, as particular types of stone were selected for different thermal applications. Pierce (1983, 1984) found that quartzite cooking stones heated quickly, boiled water quickly, fractured often when heated, but rarely fractured when placed in water. Sandstone also heated rapidly, did not fracture when heated, but "became so friable that large quantities of sand were dislodged from the exterior of the stone" (Pierce 1983), and the more often sandstone was heated, the more it crumbled. Vesicular basalt took longer to heat, requiring twice the fuel of either quartzite or sandstone, but retained heat longer than either stone (Pierce 1984). Basalt tended to fracture when heated, more often than when cooled rapidly. Due to these different capacities for the storage and transfer of heat, as well as the friability of various rock types when heated, Pierce concluded that certain stones would more likely be selected for stone-boiling foods, while others, such as sandstone, were more suitable for hearth stones (1983).

Other Stone Artifacts

Vessels, cooking pots, lamps, clubs, atlatl weights, net weights, loom weights, digging stick weights, pump drill weights, plummets, bolas, pipes, gamestones, chunkey stones, charmstones, pendants, ornaments, balls, beads, earspools, lip plugs, rings, bracelets, gorgets and effigy figurines are found in various archaeological contexts throughout North America. Relatively little research has been conducted on thermal effects on these objects, although it can be expected that they would be affected much like ground stone, as they were often fashioned of the same materials. In addition, plant, animal and mineral residues on any of these could be affected by fire.

Some additional stone material types used to make the above objects include agate, alabaster, aragonite, argillite, azurite, calcite, catlinite, chalk, fluorite, galena, gypsum, hematite, jasper, jade, kaolinite, magnesite, malachite, selenite, serpentine, slate, steatite and turquoise. Of these, agate and jasper, which are varieties of chert, can be expected to react to fires in the same manner described previously for chert. Steatite can be heated to high temperatures; it stores heat and releases it slowly, making it a good choice for cooking stones and cooking vessels. Steatite has been successfully sourced using instrumental neutron activation analysis (Truncer and others 1998), the accuracy of which might be impacted by high temperature fires. Catlinite, kaolinite, and chalk, used to make pipes or cooking vessels, have limited effects at low temperatures, often only discoloring and hardening. Little is known about the effects of fire on artifacts made of the other material types, although physical constants have been recorded for some with respect to thermal expansion, density at high temperatures, thermal conductivity and diffusivity, weight loss from heating, melting and transformation temperatures, heat fusion, and heat capacity (Birch and others 1942; Dane 1942). Some of these materials turn color when heated. For instance, azurite and malachite turn black when heated, slate often whitens, gypsum becomes cloudy and opaque, magnesite turns a pinkish-brown or cream color (and was deliberately heated in the past to make beads more colorful), and turquoise turns white (Miles 1963; Mottana and others 1977). Magnesite bubbles and releases gases prior to decomposing at 1000 °C (1832 °F), and calcite "dissociates" at 1000 °C (1832 °F) (Mottana and others 1977).

Coal is a sedimentary rock, vulnerable to fire and readily combustible. In some areas in the past, coal was ground and polished into a variety of shapes including bear teeth, elk teeth, bird heads, bird claws, animal effigies, gorgets, beads, ornaments, pendants and discoidals (Cowin 1999; Fogelman 1991; Fundaburk and Foreman 1957; Graybill 1981; Griffin 1966; Redmond and McCullough 1996; Turnbow 1992). Cannel coal is highly volatile, ignites easily, burns with a luminous flame, and was once used as a substitute for candles (Bates and Jackson 1984; Yarnell 1998). Lignite, a soft brownish-black coal that becomes pasty when heated, and jet, a dense, black lignite that can be highly polished, were used as inlay on shell (Miles 1963), or made into animal forms. In the ground, coal veins ignited during wildfires can smolder for years after ignition (Wettstaed and LaPoint 1990), and several coal mines have been burning for more than a century (Maclean 1999; Pyne 1997).

Minerals such as mica and copper were also used prehistorically. Sheet mica was cut and crafted into spectacular shapes, such as bird talons, serpents, hands and bear claws, and was overlain decoratively on a variety of ornaments (Jennings 1974; Prufer 1964; Peschken 1998). Some mica objects were decorated with incising and painting; fire can smudge and destroy pigments on these delicate objects. When heated, mica loses water, becoming more friable and less flexible. Although little else is known about fire effects to mica, the thermal expansion of muscovite mica has been measured at increasing temperatures. Compared to its size at 20 °C (68 °F), it expands 0.03 percent at 100 °C (212 °F), with expansion to 0.15 percent at 200 °C (392 °F); 0.37 percent at 400 °C (752 °F); 0.66 percent at 600 °C (1112 °F); 1.3 percent at 800 °C (1472 °F); and 1.55 percent at 1000 °C (1832 °F) (Dane 1942). Expansion can lead to exfoliation of mica.

Native copper melts at 1082 °C (1979.6 °F) (Mottana and others 1977). Copper was quarried prehistorically, and in some regions, fire and cold water may have been used to separate copper from the surrounding rock overburden (Quimby 1960), after which it was cold-worked and heated prior to shaping (Farquhar and others 1998; Jennings 1974). Copper nuggets were hammered into thin sheets, which were beaten together to make thicker objects, and shaped by abrading (Lewis and Kneberg 1958) into awls, punches, chisels, flakers, harpoons, spear points, knives, adze bits, panpipes, bells, plaques, rings, effigies, breastplates, beads, ear spools, headdresses and hair ornaments. Copper was also used to overlay wooden and shell objects such as gorgets, pendants and earspools. Thin sheets were sometimes embossed by pressing the copper over a carved wooden die, painted, or decorated with feathers or fabric (Burroughs 1998; Fundaburk and Foreman 1957; Lewis and Kneberg 1958; Prufer 1964). Fire can be expected to distort, obscure or destroy decorative elements on copper.

Corrosion and oxidation often provide a protective surface on copper at archaeological sites, unless heating cracks the corrosive film and allows it to grow inward (Schiffer 1987). As temperatures increase, corrosion rates increase, with wood ash accelerating corrosion (Schiffer 1987). Copper used in modern applications discolors with a dark red or black oxide that thickens under higher heating conditions and with longer heat exposures (NFPA 1998). Prior to melting, copper blisters, exhibits surface distortions, and forms blobs and drops on its surface (NFPA 1998). After melting, the copper re-solidifies, forming irregularly shaped and sized globules that are often tapered or pointed (NFPA 1998). Several techniques have recently been used to source copper, including neutron activation (Julig and others 1992), X-ray fluorescence (Wager and others 1998), and thermal ionization mass spectrometry (Woodhead and others 1998). It is probable that fire would affect the accuracy of these analytical techniques.

Native American objects made with smelting and casting techniques adopted from French, English, and Spanish colonists include lead, pewter and brass pipes; silver bow guards and other silver work; and steatite and catlinite pipes inlaid with pewter and lead. These would be thermally altered in fires in the same manner as materials described in the chapter on historic artifacts (chapter 6). These objects date from the late 1600s through the present (Furst and Furst 1982).

Implications for Cultural Resource Protection and Fire Planning

The key factors that seem to affect the nature and extent of fire damage to archaeological resources, including lithic artifacts, are fire intensity, duration of heat, and penetration of heat into soil (Traylor and others 1983). Research shows that as temperatures increase, so do effects, and that effects increase as the length of time exposed to heat increases; if exposure time is long enough, effects can occur to stone tools even at reduced temperatures. Buenger's fire simulations show that the two most important components of the fire environment resulting in thermal effects to surface artifacts are fuel loads and wind velocity (2003). Increased fuel loads offer longer heating times, and increasing winds bend the flames closer to the ground where surface artifacts are located. Insulation from heat, even with a few centimeters of soil or incompletely consumed fuel, is often adequate in reducing impacts (Anderson and Origer 1997; Buenger 2003; Lissoway and Propper 1988; Picha and others 1991; Pilles 1984; Seabloom and others 1991). The mass of lithic artifacts is another factor determining the nature of thermal effects. More massive artifacts are more susceptible to fracture from thermal shock than thin ones, due to uneven heating and cooling (Bennett and Kunzmann 1985; Luedtke 1992; Perkins 1985).

Surface artifacts generally suffer the most damage in fires, although many will often retain data potentials, even on sites burned numerous times in the past, or that have recently been subjected to wildfires or prescribed burns. Some lithic and ground stone scatters, as well as other types of archaeological sites, are strictly limited to surface contexts, due to shallow soils or depositional history. These sites are obviously more threatened by fire than those with deep subsurface deposits. Since even shallow soils offer some protection to artifacts, one can conclude that subsurface materials will generally retain the most data potential following wildfires. However, the surface of a site at any given point in time can change as a result of numerous agents, including deflation, erosion, deposition, windthrown trees, animal burrowing and human activities. These alterations in site stratigraphy are often not obvious, even when the site is excavated. In areas of the country where bioturbation and windthrown trees commonly mix soil deposits, the material on the surface has often been found to reflect the full temporal range of site occupation, providing a snapshot of the site's chronology (Jackson 1999; Jackson and others 1994a).

Prescribed burning will result in some predictable loss of various types of data associated with stone artifacts. Losses can be anticipated to be the greatest for prescribed burns planned in areas that have not had prior fuels management projects. However, if fuels can be reduced on sites prior to burning—either through hand removal of downed fuels or hand thinning (Siefkin 2002), or by mechanical means when appropriate (see Jackson 1993; Jackson and others 1994a)—data loss will be reduced. Collecting surface samples prior to burning would secure the data possibly impacted by the prescribed burn. However, in many areas, fuels are now so dense that the presence and nature of surface artifactual materials are unknown. Burn prescriptions can also be designed to reduce potential effects. For example, a head fire might cause fewer effects to artifactual materials on the ground surface than a cooler, slower-moving backing fire, due to the increased fire residence time of the latter (Smith 2002).

Since fire suppression and exclusion began, many areas of the country have lost numerous fire cycles. These lost fire cycles represent a tremendous fuel buildup, with a resultant increase in fire intensity, burn times, and fire severity (USDA 1995), and increased threats to cultural resources (Benson 1999; Blakensop and others 1999; Gaunt and others 1996; Hester 1989; Kelly 1981; Kelly and Mayberry 1980; Lentz and others 1996; Lissoway and Propper 1988; Pilles 1984; Siefkin 2002; Wettstaed and LaPoint 1990). Since fire suppression activities usually result in the greatest disturbance and data loss on sites, it is imperative that we work toward removing fuels proactively to reduce these effects. It is ironic that in many cases, and for several artifact classes including stone tools, frequent past burning may have helped preserve certain types of data resident in artifacts, while today's wildland fires and prescribed burns are impacting and destroying the same data, because of higher fuel loading.

Future studies need to explicitly state what criteria are being used to determine effects, and what is not being analyzed. Attempts should be made to standardize data related to effects, including fire environment and fire severity, as well as alterations to artifacts. Prescribed fire experiments need more stringent methods for monitoring and reporting burn temperatures, relative humidities, fuel and soil moistures, fuel loading, fire intensity, fire severity, ground charring, and the length of time that various surface and buried artifacts are subject to heat. Effects that now appear inconsistent or contradictory might be found to align more closely, if we can understand how the variables present in the fire environment affect lithic artifacts and other cultural resources.

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Chapter 5:

Fire Effects on Rock Images and Similar Cultural Resources

Introduction

Throughout human global history, people have purposely altered natural rock surfaces by drilling, drawing, painting, incising, pecking, abrading and chiseling images into stone. Some rock types that present suitable media surfaces for these activities are fine-grained sandstones and granites, basalts, volcanic tuff, dolomites, and limestones. Commonly called rock "art," depiction of patterns, images, inscriptions, or graphic representations might be considered today as 'artistic' as is Old World Paleolithic "cave art" for example, but most of those early originators attached different cultural values to these expressions. Historic rock inscriptions made by literate persons are also of high value as "documents."

Images on rock are subject to natural weathering by several processes: freeze/thaw, wet/dry, heat/cold, wind-carried erosion materials, natural salts and minerals, ultraviolet rays, direct moisture and atmospheric conditions (fig. 5-1). Vandalism to these resources is a very serious threat in many areas (fig. 5-2). Rock surfaces may also exhibit numerous small, shallow pits or cupules, formed by pecking, chipping or abrading, or pecked curvilinear nucleated cupules (PCN) (fig. 5-3). The cupules may be in clusters or patterns on vertical or horizontal rock surfaces. Accessible rock surfaces may also be worked to produce bedrock mortars (BRM) and concave milling surfaces for processing food materials. Stones may be moved to form images, patterns, complex designs or mounds. Some researchers use the term "geoglyph" to refer to these human changes to ground surfaces, often as very large and striking images when visualized from above (fig. 5-4). In arid lands, stony ground surfaces were altered to achieve a contrasting image to lighter colored soils below dark desert gravels. These cultural activities are best considered as patterned behavior, not aimless or haphazard in terms of placement, pictorial content, and variety through time and space. Important evidences of image chronologies may result from re-use of rock surfaces, re-painting, and younger designs superimposed over earlier ones (Hedges 1990).

We distinguish between pictographs (painted expressions using mineral colors or charcoal, often with a binder material) and petroglyphs or images made by pecking, carving, abrading, scratching, and incising, or combinations of these methods. Petroglyphs are usually created with these methods to remove darkened appearance of naturally weathered stone surfaces to expose lighter colored rock matrix to achieve a contrasting image. Both types of images may occur in mixed expressions or only one technique may appear dominant.

Figure 5-1—Natural weathering processes in action. Top: Exfoliation on granite. Bottom: Natural spalling at the Tate Site, Lincoln National Forest (photos, Forest Service, Lincoln National Forest).

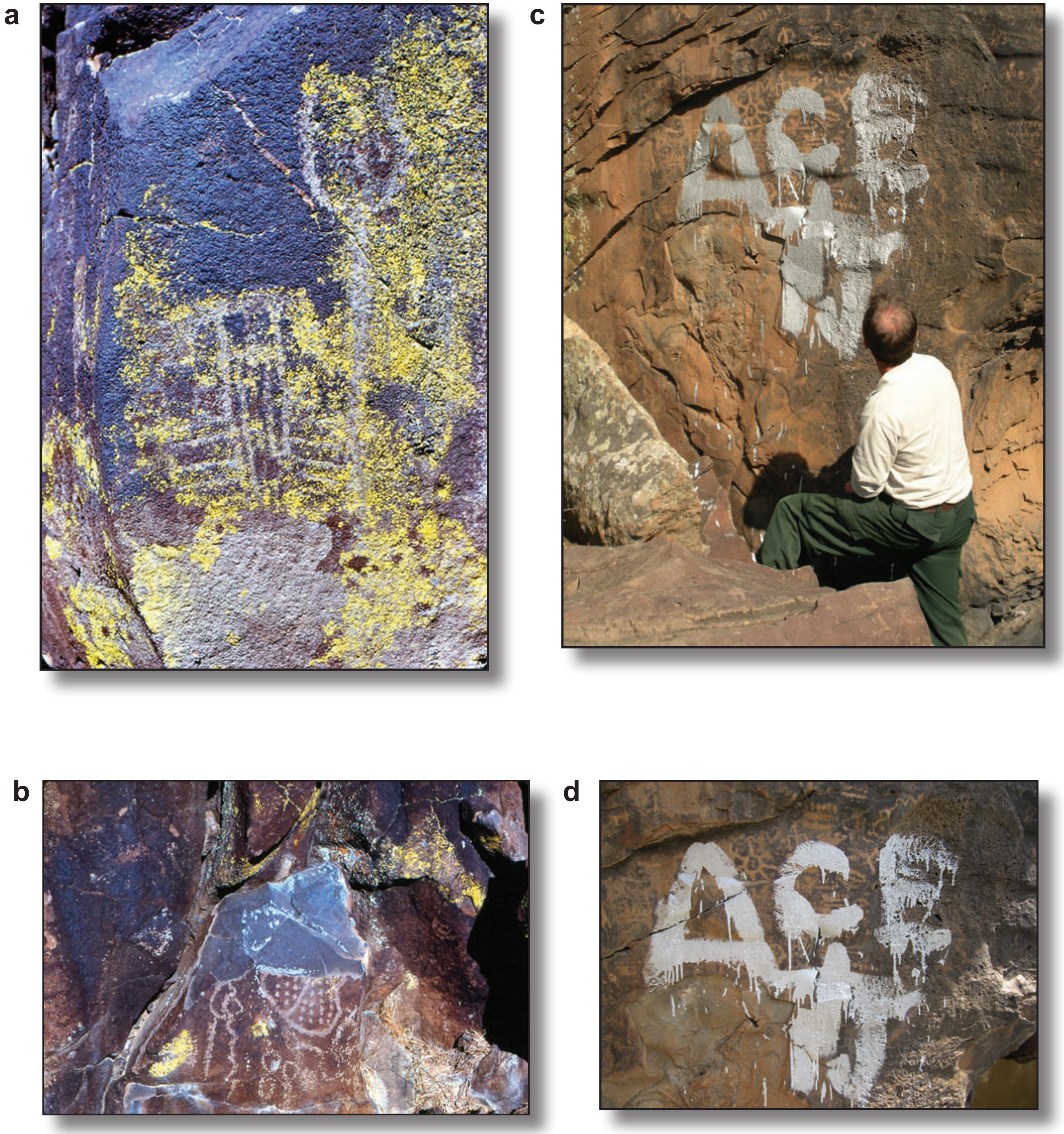

Figure 5-2—(a,b) Natural weathering and vandalism at Inscription Canyon, San Bernardino County, California, 1971. a) Lichen growth beginning to obscure petroglyphs. b) Vandalism, attempt to remove the petroglyphs. (c,d) Vandalism, defaced petroglyph panel at Keyhole Sink on the Kaibab National Forest (photos, Forest Service, Southwestern Region, Kaibab National Forest).

Figure 5-3—Cupule boulders, both examples from Riverside County, California.

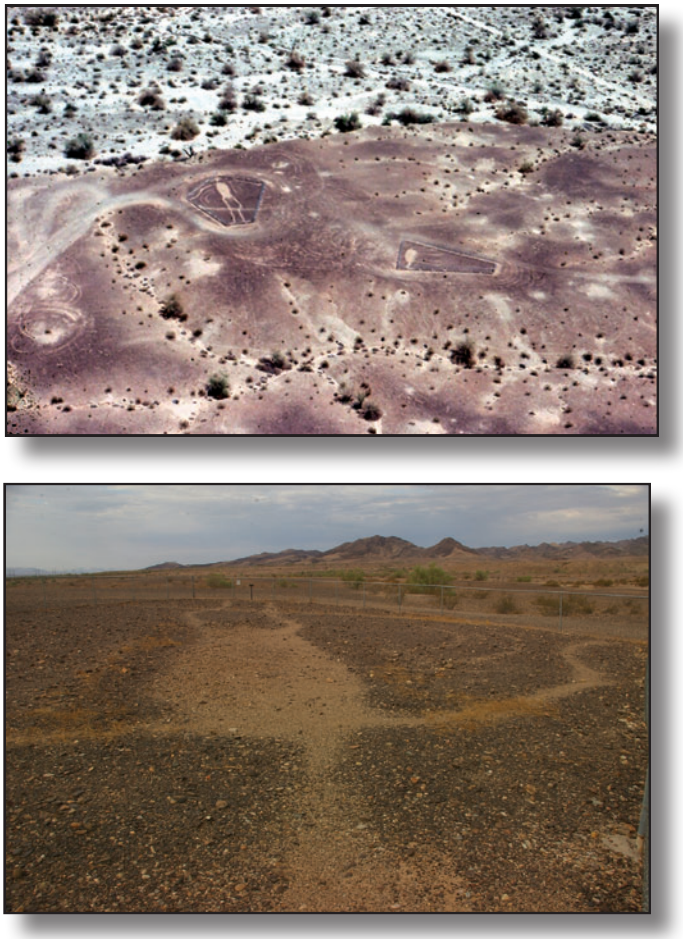

Figure 5-4—Examples of intaglios or geoglyphs. Top: Blythe (California) Intaglios along the Colorado River at site CA-RIV-14. Bottom: Close-up of one of the figures.

Setting and Placement

The setting and placement of these cultural resources are often away from customary habitation and may be seen at almost any location. Rock images may be within caves, rock shelters, or overhanging cliffs where vegetation may flourish as potential fuels. Images or patterns may be on above-grade outcrops, vertical surfaces, or at-grade horizontal locations, on expanses of exposed bedrock found along drainages, ridgelines, or topographic features related to water sources. In some locations, pecked handholds, steps, or trail markers may exist with modern hiking trails and other access routes. Since bedrock-milling mortars are associated with food gathering and processing, evidence of temporary camping may also be present in surrounding mineral soils.

Many examples of complex rock images are associated with topographic features, such as canyons, draws, and ridges that support growth of potential fuels today and provide access routes across terrain into higher elevations. Some examples will be found in isolated spots, often with a landscape view, but others are within modern urban/suburban environments (Bostwick 1998). In some western States, circular rock alignments indicate temporary shelters and would not be called geoglyphs. Images or inscriptions on tree trunks—sometimes called “dendroglyphs”—are unique historic resources documenting historic land uses in timbered regions (chapter 6; Coy 1999). Recognized historic trails are sometimes documented by travelers’ names and dates on trees or rocks that may be absent in historical records but may be accompanied by historical archaeological materials at campsites.

Heritage and Research Values

Heritage and research values of rock images, geoglyphs, and other associated prehistoric or historic visual depictions are characterized by the following values that justify active preservation and conservation management:

- Cultural values for contemporary tribal communities as spiritual places where ancestral practitioners conducted necessary ceremonies, noted astronomic observations, or recorded past tribal events (for example, Writing-on-Stone Provincial Park, Alberta, Canada; Saddle Rock Ranch Pictograph Site within the Santa Monica Mountains of California illustrating Spanish horsemen; Cave of Life petroglyphs in Petrified Forest National Park, Arizona).
- Design elements indicate past land use by ancestral social units who marked places on customary lands by producing visual signs (for example, Newspaper Rock petroglyphs of Hopi clan symbols in Petrified Forest National Park, Arizona; Hawaiian "ahupua'a" or land use unit boundaries (Cox and Stasack 1970)).
- Rock image elements distributed over an area or region indicate connections by past native peoples to lands their descendants may not occupy today. Traditional leaders who attribute sacred values to lands as witnessed by "rock art" sites consider these resources as very special identifiers. Such places are included in the May 1996 Presidential Executive Order 13007 "Sacred Places," directing Federal agencies to preserve such locations as public heritage values to all citizens.
- Most serious researchers use non-destructive and detailed photographic and other methods of recording, assessing, and describing rock images and geoglyphs, which recognize the complexity and variety of these cultural expressions over time and space (Bock and Bock 1989). American Rock Art Research Association (ARARA) members, affiliated local interest groups, and professional researchers need to follow high standards of field work and publications. Previous methods such as chalking, rubbings, crayon use, castings or applications of latex coatings, even kerosene washes and other embellishments should always be avoided (Labadie 1990; Lee 1990; Whitley 1996a).
- Use of ethnological information by some leading researchers has produced innovative studies that link stone images to native belief systems, philosophies of life, individual expressions, and past intergroup events (Crotty 1990; Robbins 2001; Whitley 1994, 1996b). Rock art sites and obsidian artifacts are potential sources for collaborative ethnographic studies regarding Native American uses of fire for manipulation of environments (Arguello and Siefkin 2003; Keeley 2002; Loyd and others 2002; Underwood and others 2003; Williams 2001).
- Native and non-native inscriptions, trail markers, and food preparation stations have values for interpreting environmental history, landscape change, travel prior to modern methods, and adaptation of subsistence practices by inhabitants through changing land use patterns.
- Inclusion of rock image resource in Federal or State historic property registers as significant public heritage sites denotes official recognition that triggers specific preservation compliance actions required by legislation, as well as defining public education values (Marymor 2001).
- Dating of rock art through scientific methods depends on assessing the integrity of the resource in terms of contamination, physical damage and presence of datable organic materials. Notable successes have been developed to give radiocarbon age determinations as numerical values as well as relative ("older than" or "younger than") ages (Chaffee and others 1994; Dorn 1994, 2001; Francis 1994).

Fire Effects

Some major rock image examples and related archaeological resources clustered together on public land areas may be described or formally documented in existing technical reports, electronic or paper archaeological site inventory records, or summaries of resources in a protected status (Labadie 1990; McCarthy 1990). But often, essential information about location, characteristic, and existing condition is not readily available during emergency situations. Field crews will probably encounter isolated, poorly known, or undocumented 'rock art' on vertical or ground surface outcrops that may also include bedrock mortars or grinding surfaces. Protection actions such as those suggested in the **Mitigation and Protection** section should be taken in these situations, under guidance from a fire management trained Cultural Resource Specialist. Some effects are short term while others are longer duration; temporary changes such as soot deposits may be removed naturally. Untrained persons should not attempt direct conservation measures.

Rock shelters, overhangs, and vertical rock faces containing rock image panels may suffer two types of damage from wildland fires: thermal effects from energy (heat) absorbed and depositional damage from exposure to smoke, soot, ash, smudging, and tars as combustion products (Loyd and others 2002). The energy may result from either radiation or convection but higher temperatures are associated with the former (chapter 2). Common results are discoloration, exfoliation or spalling, and heat absorption (fig. 5-5). Smudging occurs when combustion products precipitate on or adhere to exposed rock surfaces. Chemical and physical changes are probably caused by heat penetration and charring of organic pigment binder materials of painted elements. Spalled or 'pot-lidded' surfaces or the forming of minute cracks in fine grained rock types occur when normally absorbed moisture becomes heated, causing rock grains and moisture molecules to expand and lose normal adhesion.

Illegal campfires in spaces such as rock shelters or caves 30.5 meters (100 feet) or less from images can also produce extensive spalling, sooting, or other damage to natural rock surfaces, but restoration is possible in some cases (fig. 5-6). Prevention of such illegal camping should be a management and enforcement priority.

Wildland and prescribed burn suppression activities including use of heavy equipment has resulted in severe damage to ground level 'rock art' made upon exposed bedrock formations (fig. 5-7, 5-8, 5-9). Foam, fire retardant, or water applied during mop up operations to still hot rock surfaces can also cause spalling. Organic materials in some retardant gels remain on image surfaces or fertilize micro or macro-plant growth.

Figure 5-5—Spalling and exfoliation caused by fires. Top: Spalling of rock art following the 2003 Hammond Fire, Manti LaSal NF, Utah (Johnson 2004). Pictograph damaged by heat from forest fire (photo Clay Johnson, Ashley NF). Bottom: Typical exfoliation of granitic rock where fuels are nearby and burning very hot. No cultural features were affected.

Figure 5-6—Examples of graffiti and illegal campfire built at the base of a rock painting at site (CA-RIV-45) in Tahquitz Canyon, Riverside County, California.

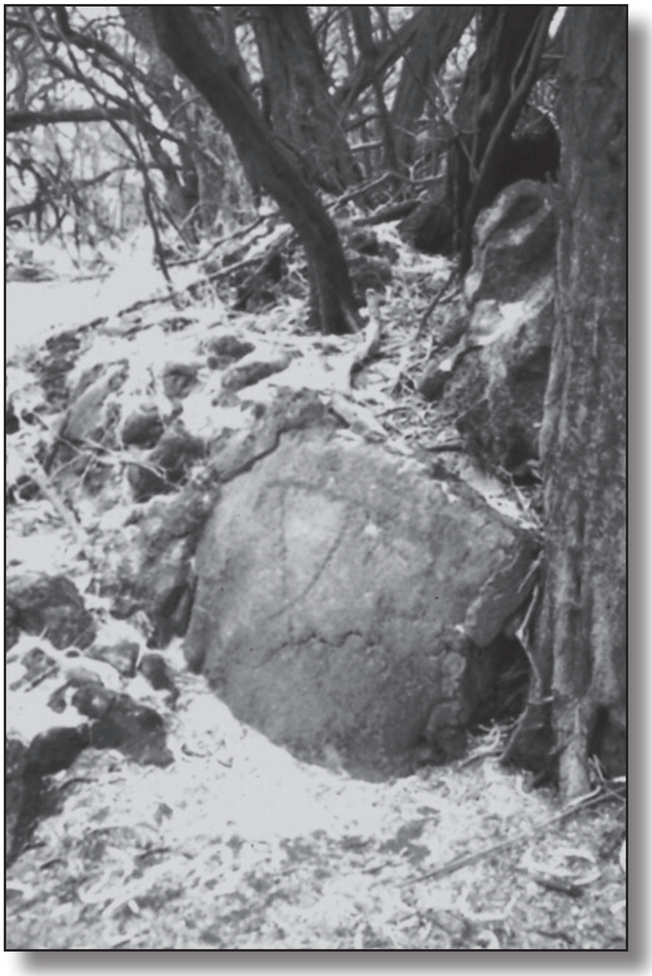

Figure 5-7—Fire-damaged petroglyph in Hawaii.

Figure 5-8—Fire-affected milling equipment noted after the Louisiana Fire Incident in 2002. Top: Granite handstone. Note most of the upper worn, polished surface has weathered away. Bottom: Schist metate surface with only small worn and polished areas remaining.

Figure 5-9—Cupule boulder damaged during the Louisiana Fire Incident in 2002. Top: View showing the north rock exposure. Cupule Panel 1 shown by arrows and extent of damage to rock surface. Bottom: Detail of damage to panel.

Certain types of lava flows are thinly covered by fragile silica coatings—which native peoples removed to produce petroglyphs—that are very easily damaged by foot traffic, hose lines, or hand tool use. Stone arrangements or 'geoglyphs' can also receive damage from machinery, hand lines, fire camps, heliopads, and vehicle parking.

Field Examples

Over the past two decades, at least 20 examples of 'rock art' resources impacted by wildland fires or vandalism have been reported within several States (Kelly and McCarthy 2001, 2002). While these examples are only a few from an unknown number of "rock art" resources impacted by fires, they illustrate fire-generated impacts on different rock types and images, issues of fuel loading near archaeological resources, and post-fire observations.

Hawaii

On the Island of Hawaii, brush firefighting in March 1990 included zig-zag dozer tracks over a'a lava flows with numerous native Hawaiian petroglyphs, destroying and severely damaging scores of unrecorded elements (Lee and Stasack l999). Burning of private sugar cane fields prior to harvesting resulted in generation of high heat from long flame length fires and accumulation of ash and soot on rock art examples (J. Mikilani Ho, personal communication; NPS 1999); the use of bulldozers for this activity also resulted in damage to basalt outcrops with rock art. Examples of increased visibility for rock art, as well as covering by fresh flows, ash, or acidic moisture are documented for Hawaii Volcanoes National Park (Edward and Diane Stasack, personnel communication, 1999).

Arizona

Within Coconino National Forest, the Deadman Wash locality contains 48 rock art sites, which were partially subjected to a wildland fire in 1996 (fig. 5-10) (Kolber l998). One site was heavily damaged by high heat on basalt surfaces, causing exfoliation and substantial to total loss of element clusters (fig. 5-11).

Figure 5-10—Lava flows on the Island of Hawaii are often exposed to damage from fire, fire suppression, and other cultural practices (a) Puuloa Petroglyphs (b) Puuloa Petroglyphys; (c) Puako Petroglyphs.

Figure 5-10—(Continued)

Figure 5-11—Heavy fuel accumulation and consumption around basalt outcrops at the Deadman Wash site Coconino National Forest, Arizona.

Texas

Hueco Tanks State Historical Park near El Paso contains spectacular American Indian rock art dating from Archaic period to historic Mescalero Apaches, Kiowas, and Comanche tribes. Guided visitor tours and a management program, including conservation projects, are positive steps ensuring preservation and study of these well-known examples. Soot coatings and sprayed graffiti at one site were treated with mixed results, but more elements were revealed after smoke blackening was removed (Ronald Ralph, personal communication, 2000). A recent fast-moving fire at the Alibates Flint Quarries National Monument near Amarillo caused spalling of dolomite outcrops and boulders, some of which contained rock art; no images were damaged. Whether high heat caused micro-fracturing of stone surfaces near petroglyphs or not is unclear but may increase deterioration of the images in the future (Dean 1999).

California

Within Cleveland National Forest, a single pictograph panel of an anthropomorphic figure—a ‘rake’ pattern—and other images were subjected to a high temperature fire from nearby fuels (Cavaioli 1991). Only two elements were undamaged and red hematite elements were discolored and altered from rock surface spalling and high temperatures. In 1982, another rock art site was damaged from spalling due to burning of heavy fuels nearby and target shooting later. At Vanderburg Air Force Base, burning of brush in proximity to a major rock image site caused spalling of rhyolite surfaces and loss of painted design elements (Hyder and others 1996). In the 1999 “Willow Fire” in San Bernardino NF, intense heat caused blistering of two unrecorded painted panels and loss of details (McCarthy 2000).

In the southeastern California Mojave Desert, Bureau of Land Management’s Black Mountain locality, fast-burning grass fires did not alter rock art on basalt outcrops but did result in greater visibility and light smudging, which faded with time. An intentional campfire set in the early 1990s near a small rock art panel on local granite resulted in significant spalling and blackening, which faded later. Damage to rock art on granite surfaces depends on fire heat, nearby fuels, and rate of ignition (Sally Cunkleman, personal communication, 1999).

Colorado

Mesa Verde National Park contains superlative ancestral Pueblo rock art associated with village communities occupied between the 12th and 14th centuries. During the 1996 Chapin 5 wildfire (Sidebar 5-1), three panels on the sandstone of 'Battleship Rock' sustained discoloration and extensive spalling (Cole 1997; Floyd-Hanna and others 1997-98). This significant rock art site had been documented several times since 1989 by chalking, photography, and written descriptions, tracings, and replication for Visitor Center display. Of the three major panels, two sustained extensive damage as compared to earlier documentation. Standing trees, brush, and considerable duff fuel loading indicated absence of fire until 1996 in the vicinity of Battleship Rock. A monitoring program has been instituted to watch further changes since Park management, in consultation with local tribal authorities, decided not to attempt stabilization or restoration of damaged surfaces (Desert News Archives, AP: December 1, 1996).

A 9,000-acre fire occurred in 1996 within Comanche and Cimarron National Grasslands, near La Junta. A 'Volunteer in Time' project revisited 19 of 77 sites to assess any fire damage (Mitchell l997). About 16 unrecorded rock art panels were observed but only two sustained damage. Close proximity of standing trees as fuels to rock surfaces (0.3 to 0.6 meters [1 to 2 feet]) accounted for spalling of sandstone rock faces, fortunately without images. Spot fires and light ground fuels resulted in minimal damage to sites and rock art panels but exposed additional sites for recording (Mitchell 1997).

Utah

In 1981, Canyonlands National Park sustained a 200-acre wildland fire named for a petroglyph panel called 'Four Faces' (Noxon and Marcus l983). While not damaging the four elaborate anthropomorphic figures directly, nearby sandstone exposures sustained smoke blackening and extensive exfoliation due to moisture expansion within the local type of sandstone. Pinyon-juniper fuels in quantity and short distances from the Four Faces panel provided sufficient heat source for convection transfer to sandstone cliff faces at a height of 12.2 meters (40 feet) above ground surfaces.

Sidebar 5-1—Rock Art

Chapin 5 Fire, Mesa Verde National Park, Colorado, August 17–24, 1996
References: Floyd-Hanna and others (1997); Ives and others (2002)

General Information:

- Elevation: 2,078.7 m (6,820 ft) at the south end canyon to 2,561.8 m (8,405 ft) in the north rim of the mesa
- Vegetation: Ranges from shrub communities, to pinyon-juniper woodland, to semi-desert vegetation on shale outcrops at the lower south end of the mesa; riparian vegetation in canyon bottoms
- Topography: Chapin V Mesa slopes from north to south and is cut by canyons
- Type of study: Post-fire assessment

Fire Description:

- Temperature range: 15.5-29.4 °C (60-85 ºF)
- Duration: 7 days
- Relative humidity: 23-85%
- Intensity: 23% of area burned at high intensity, 55% at moderate burn intensity, and 18% at low burn intensity; 4% unburned area
- Type of fire: wildland
- Energy Release Component (ERC): 39-70
- Burning Index (BI): 19-67

The Chapin 5 fire occurred in August of 1996 and burned 19.3 km^2 (4,781 acres) of Mesa Verde National Park. Red-carded archaeologists worked closely with firefighters and monitored fire suppression impacts to heritage resources. About 150 sites, including 75 previously unknown sites, were encountered during suppression activities. About 295 sites were known to exist in the burn area and an additional 366 unrecorded sites were located after the burn (USDI 1999). Sites included numerous masonry pueblos, 27 cliff dwellings, pithouse complexes, agricultural features, burial sites, historic summer shelters, hogans, and sweat lodges (USDI 1996).

The fire burned two of the four Battleship Rock petroglyph panels, causing extensive damage (figs. 5-S1, 5-S2). Following the fire, the ground surrounding the petroglyph panels was covered with ash. Spalling and discoloration (reddish, black, and gray areas were noted) affected some glyph elements to the point that they could not be recognized as complete forms. Fragments of spalled sandstone lay at the base of panels (Ives and others 2002).

Immediately after the fire, a Burned Area Emergency Rehabilitation (BAER) team assessed the extent of burn damage. They submitted an emergency treatment plan in September of 1996 and fieldwork began shortly thereafter. Teams of archaeologists and hydrologists worked for over three field seasons to assess archaeological sites and establish erosion control. They adapted new methods of damage assessment from methods established at Bandelier National Monument after the 1996 Dome Fire. Hazard trees were cut down, water-bars constructed and excelsior strips laid over the ground to prevent soil erosion and promote vegetation growth. Much of the burned area was also seeded with grass. A 1999 assessment (USDI 1999) found the project successful. Significant damage to sites had been avoided, 661 sites had been assessed and 333 had been treated to prevent damage.

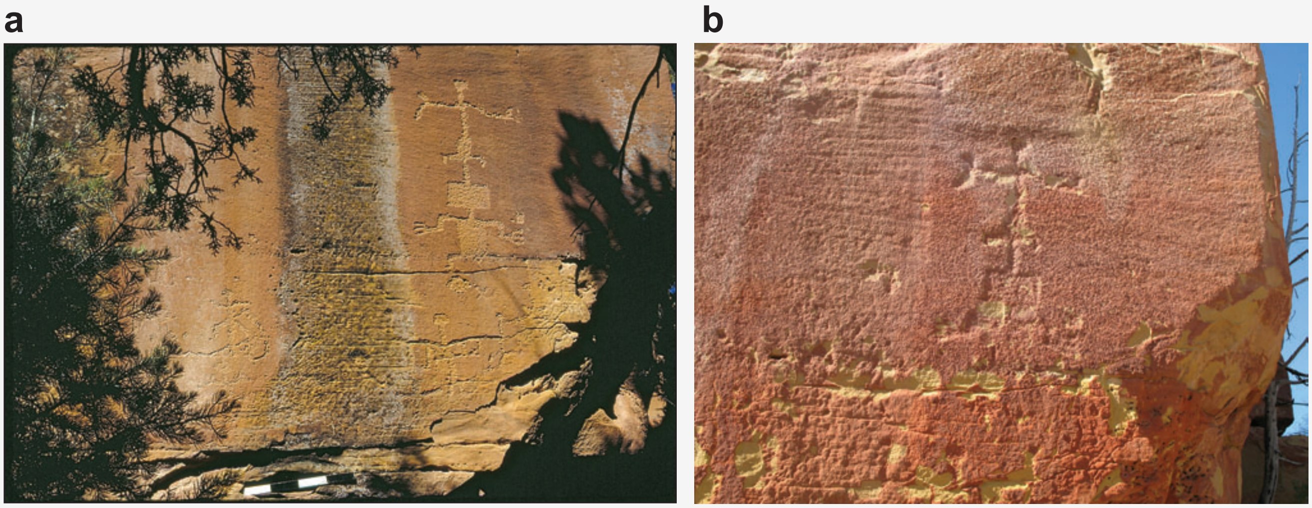

Figure 5-S1—Direct effects of the 1996 Chapin-5 Fire, Mesa Verde National Park, Colorado on the Battleship Rock petroglyph; Panel 3R, before (1989) (a) and after (2006) (b) (compliments of S.J. Cole).

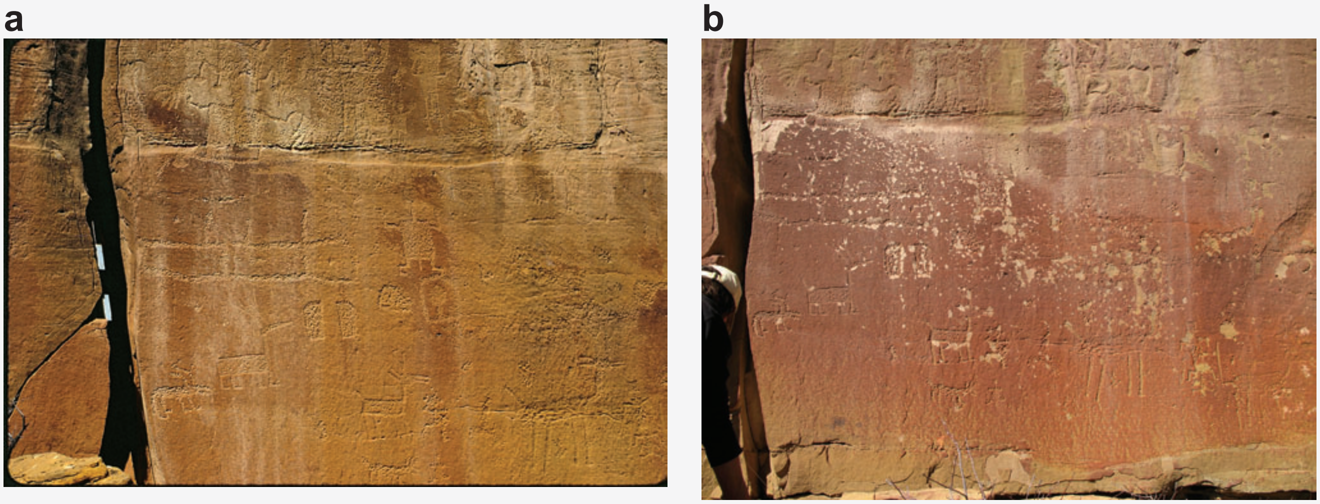

Figure 5-S2—Direct effects of the 1996 Chapin-5 Fire, Mesa Verde National Park, Colorado on the Battleship Rock petroglyph Panel 2L, before (1989) (a) and after (2006) (b) (compliments of S.J. Cole).

Washington

In 1997, Horsethief State Park at Dallesport, sustained a fire caused by a train spark. Images on basalt outcrops along the northern shoreline were damaged and the glassy or silica-like surfaces were exfoliated by heat.

Kentucky

In Daniel Boone National Forest, a wildland fire extensively damaged one rock art site (site number 15Ja234).

Nevada

In eastern Nevada, a rock art site composed of several panels within a series of overhangs at Reed Cabin Summit was totally destroyed by brush fueled fires. Rhyolite rock surfaces exfoliated, spalled, and were smoke-blackened, obscuring or rendering the images destroyed. Some informal documentation had been done earlier but was not systematic. An arson fire in Condor Gulch also impacted known rock art sites in similar ways (Mark Henderson, Bureau of Land Management, personal communication, 2001).

Field Examples: Observations

- Major fire damage to these resources and natural stone used in the production of the cultural images is usually left untreated and unrestored. Decisions not to carry out conservation or restoration actions seem based on assumed lack of fiscal resources, incorrectly assuming that such damage cannot be treated or restored, and that loss of resource integrity is an acceptable consequence of a natural process for wildland fires. Some technical studies on chemical and physical applications to damaged rock art show that conservation and treatment are possible (Dean 1999; Grisafe and Nickens 1991a, b; Ralph 1990; Silver 1982). Funds for mitigation of fire damage to cultural resources are included in the Burned Area Emergency Response (BAER) program. Reprogramming of fiscal year funds to meet specific cultural resource preservation needs should be considered. In some cases, a professional conservator's assessment to let natural processes "clean" images temporarily obscured may be the best decision.
- Some reported field examples describe post-fire characteristics of a rock image resource, without comparison to pre-fire condition or estimates of convection-radiation energy levels reached, or other fire behavior data at the location. Those field reports that offer a "before and after" comparison show extensive discoloration, exfoliation, and greater exposure of the cultural resource for potential vandalism. When heat levels or duration times were comparatively mild, soot deposits were successfully removed and the resource returned to pre-fire condition.
- Sandstone, granite and rhyolite parent rock types suffered damage from high levels of energy releases from nearby fuels and fire behaviors, but images on basalt or lava rock types sustained only light soot deposits and temporary increase to visibility. Rock art on Hawaiian lava flows, however, often sustains considerable damage from ash, toxic moistures, soot deposits from fresh flows, and use of fire-fighting equipment during periodic field fires (fig. 5-12) (Kelly and McCarthy 2001).
- Useful site inventories of 'rock art' resources exist at some institutions (for example, Rock Art Archive of UCLA's Institute of Archaeology; Sink 1998) and compiled bibliographies have been annotated (McLane l993). Specific management plans for rock art resources are few but offer better stewardship regarding public access, fire management, preservation, and research (Labadie 1990; Lee 1990; Marymor 2001; Whitley 1996b).
- Preservation strategies such as removal of potential fuels, documentation of major at-risk sites by skilled specialists, and use of GIS overlay maps during a suppression campaign by Incident Command staff are recommended. NPS Pacific West Region archaeological staff works with prescribed fire specialists to conduct pre-burn terrain and archival records checks to avoid inadvertent impacts to undocumented sites (Malony and Zimpel 1997).

Mitigation and Protection

Specific fuel removal will lessen potential smoke damage and heat impacts to rock surfaces (fig. 5-13). "Black line," protective foam barriers, fire resistant tarps, hand-lines, and hose lays around known sites or fire resistant tarps can be deployed with resource advisor's participation. Technical documentation by skilled specialists can establish a photographic, video, narrative, and graphic record prior to a local fire event; this record provides a baseline condition assessment for monitoring activities later. Increased visibility may also prompt unwanted visitation.

Preventing loss of color, design elements, complexity of panel or cluster relationships to outcropping configuration may be impossible. Through documentation using ARARA accepted techniques and approaches we may preserve rock art characteristics (Dean 1999).

Figure 5-12—Sooting (a) and exfoliation (b) of rock art images on basalt outcrops at the Deadman Wash site Coconino National Forest, Arizona.

Figure 5-13—Vegetation surrounds cultural features, posing a threat from fires. Top: Example of a bedrock mortars surrounded by grasses, at risk from a fire. Bottom (a,b): Fire effects after Piute Fire (photo, Mark Howe 2008). Many milling features are likely in poor condition due to past fires dispelling the notion that stone artifacts are not perishable. Repeated fires over time along with seasonal freeze and thaw cycle contribute to destruction of milling features uncommonly faster by accelerating exfoliation of the rock layers.

Prescribed fire plots may include rock art sites, so management of nearby fuels would be required in the burn plan. Malicious damage during fire suppression is subject to law enforcement, either using Archeological Resources Protection Act 1979 (amended 1988), Code of Federal Regulations regarding Federal property damage, State resources codes, or local county ordinances. Post fire suppression reports, rehabilitation plans, and other incident reports should include details regarding rock art and other archaeological sites within burned terrain. Expert advice from an experienced conservator will be necessary.

Restoration and Stabilization

Major damage to significant rock art, geoglyphs, or related modifications of natural stone is often left unrestored. Pioneering studies of chemical stabilization of porous stone types such as sandstone have been performed (Grisafe and Nickens 1991a, b; Turner and Burke 1976). These authors used experimental stone samples to determine effectiveness of various chemical materials to artificially strengthen weakly bonded stone without changing color, porosity, or permeability. Grisafe and Nickens (1991a) studied a Kansas rock art site and found stone samples taken nearby were strengthened by an organo-silicon compound dissolved in a ketone fluid medium. Bonding of sand grains with no change in appearance or permeability resulted from their experiments. Turner and Burke's (1976) study used stone samples from Davis Gulch in Lake Powell near known rock art sites and from Natural Bridges area of northern Arizona. The most successful material was a polymerized methyl methacrylate, applied in a wet method to sandstone samples. These early efforts may not be allowed in current times because of recognized hazardous nature for some chemicals used and absence of monitoring data over time regarding weakening or disintegration of applied materials.

Resources Available

The American Rock Art Research Association website: www.arara.org.

University of California, Los Angeles Institute of Archeology Rock Art Archive. Information available: http://www.sscnet.ucla.edu/ioa/rockart/.

International Newsletter on Rock Art (INORA), sponsored by UNESCO's International Council on Monuments and Sites (ICOMOS). Information available: http://icomosdocumentationcentre.blogspot.com/2009/01/inora-international-newsletter-on-rock.html.

Charles Haecker

Chapter 6:

Fire Effects on Materials of the Historic Period

In a literal sense "historical artifacts" and "historical sites" are all artifacts and sites dating after the introduction of written history in any region. For example, in New Mexico, these would be sites dating after AD 1540, the year of the first Spanish *entrada* into what would later become the State of New Mexico. In many instances, historical sites can also include those sites created by American Indians who possessed at least some Euro-American objects, and/or whose methods of construction were influenced to some degree by Euro-Americans. The National Historic Preservation Act defines antiquities as over 50 years old; therefore, even late 20th century historical sites may be considered eligible to the National Register of Historic Places. (It is important to note that **only** cultural resource specialists can make a determination regarding the eligibility of a cultural resource to the National Register of Historic Places; see chapter 1.) Given this time depth and regional/ethnic diversity there exists a wide variety of historic architectural designs made of materials such as adobe, sod, logs, planks, firebrick, formed concrete and, quite often, combinations thereof. Artifacts present at even the most humble of historical sites can number into the thousands; virtually anything listed in a nineteenth century mail-order catalog could be found on a frontier ranch.

There are countless historical sites that have been continuously occupied up to present-day, resulting in an even greater variety of building materials and artifacts of varying degrees of combustibility. For example, a cabin built in 1870 might have the original log walls exposed in the interior rooms, its exterior walls lined with turn-of-the-century clapboards, which in turn are overlaid by aluminum siding installed in 1955. The nearby trash dump might contain fragments of ca. 1870 whiskey bottles, parts from a ca. 1900 wood stove alongside 1930s automobile tires, all capped over by a 1968 "Avocado Green" refrigerator. A grass fire might not affect the house, but the 1930-vintage tires could catch fire, resulting in destruction of the historic dump.

A review of the literature regarding effects of fire on cultural resources indicates an explicit bias in favor of studying the effects of fire on prehistoric resources, as opposed to studying these effects on historic structures and artifacts. Consequently, the following information is based in part on unpublished, anecdotal observations, conjoined with empirical data obtained from experiments conducted by arson investigators. The latter data contain a wealth of information that should be consulted by cultural resource managers and fire managers when considering the effects of fire on the wide array of historic period materials.

Types of Fire Damage

- *Distortion* happens when materials change shape, temporarily or permanently, during fires. Nearly all materials expand when heated, affecting the integrity of solid structures when they are made from several materials. If one material expands more than another material, the difference in expansion can cause the structure to fail.
- *Spalling* is a condition associated with masonry plaster and concrete building materials and some artifacts. The primary mechanism of spalling is the expansion or contraction of the surface while the rest of the mass expands or contracts at a different rate. Spalling of concrete, masonry, or brick usually occurs due to high temperatures from an accelerant, for example, creosote-soaked railroad ties used as building material (NFPA 1998). An example of spalling on artifacts occurs when the colorless glaze on historic ceramics separates from the underlying ceramic paste.
- C*harring* is the carbonization of a fuel during heating or burning. The rate of charring is nonlinear and varies with wood density, a property that varies with species and growing conditions, and with the duration of heating. An often-quoted simple "rule of thumb" for pine is that charring occurs approximately at the rate of 3.5 cm (1.4 in) per hour at 750 °C (1382 °F) (DeHaan 1991).
- *Calcination* refers to the various changes that occur in cement- and gypsum-based plasters during a fire. Calcination involves driving the chemically bound water out of the plaster, turning it into a crumbly solid (NFPA 1998). Charring of organic binder, if present, will also weaken the plaster.
- *Build-up* of hazardous, highly flammable vegetation within abandoned/collapsed structures is a common occurrence at historic sites. *Collapsed, rotted roof beams* can catch fire quickly, especially if dry vegetation, for example, tumbleweed, has piled up within or adjacent to the structure. Once ignited, the building materials become the primary fuels that will dictate severity of the fire and the resulting effects on its contents.
- *Fighting the fire* may cause some site damage. For instance, use of water to fight a fire on a historic trash dump could crack super-heated artifacts; use of a fire rake over a trash dump could damage the artifacts; and chemical fire retardants may alter the surface appearance of artifacts.
- *Removal of vegetation* by a fire may result in erosion of the site, and exposure of surface artifacts might lead to site vandalism.

Historic Structures

Native Materials Structures

American Indians traditionally used readily obtainable raw materials from the land around them, fashioning structures from wood, bark, leaves, grass, reeds, earth, snow, stone, skin, and bones. Their principal types of construction were (1) tensile or bent frame with covering for example, wigwam, wickiup; (2) compression shell, for example, hogan, tipi; and (3) post-and-beam wood frame with various walling materials, for example, earth lodge, plank house (Nabokov and Easton 1989). Such structures usually were not conceived as articles of permanent craftsmanship; once abandoned they quickly deteriorated. However, aboveground remnants of late prehistoric and historical periods combustible structures exist in the arid and/or high-elevation regions of the United States and Canada.

American Indians sometimes incorporated building materials of Euro-American origin since at least the mid-19th century. Such a structure might follow the traditional building form yet be constructed of an amalgam of native and Euro-American building materials. Euro-American building materials are intended to last for many years even after structural abandonment and collapse; therefore, such objects as firebrick, milled lumber, and corrugated roofing may also be the surface indicators of an American Indian historical site.

Adobe—Soil for the making of adobe bricks or for use in rammed earth walls is available in virtually unlimited quantities almost everywhere. Proportions of sand, silt, and clay vary in the ground. If these proportions are unsuitable, the soil is tempered or balanced by the addition of another material, such as straw, hay, or other fibrous vegetal matter. Earth-wall structures can be found from high mountain passes to the humid lowlands of the eastern seaboard. Its basic form of construction consists of a solid, load-bearing wall built up of sun-dried bricks molded into flat layers, with adobe mud used as mortar (fig. 6-1). Surfaces are then smoothed with adobe plaster, which is a thin mixture of water and clay mixed with gypsum (calcium sulfate). For roof construction, closely spaced beams in the form of round logs are laid transversely on the tops of the walls. Thin branches, sticks, or reeds, laid in a dense mass over the logs, support a thick blanket of clay that makes a durable roof slightly pitched toward drain spouts outside the walls.

Susceptibility to Fire: Walls of an intact, well-built and maintained adobe structure will resist damage from an external fire source. Fire damage, however, can

Figure 6-1—19th century Hispanic structure, New Mexico; constructed of sandstone, adobe plaster, and log roof beams.

occur from even a low temperature fire if (1) vertical wooden support posts and lintels are in an advanced state of decay; (2) the wooden roof support posts have collapsed, exposing the vegetal roof material; or (3) the roofless structure contains an accumulation of dry and decayed material that is highly flammable. Gypsum plasters will calcinate when exposed to sufficient heat, resulting in spalling. Plaster spall, in turn, may expose otherwise protected vertical posts, which may also burn when exposed to fire. Adobe bricks, mud mortar, and plaster may be weakened by fire if the straw binder burns.

Hogan, Tipi, Wickiup—The *hogan*, a traditional Navajo dwelling, is susceptible to fire. Thousands have been recorded as historic archaeological features; 4,510 hogans have been recorded in New Mexico alone, with thousands more in Colorado, Arizona, and Utah. It was, and still is, a permanent single family house, built to retain heat in the winter and to keep cool in the summer (fig. 6-2). Earlier hogans began as a framework of five heavy poles set up in a cone shape, like the tipi (fig. 6-3), but with a small vestibule entrance. It had a smoke hole and was insulated with a heavy layer of sod. It was known as the "forked stick hogan" because of the shape of the poles that held up the structure. The surface remains of 389 forked-stick hogans have been recorded in New Mexico. Some of these remains date as early as A.D. 1550, up to the early 1800s. Eventually, stone-walled hogans and the present-day log wall hogan evolved because of the influence of Euro-Americans. By 1850 the Navajo had adopted, in part, the log technology of Euro-American pioneers to build the hogan walls. But furniture arrangement, roof construction, lighting, interior functioning, and the overall shape of the building remained the same.

Figure 6-2—Remains of a 17th century Navajo Hogan, New Mexico. These wood remains were later collected by fuel wood gatherers.

Other American Indian combustible structures include Shoshone semi-standing log structures in eastern Nevada (Simms 1989), *tipi*-like structural remains in eastern California (Bettinger 1975, 1982), and brush *wickiup* (fig. 6-4) remains in Death Valley National Monument (Deal and D'Ascenzo 1987; Wallace and

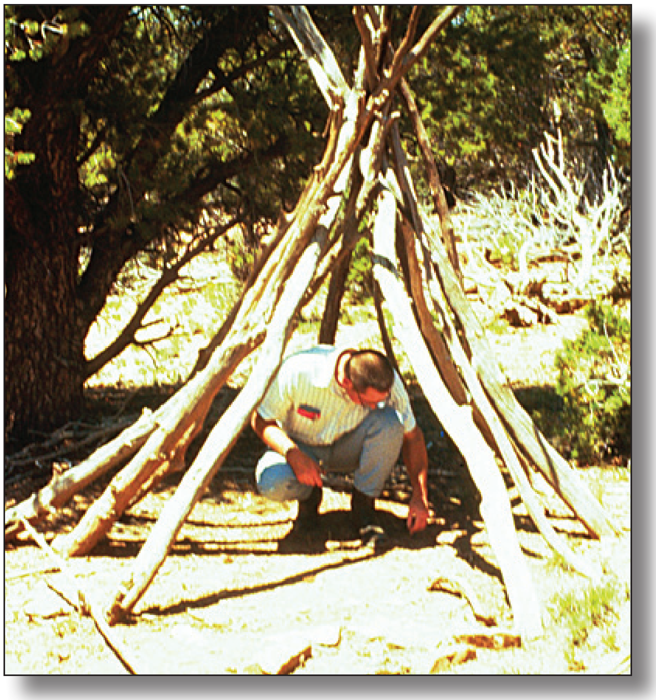

Figure 6-3—19th century tipi poles, Yellowstone National Park. These poles were later destroyed in a forest fire.

Wallace 1979). Other combustible features sometimes found on historical period American Indian sites are *ramadas*, which are sun shades constructed of vertical posts with a pole-and-brush roof; livestock pens constructed of brush and poles; and firewood piles.

Susceptibility to Fire: Hogans have been and are constructed of a variety of materials, including adobe and logs (see "Susceptibility to Fire" for adobe and log cabins). Sandstone is a common hogan building material. When exposed to sufficient temperatures, the surface of sandstone oxidizes, turns color, and spalls. The remains of forked stick hogans are especially susceptible to fire since the wood can be quite old—some have been dated to over 350 years old—and very dry. Many of these remains have the appearance of firewood piles and are in danger of being burned or hauled out by prescribed fire burn crews and firewood cutters. Given their construction materials and collapsed appearances, wickiups, tipi poles, forked-stick hogans, and ramadas are likewise in danger of being mistaken for hazardous fuel loads.

Monuments—This category includes grave markers, shrines, and cairns, the latter defined as a pile of stones used to denote a specific location. Varieties

Figure 6-4—Remains of an early 20th century wickiup, Death Valley, California.

of materials are used to construct grave markers, ranging from commercially manufactured and inscribed marble or cement slabs, crossed pieces of wood, or simply upright boards and unmodified stones. Although typically grouped within a community cemetery, grave markers can be found in association with homesteads, and even alongside roads and trails (fig. 6-5). Shrines usually incorporate an icon or symbol that is typically, but not always, religious in nature. Like grave markers, shrines may be constructed from a variety of materials, and also can be found virtually anywhere. Cairns, which are of ancient origin in concept and are easily constructed, can demarcate boundary corners, a trail route, a place of significance in history or prehistory, a cache of trade goods, or a burial. Some cairns hold significance that is sacred to American Indians; therefore, cairns should be given consideration as cultural resources, unless identified otherwise.

Figure 6-5—19th century Russian grave, Nelson Island, Alaska. Note potential fuel load of cured grasses that surround the grave.

Culturally Modified Trees—Culturally modified trees in various regions of the western United States and Canada are important archaeological and ethnographic resources (White 1954). As examples, there are bow stave junipers in the Great Basin (Wilke 1988); bark peel ponderosa in Montana and New Mexico (fig. 6-6) (Swetnam 1984); and Northwest red cedars, from which bark was harvested for making containers (Schlick 1984), or planks extracted from still-living trees (Hicks 1985; Stewart 1984). These culturally scarred trees are part of the landscape and are important cultural resources and, as such, should be given the same regard as hogans, wickiups, monuments, etc.

Figure 6-6—Ponderosa bark peel tree on a Mescalero Apache camp site, Guadalupe Mountains National Park, Texas.

Log Cabin—Swedes who settled along the Delaware River in 1638 introduced the log cabin in America. It was not until around 1700 that non-Swedes built log cabins (fig. 6-7). By the mid-1700s, the log cabin had become the standard frontier dwelling, inhabited by all nationalities, as well as by American Indians. The log cabin had many features desirable to the early settlers and later pioneers moving westward. It was quickly built from indigenous materials—trees and rocks cleared from land to be used for farming. It was easy to build because it did not require an extra framework to hold up the walls. The fireplace was made of large stones and the chimney of sticks lined with mud. The floor was tamped earth and the roof split cedar shingles. Early log cabins were sometimes erected close to each other inside a log palisade to make a protected community.

Susceptibility to Fire: It is safe to say there is a close correlation between the presence of historic log structures and the abundant availability of trees. There are numerous examples of forest fires that have destroyed such structures. The primary cause of fire damage to a log structure is the general fire regime of the region, not of the logs themselves. All cabins, when made of the same materials, essentially have the same flammability potential. Yet there are also some contributing factors to consider as well: condition of the logs, for example, dry rot; average relative humidity of the region (log cabins in the Northwest Coast region have a far less chance of burning than cabins found in the Southwest high desert); flammability of roofing material (wood shingles versus corrugated steel roofing); and accumulation of flammable materials such as moss, pine litter, vegetative growth, and any chemical accelerants that may be within and around the cabin.

Figure 6-7—19th century log cabin, Colorado.

Baled Hay and Sod—The High Plains prairie lacks trees, stone, or fuels for firing bricks. Euro-American settlers may first have lived in quickly-built dugouts carved from small ravines or south-facing hills. Like the American Indians who constructed lodges from earth, the pioneers also used wild grasses and domestic hays baled into large building blocks to construct substantial, well-insulated homes. The front of the dugout was usually walled with sod bricks into which a door and window were cut. Baling machines were introduced in the 1850s and, by 1890, settlers were using hay bales as a construction material for houses and barns. Fire was a particular hazard to the baled hay house and extreme care had to be taken with cooking and heating. Plastering is a necessity for a hay bale structure, perhaps less so with a sod structure. A cement-based plaster was commonly used to protect the hay from moisture and as a fire retardant.

Sod bricks were made from ground plowed into 30.5 to 35.6 cm-thick (12 to 14 in) strips. These strips were cut into two-foot lengths and then placed lengthwise with the green grass facing down, making a wall two feet thick. When the desired height was reached, huge cedar ridge pole and cedar rafters were placed on the top of the walls to support a willow brush matting and sod roof. More affluent settlers built their sod houses with a wood frame roof covered with sheeting boards and tarpaper to support the sod.

Susceptibility to Fire: Due to their high organic dust content, hay bales are far more susceptible to fire than the straw bales commonly used today. If the plaster of a historic hay bale structure is partly missing, then the fire hazard is much greater—even a minor grass fire or an ember could ignite the structure.

Structures Using Manufactured Materials

As compared with structures of native materials, structures of this category include a much greater variety of construction materials. For example, a homestead might have fieldstone floor support columns, cement-mortared log walls, a stick-and-mud chimney, milled wood rafters, and corrugated steel roofing. Metal fasteners such as nails, bolts, and wood screws, are also present in relative abundance. Each of these building materials has its own rate of decomposition/oxidation, with a concomitant variation to its susceptibility to fire. As another example, a cement-plastered, adobe-walled structure could have creosote-soaked railroad ties employed as corner posts. If the plaster has spalled off from the railroad ties due to differing expansion rates, the structure is in much greater danger of burning from even a low-temperature grass fire. This is because creosote, used as a preservative on railroad ties, is an accelerant—and if the railroads tie has dry-rotted, the fire hazard would be even greater.

Frame Structures—Wood was the obvious choice for most early buildings and bridges. The introduction of the nail- and spike-cutting machines after 1790 and of the power-driven circular saw in 1814 greatly increased the production of boards and heavy timbers. Mass production of cut nails by the early nineteenth century permitted the development of light, or "balloon" frame building construction during the 1830s. Such inexpensive structures could be built where wood was not abundant, for example, the prairie and desert region of the American West. The advance of the railroad network throughout the West after the Civil War greatly increased the availability of milled lumber. This building material provided an alternative to native materials such as adobe, sod, and logs.

Susceptibility to Fire: A strong likelihood exists that a dilapidated, unoccupied historic frame structure eventually will be destroyed by fire. A dry-rotted frame structure, especially one in close proximity to an abundance of wildland fuels and other flammable materials (for example, Russian thistle, manure, accelerants such as rubber tires, and creosoted railroad ties), can quickly burn. Corrugated sheet metal, introduced as a fire retardant during the late 19th century, may still protect the historic structure when used as roofing and wall sheathing. However, if the structure is on piers, a grass fire could spread under it and ignite any dry-rotted floorboards.

Shacks—These structures are small, temporary, and crudely built, with walls perhaps made from tree limbs, recycled boards, doors, and railroad ties; the roof might be made of large pieces of bark, tar paper, corrugated metal, tarpaulin, rubberized cloth and, by the mid-twentieth century, sheet plastic (fig. 6-8).

Susceptibility to Fire: Being of an impermanent nature, shacks as archaeological features are usually totally or partially collapsed. Wood, when present, is in various stages of decomposition, with other building materials, for example, tarpaper, also deteriorated. Even low temperature grass fires can ignite and destroy these remains. The building material might be especially combustible due to accelerants, for example, creosote-soaked railroad ties, and glue used to make plywood.

Cement-Mortared Fieldstone, Firebrick, Cinder Block, Cement Aggregate—Structures utilizing these building materials are, in varying degrees, resistant to fire. Fieldstone, that is, unmodified native rock, is most resistant to fire damage. Firebrick is a common building material if good clay and fuel sources are locally available, or acquired from manufacturers. Cinder block has been a building material since around 1920. Cement—made of crushed and slaked limestone or crushed and slaked oyster shell, the latter used along the coastal regions of southeastern United States—has been a common building material mainstay for hundreds of years in the United States and Canada.

Figure 6-8—Late 19th century homestead, South Dakota. Note heavy grass fuel load.

Susceptibility to Fire: Low-fired, relatively porous firebrick, which is typical of non-commercial, locally made brick used at many historical sites, can weaken and crumble if the fire is hot enough. Lime-based mortar can be affected by fire. It can calcinate and crumble under sufficient heat, thereby loosening the firebrick and, if not replaced, causing the brick wall to eventually collapse. Cinder block and masonry surfaces may spall, which appears as distinct lines of striation and loss of surface material resulting in cracking, breaking, chipping, and formation of craters on the surface.

Historic Artifacts

The great majority of historic artifacts can be assigned to three materials categories: glass, metal, and ceramic. A fourth materials category of "Miscellaneous Materials" includes objects of leather, rubber, wood, plastics, bone and shell.

Glass

Glass is a combination of soda, lime, and silica, a composition that appears colorless. Glass color is the result of several factors, including both intentionally and unintentionally added chemicals in the glass formula. Glass articles and fragments constitute a significant portion of most historic artifact collections. These items represent common household foods, beverages, medicines, cosmetics, cleaners, windows, and lamps. Their evolution includes many manufacturing changes, some of which are useful dating aids. Period of use/disposal and function of a glass container can be determined by its shape, color, method of closure and, if present, its label, the latter made of paper, enamel paint, and/or raised lettering. If present, alpha/numeric codes on glass containers can also provide the year and place of manufacture, and the company that manufactured it, as opposed to the company that sold the contents of the container. Windowpane fragments are clues regarding the architectural layout of a structure, and the socioeconomic status of the original owners of the structure. In addition, the mean thickness of a window pane fragment can be used to derive a relatively accurate initial construction date for a dwelling (Moir 1987).

Susceptibility to Fire: Glass can be affected by heat buildup, smoke, and flame. Smoke staining and melting of glass items tend to occur in direct relation to the heat buildup, the intensity of the fire, the speed of fire spread, and nearness to the fire. Soda lime glass contains a mixture of alkali and alkaline earth to make it more durable and easier to produce. For hundreds of years this family of glass has been used for containers, window glass, pressed- and blown-ware, and lighting products where exceptional chemical durability and heat resistance is not required. Its melting temperature is 695 °C (1283 °F). Lead glass contains lead oxide (and, sometimes, lead silicate) and melts easily. Solder and glazes for decorating enamels on tableware are based on these low melting lead glazes. Their melting temperature is 380 °C (716 °F).

An increase in the temperature of a glass object causes a proportional increase in that object's molecular activity. The hotter the object the greater the molecular activity on its surface, which inhibits the amount of smoke staining that will form. A glass object heavily stained by smoke and soot was, therefore, cooler than one with a light buildup of soot. A heavy soot buildup on a glass surface suggests that the item was far from the fire's point of origin. However, a light soot buildup suggests that the item may be at or near the point of origin.

- *Checkering* of glass refers to the half-moon shapes that are sometimes seen on the surface of glass items. These half-moon shapes result after droplets of water (usually from fire fighting) land on a heated surface.
- *Crazing* refers to the cracking of glass into smaller segments or subdivisions in an irregular pattern. The extent to which a glass object (for example, window pane, soda bottle) will crack or craze is related to the type of glass involved, its thickness, the temperature range to which it was exposed, and its distance from the point of origin. Crazing into small segments or pieces suggests that the item was subject to a rapid and intense heat buildup. It also suggests that the items may be at or near the point of fire origin (NFPA 1998).

On historic archaeological sites, glass artifacts, usually in the form of fragments, are commonly concentrated within domestic trash dumps. Occasionally there is evidence indicating that the trash dump had been purposely burned during the period of site occupation. Where such trash burning occurred, there is sometimes evidence that glass artifacts melted or shattered. Fire temperatures can easily be reached that would craze and/or heavily soot glass. Enamel paint labels could oxidize, causing colors to change and the paint to flake off. It is less likely that a low temperature fire, such as a grass fire, would reach the melting point of glass, although whole objects, for example, bottles, might crack or even shatter from the heat. Fires having heavy fuel loads can reach temperatures that are hot enough to melt glass artifacts into unrecognizable lumps.

Ceramics

Ceramic materials from the historic period have long been used by archaeologists for a variety of purposes, from dating the period of a site's occupation to understanding the role played by a site's occupants in a wider socioeconomic network. There is a vast body of information that deals with the various historic ceramics' pastes, glazes, decorations, and shapes (Majewski and O'Brien 1987); however, little quantifiable information exists regarding the effects of fire on historic ceramics, relative to the fire studies conducted on prehistoric ceramics.

Ceramics can be divided into four primary categories that are based on the character of the ceramic fabric, or body, of the object:

- **Unrefined Earthenware**—the body is made of coarse-grained clays; fired between 500-900 °C (932-1652 °F); body is easily scratched and broken, absorbs moisture; body is thick relative to refined earthenware. Unrefined earthenwares may also be glazed using powdered tin as a flux in the glazing process. These ceramics, called *majolica, faience*, or *delft*, are typically found on North American sites dating prior to circa 1780, and were quickly replaced in popularity by *white-bodied refined earthenwares*.
- **Refined Earthenware**—fine-grained clays; fired between 1100-1500 °C (2012-2732 °F); stronger, thinner body relative to unrefined earthenware; surface is sealed and protected with a translucent glaze. White-bodied refined earthenware is the ceramic most commonly found on nineteenth and twentieth century sites. These ceramics are durable, inexpensive, and come in a wide variety of shapes and decorations.
- **Stoneware**—coarse-to-medium grained clays; fired between 900-1100 °C (1652-2012 °F), becoming non-porous; body is strengthened by its thickness and (usually) vitreous glaze. Popular throughout the nineteenth and early twentieth centuries, stoneware was usually reserved for making utilitarian vessels such as crocks, jugs, and ale bottles.
- **Porcelain**—superfine-grained clays; fired between 1250-1450 °C (2282-2642 °F); vitreous, translucent, extremely hard body. This is a "high status" ceramic, thus rare on historic sites relative to the other ceramic types.

We will make the assumption here that all unglazed, unrefined earthenware Euro-American ceramics, for example, a flowerpot, have essentially the same chemical and physical properties as prehistoric ceramics. All unglazed, unrefined Euro-American earthenware that are exposed to wildfire, therefore, should exhibit essentially the same physical and chemical transformations exhibited by unglazed prehistoric ceramics.

Susceptibility to Fire: All earthenwares are affected by fire to varying degrees, depending on the characteristics of the paste, glaze, painted decoration if present, and temperature of the fire. The alkaline glaze that is typically used on high-fired refined white earthenwares (also known as ironstone, "hotel ware," and semi-porcelain) can crackle even in a low temperature fire, and the underlying ceramic body of the

Sidebar 6-1—Cultural Landscape Restoration

Prescribed burn experiment, Knife River Indian Villages National Historic Site, North Dakota
Oct. 15th, 1988 and Nov. 2nd, 1988
References: Picha and others 1991

General Information:

- Elevation: 506-572 meters (1660-1878 feet)
- Vegetation: prairie grassland
- Topography: level plains
- Type of study: prescribed burn experiment

Fire Description:

- Temperature range:
  - Maximum temperature reached: 316 to 399 °C (600-750 °F)
  - Soil temperature (recorded by Tempilstick crayons)
  - Plot 1-3 soil temp: 6.1 °C (43 °F) pre-burn, 8.8 °C (48 °F) post-burn
  - Plot 4 soil temp: 14.1 °C (57 °F) pre-burn, 18.0 °C (64 °F) post-burn
- Duration: Plot 1-3: 1 minute; Plot 4: 30 sec.
- Relative humidity: Plot 1-3: 54%; Plot 4: 78%
- Fuel:
  - 2 plots = mixed grasses and buckbrush
  - 1 plot = mixed grasses with much less buckbrush
  - 1 plot = mixed grasses, buckbrush and added clippings
- Type of Fire: Prescribed burn

Discussion

In 1991, researchers conducted a prescribed burn experiment at Knife River Indian Villages National Historic Site in North Dakota (Picha and others 1991). They recorded effects of prairie fire on a variety of artifact material types. Specimens included non-flint cobbles, chunks and cobbles of knife-river flint, flaked flint, potsherds, cow rib-bone fragments, mussel shell fragments, wood, charcoal, lead pieces, and glass beads.

Researchers placed specimens in four adjacent burn plots, each measuring 10 m^2 (12 y^2). Fire temperature was measured with heat-sensitive crayons, and soil temperature was recorded by use of a "temperature probe" before and after each burn (Picha and others 1991:16). Specimens were placed at the surface of two plots (one with light fuel and one with heavy fuel) and 2 cm (0.8 in) below the surface of the other two (one heavy and one light fuel) plots. No unburned control and no replication of burn plots were included in this study. The maximum fire temperature reached during the experiment was 399 °C (750 °F), and heating duration was estimated to be about 1 minute.

The specimens were collected after the first precipitation and examined for change in color, shape, and size. No effects to charcoal could be observed. Pottery and large natural cobbles were only minimally affected. Most fire effects occurred to items that had been at the surface. All material types besides charcoal exhibited some color change due to smoke blackening or scorching. Other effects, such as fracture and deformation, were most severe to small thin items. Organic materials were found specifically vulnerable to fire.

Several of the observed effects to surface artifacts represented potential loss of archeological information. Flaked stone and animal bone were altered to resemble intentionally heat-treated flint and bone exposed to cooking fire. Mussel shell disintegrated and the wooden objects partially combusted. Glass beads were partially melted and discolored by soot, and small pieces of lead had melted.

softer-paste white earthenwares can oxidize and turn yellowish brown. Majolica glaze is fragile; its body is soft and porous, and can absorb water. Thus, majolica glaze will crackle and spall even in a low temperature fire (Haecker 2001).

If the ceramic decoration is an overglaze paint, that is, lying on the surface of the glaze, the paint will be damaged to some degree. If the fire reaches temperatures higher than that used to manufacture the ceramic it is possible that the glaze will oxidize or burn, and the whole vessel or vessel fragment (sherd) might split laterally in places. Water droplets hitting the surface of a super-heated ceramic can crack and shatter it (Haecker 2001). Porcelain melts at around 1550 °C (2822 °F) (NFPA 1998). If its paint decoration lies on the surface of the vessel, the paint could become discolored and/or burn off at temperatures much lower than this.

Metal

The melting of certain metals may not always be caused by reaching their melting points. Instead, it may be caused by alloying. During a fire, a metal having a relatively low melting point may drip onto or come into contact with other metals that do not often melt in fires. This phenomenon can also occur when component parts of a heated object are in contact with each other. That mixture (alloy) will melt at a temperature less than the melting temperature of the higher-melting-temperature metal and, in some cases, less than that of either metal. Examples of relatively low-melting-temperature metals are aluminum, zinc, and lead (table 6-1). Metals that can be affected by alloying include copper and iron (steel). Copper alloying is often found, but iron (steel) alloying might be found in only a few cases of sustained fire. Even if the metal object does not melt it can warp out of shape (NFPA 1998).

Cans represent one of the more common types of metal artifact found on post-1850 sites. Like glass containers, cans have been intensively studied by historical archaeologists and, like glass containers, are most useful in dating sites and providing evidence about subsistence and life ways. Information regarding date and contents can be determined by the dimensions and shape of the can, the techniques used to manufacture the can, and by the enamel paint or paper labeling.

Table 6-1—Melting points of materials commonly found on historical sites (derived in part from NFPA 1998:28).

Material	Temp.[a] (F)	Temp.[a] (C)	Artifacts
Plastics	167-509	75-265	Disposable containers, toys
Solder (tin-alloy)	275-350	135-177	Patch repair work on brass and iron objects
Tin	449	232	Kitchenwares, toys, can lining, building materials
Pot metal (copper-lead alloy)	572-752	300-400	Flatware, pots, faucets
White pot metal	572-752	300-400	Kitchenwares
Lead	621	327	Bullets
Zinc	707	375	Plating for iron objects, e.g., cans
Glass	1100-2600	593-1427	Bottles, window pane
Unrefined earthenware	1112-1832	600-1000	Flowerpots, some marbles, prehistoric ceramics
Aluminum	1220	660	Kitchenwares
Brass (yellow)	1710	932	Cartridge cases, military buttons and insignia
Silver	1760	960	Coins, jewelry
Stoneware	1832-2192	1000-1200	Crocks, jugs, ale bottles
Gold	1945	1063	Coins, jewelry
Copper	1981	1082	Kitchenwares, building materials, coins
Refined earthenware	2192-2912	1200-1600	Dinnerware ceramics
Cast iron	1920-2550	1350-1400	Kettles, Dutch ovens, wood stoves
Steel (stainless)	2600	1427	Eating utensils, kitchenwares
Nickel	2651	1455	Plating
Steel (carbon)	2760	1516	Heavy machinery parts
Iron	2795	1535	Tools, nails, horseshoes, cans, corrugated roofing
Porcelain	2822	1550	Dinnerware ceramics

[a] Temperatures are approximate.

Since cans are made of rolled tinned steel, they will eventually deteriorate if deposited in a moist, humid environment. In the dry Southwest, however, cans found on historic sites over one hundred years old may lack labels but are often in relatively good condition, albeit rusted.

Occasionally, there is archaeological evidence indicating can/trash dumps were burned by the sites' historic occupants, as evidenced by layers of wood charcoal found within the dump. These wood fires would have been hot enough to destroy the labels; however, the shape of the can usually remains the same. An exception might exist regarding fire damage on 19th and early 20th century lead-soldered cans (fig. 6-9). Since solder melts at 135-177 °C (275-350.6 °F), it is likely that such cans would be damaged by low temperature fires. The resultant alloying of the solder with the tinned steel also could cause the latter to become fire damaged at lower-than-normal temperatures. The tinned surface of the can may also burn off, thereby increasing the rate of oxidation of the steel body and ultimately the loss of diagnostic information (for example, can diameter, stamped lettering).

Kitchenware includes an extensive array of objects that can be found on the surface of historic sites and can be affected by fire:

- Cast iron objects such as kettles, pans, Dutch ovens, and wood stoves can crack if exposed to temperatures above 1050 °C (1922 °F). Even at temperatures lower than this, if water is applied to these objects, such as during the fighting of a fire, cast iron can crack from the sudden cooling.
- Enameled ironware (also known as agate ironware) objects such as plates, coffeepots, and kettles, have been popular household items since the late 19th century. Such objects are susceptible to damage by low temperature fires: some of the enamel can craze and/or pop off, exposing the underlying rolled metal to oxidation. Partial loss or discoloration of the enamel, however, should not affect the ability to date the artifact.
- Steel utensils that are plated with tin, brass, or silver will have their surfaces discolored and possibly burned off in a fire (table 6-1).

Construction, transportation, and agricultural/ranching hardware items made of metal are often present on historic sites. Such items are typically made of cast iron, wrought iron, and steel, and, due to their sturdy construction, usually impervious to most fires. However, their surfaces might become pitted; paint surfaces, if present, can blister and/or burn off; and enhanced oxidation of the surface of the object may occur if water used to extinguish the fire also rapidly cools the artifact.

Copper and brass objects on historic sites are less common relative to steel and iron objects. Typical brass artifacts found on historic sites are ammunition cartridge cases that have been fired; sometimes unfired cartridges are also found. Cartridge cases are useful in dating a site, with data obtained from the object's dimensions and, if present, from its headstamp. Normally, cartridge cases are not seriously affected by fire, given the relatively high melting point of copper and brass; discoloration might occur but dating information is still present. However, there is one reported instance where fire has destroyed such artifacts. This occurred on the Little Bighorn Battlefield when, in 1983, a grass fire burned over this site. Several unfired cartridges

Figure 6-9—Lead soldered cans in a test fire using straw as a fuel load. Note beads of melted solder.

associated with the battlefield exploded. Also, several lead bullets found on the surface had partially melted as a result of this grass fire (Richard Harmon, personal communication, 1999).

The burn-off of vegetation on a historic battlefield is an atypical situation. One must keep in mind, however, that even a low-temperature grass fire could detonate unexploded cannon ordnance, perhaps injuring members of the fire crew.

Miscellaneous Artifacts

- *Leather* is a material that is sometimes found on the surface of historic sites. Such objects as shoes, belts and horse tack become dry and brittle over time. Leather will char in a grass fire, and will be completely consumed at hotter temperatures.
- *Rubber* and *rubberized objects* are present on many historic sites, some dating to the Civil War period and even earlier. Rubber can be ignited and completely consumed at low temperatures such as those reached by grass fires (Haecker 2001).
- *Plastics* can appear on historic sites that date to the early 20th century, but is most common after circa 1950. Plastics have been used to manufacture a wide variety of objects such as toys, buttons, tool handles, and containers. Various plastics have varying melting points but most plastic objects would be affected to some degree by a low temperature fire.
- Of course, artifacts made of wood are quite common on historic sites, and can include everything from buckboards and Model T car seat frames, to ox yokes and axe handles. When present on a site and in the open they usually have some rot, increasing their susceptibility to destruction by fire.
- Bone, especially if dry and porous, will char in a grass fire, and will be completely consumed in a high temperature fire (Haecker 2001).
- Shell buttons will become discolored, flake and split laterally along the laminations, and eventually turn to powder if subjected to a high temperature fire (Haecker 2001). This will also occur at lower temperatures if the buttons are very small and thin.

Summary

Historical sites that are eligible to be included in the National Register of Historic Places usually include a variety of materials not found on prehistoric sites. These materials vary widely in their susceptibility to fire effects. To date, there is little empirical data regarding the effects of fire on historic period materials. This dearth of information is offset somewhat by data derived from arson investigations, which should be consulted by cultural resource managers and fire managers.

Types of fire damage include *distortion*, *spalling*, *charring*, and *calcination*. Heat can be transferred within a structure by metal fittings such as nails and bolts. The chemicals used in manufacturing certain building materials (for example, plywood glues, creosote-soaked railroad ties) are accelerants, which increase the risk of fire damage even when the fire source is of relatively low temperature, such as a grass fire.

Artifacts are typically assigned to four material categories: glass, ceramics, metal, and miscellaneous. Glass can be affected by heat build-up, smoke, and flame. Examples of low-temperature fire damage to glass include the loss of paper and enamel paint labels, soot staining, and shattering of glass containers. All ceramics are affected by fire to varying degrees, depending on the physical characteristics of a given ceramic, and temperature of the fire. A fire may result in crazing of glazes and spalling of the ceramic body, burn-off of some types of designs and, if the fire is hot enough, cause calcination, even melting. Sufficiently high temperatures may not always cause the melting of certain metals. Instead, alloying may cause it. A low-temperature fire can completely destroy artifacts made of such miscellaneous materials as rubber, plastics, shell, and bone.

Exposure of a historic structure or object to fire, regardless of the temperature that is generated, does not necessarily equate with destroying its value as a cultural resource. For instance, a low-temperature prescribed fire that burns over a trash scatter may discolor fragments of ceramics and glass; however, the diagnostic aspects of these artifacts, such as decoration and vessel shape, may still be recorded with accuracy.

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Chapter 7:

The Effects of Fire on Subsurface Archaeological Materials

Fire and Cultural Sites

In this chapter, we concentrate on the effects of fire on subsurface archaeological deposits: the matrix containing post-depositional fill, artifacts, ecofactual data, dating samples, and other cultural and non-cultural materials. In order to provide a context for understanding these data, this paper provides a summary of previous research about the potential effects of fire on subsurface cultural materials.

As a case study, the results of recent archaeological testing at six Ancestral Puebloan sites located in Bandelier National Monument, New Mexico, are presented. The tested sites are all prehistoric structural sites dating to the period A.D. 1200-1500. The specific focus of the study was to define the extent of alteration to subsurface deposits when archaeological materials experienced different burn severities. The results are discussed in terms of the current status of knowledge about fire effects to buried cultural materials.

Investigation of the nature and extent of fire-related alteration of cultural materials represents a significant cultural resources management concern. Wildland fires can be expected to occur naturally wherever there are sufficient fuels. A field researcher could expect that a given archaeological site in a fuel-rich area has been burned over one or more times in the past. This fact leads some to conclude that the impacts wrought by contemporary wildland fires are negligible, ignoring a crucial element of the contemporary fire scenario—fire exclusion. Since the nineteenth century, most natural fires occurring in rural landscapes have been suppressed as quickly as possible, while in the more distant past most fires were allowed to burn out naturally. Fire suppression has led to large accumulations of fuels and drastic alterations of vegetation patterns. These factors, in turn, support fires that burn faster, more intensely, and potentially wreak more damage to cultural sites and materials than fires of the past. The impacts of contemporary wildland fires on archaeological sites are potentially profound.

Available data, though scant, indicate that in addition to causing the destruction of important sources of information, such as organic materials, the catastrophic wildland fires of the modern era may confound chronometric assays, technological analyses of ceramics and lithics, and more. Understanding the role and function of wildland fires in ecosystems past and present has broad implications for the interpretation of data from archaeological sites located in all areas suspected to have been affected by fire. For managers of cultural resources, evaluating the degree to which buried archaeological materials have been adversely impacted by wildland fire is an essential part of post-fire assessment and treatment.

For purposes of this discussion, the term "surface" is used in the manner commonly employed by archaeologists. The surface of an archaeological site is generally assumed to be the contemporary soil layer, generally the uppermost stratum at which evidence of human activity can be detected. Architectural stone, items such as sherds and lithics, and other cultural materials are frequently present on a site surface and are considered part of the site's contents. Vegetation, accumulations of soil and plant debris such as duff, and other materials deposited on the human activity surface following site abandonment may obscure the archaeological surface and frequently must be removed before the site can be mapped or further studied. An archaeological site surface is thus more-or-less analogous to the mineral soil surface as the term is used by the fire community. Frequently, reports of archaeological survey include a discussion of the percentage of ground surface visible at the time the fieldwork was conducted, specifically describing the portion of the contemporary soil layer unencumbered by duff, snow, grass, or other materials that could obscure features and artifacts.

Fire Effects and Subsurface Cultural Resources: Previous Research

Previous investigations of the effects of fire on cultural resources have included both post-fire and experimental studies. Post-fire studies are conducted following a fire (either prescribed or wild), and involve collecting data from features and/or artifacts located within the burn perimeter. Experimental studies have been conducted in field settings as well as laboratory environments. Field experiments generally involve burning a parcel of land or a smaller location—such as piles of slash—and recording the effects on cultural materials, surrounding soils, etc. In laboratory environments, fire effects studies involve heating different artifact types (or raw materials) to varying temperatures and recording thermally induced alterations.

Experimental studies of the first type are primarily concerned with replicating the effects of prescribed or natural fires on surficial and buried archaeological materials, an endeavor with significant implications for archaeological formation processes. Laboratory research addresses fire effects from two perspectives: (1) the effects of post-occupational fires on archaeological materials, and (2) the effects of human fire use to modify materials.

Sidebar 7-1—Subsurface

Long Mesa Fire, Mesa Verde National Park, Colorado, July 8–23, 1989
References: Eininger (1990); Fiero (1991); Fish (1990); Kleidon and others (2007)

General Information:

- Elevation: 2,438.4 m (8,000 ft)
- Vegetation: pinyon-juniper
- Topography: northern 6.44 km (4 miles) of Long Mesa and portions of adjacent canyons and drainages
- Type of research: post-burn site assessment

Fire Description:

- Temperature range: hot and fast burn with variable intensities; 25.5–32.2 °C (78–90 °F) range
- Duration: 15 days
- Relative humidity: 15–85%
- Fuel: high fuel loads with continuous ladder fuels; fire occurred after the dry season in pinyon-juniper vegetation interspersed by grassy clearings
- Type of fire: wildland
- Energy release component (ERC): 39–70
- Burning index (BI): 19–67

Discussion

The 1989 Long Mesa Fire occurred in Mesa Verde National Park, consumed about 12 km^2 (3,000 acres) of land and burned uncontrolled for 15 days. Damage assessments of known archaeological sites in the burn area were conducted directly after the fire. Twenty-three new sites were located and assessed; 165 of the 194 known sites were successfully relocated.

Field crews recorded the percentage of each site that was affected by fire and described burn severity. They also noted vegetation loss and impacts to architectural materials and artifacts. Suppression activities caused minor damage to only two sites. This was due largely to the work of archaeological monitors who assisted fire crews in avoiding damage to archaeological sites and to the fact that bulldozers and heavy equipment were not used.

Fire effects on archaeological sites were ranked as low, moderate, or high. High impacts included spalling and oxidation of architectural stone, scorching of artifacts and complete loss of vegetation. Sites with low impacts exhibited little or no observable fire effects; these sites were either burned only over a small section of the site area or subject to low burn intensity. Of the 188 sites evaluated, 139 (74%) were burned; 36 (19%) were highly impacted, 32 (17%) were moderately impacted and 71 (38%) exhibited only low impacts (Eininger 1990).

"Grab samples" of fire-affected and archaeologically important artifacts were collected during site assessments (Eininger 1990). The samples included 674 sherds and 172 lithics. Fire effects on these artifacts included fire-blackening, cracking, change in luster, potlidding, and color change. None of these effects appeared to affect the artifacts' information value (Eininger 1990).

Soil samples were collected from excavated test units at two of the burned archaeological sites; a few test units were also excavated in non-archaeological burned and unburned areas to provide control for analysis of fire effects on pollen (Eininger 1990; Fish 1990). Site rehabilitation, including erosion control, water diversion, and ruins stabilization, was conducted during 1989 and 1990 (Fiero 1991).

Dome Fire, Bandelier National Monument and Dome Wilderness, New Mexico, 1996
References: Ruscavage-Barz (1999); Ruscavage-Barz and Oster (1999); Steffen (2005)

General Information:

- Elevation: 1,782–2334 m (5,847–7,658 ft)
- Vegetation: pinyon-juniper and ponderosa pine
- Topography: Pajarito Plateau, on the east flank of the Jemez Mountains

Fire Description:

- Temperature range: 10.5–26.7 °C (51–80 °F)
- Duration: 9 days
- Relative humidity: 3–14%
- Fuel: The fire burned on the Pajarito Plateau, and in dissecting canyons, through pinion, juniper woodlands, ponderosa pine, and mixed conifer forests.
- Energy release component (ERC): 49–57
- Burning index (BI): 39–72
- Type of fire: wildland

The 1996 Dome Fire[1] started on April 25th and burned more than 66.8 km^2 (16,500 acres) of Bandelier National Monument and the Jemez District of the Santa Fe National Forest before it was controlled on May 3rd. Assessments of archaeological sites were conducted immediately after the fire in 1996 and in 1997. Sites were assessed for burn severity and potential heritage resource damage. Of the 515 sites assessed, 276 were impacted by fire. No sites had been disturbed by fire suppression activities. Direct and indirect effects of fire included spalling, cracking, and oxidizing of stone architecture, and soil erosion due to vegetation loss.

In 1997, Bandelier National Monument conducted a study of subsurface heating effects (SHE) on archaeological resources affected by the Dome Fire. Between May 13th and August 7th, archaeologists excavated five burned sites. Burn severity at each site had been recorded during earlier assessments. Two of the sites were heavily burned, one was moderately burned and two were burned severely. A sixth site, excavated for emergency data recovery during June of 1997, was also included in the study. Data recovered from excavation of the unburned portion of this site were used for statistical control.

Subsurface artifacts, botanical specimens, pollen samples, and faunal remains were collected during excavations and analyzed to assess fire impacts. Researchers examined the extent and depth to which fire affected these subsurface cultural materials and analyzed data to determine whether subsurface impacts reflected burn severity. Subsurface fire effects were found only to be significant near to burned roots and to be independent of fire severity.

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[1] This case study refers only to the 1996 Dome fire, not the 1993 Dome Fire that occurred in the same area.

Post-Fire Studies of Archaeological Sites

Post-fire studies conducted in the aftermath of a natural or wildland fire comprise a major focus of research addressing fire effects on cultural resources. A limited number of rigorous post-fire studies of subsurface archaeological materials and contexts affected by wildland fire events have been conducted prior to the research reported here (Connor and Cannon 1991; Connor and others 1989; Duncan 1990; Eininger 1990; Fiero 1991; Fish 1990; Hull 1991; Lent and others 1996; Rowlett 1991b; Traylor and others 1990). In general, these studies tend to describe subsurface heating effects as negligible below certain depths. These statements are typically framed, however, in terms of visible evidence of fire damage to subsurface archaeological materials in comparison with surface materials. A subset of the post-fire studies do not deal with archaeological sites, but instead focus on particular archaeological material types such as ceramics, lithics, etc.

The post-fire studies of burned sites reported here suggest that heating generally does not affect materials at depths greater than 15 centimeters (6 inches) below the ground surface, even at heavily burned sites. The exception to this, as indicated by the subsurface heating effects study described below, is the burnout of tree roots, which can penetrate well below 15 centimeters (6 inches) depending on the size of the root (and the amount of available oxygen) and serve as a conduit to carry heating effects to strata deep within sites (also see Hvizdak and Timmons 1996; Timmons 2000). Fire may also burn longer and deeper below the ground surface in organic sediments (including cultural deposits), which contain more fuel.

An additional issue of concern is whether fire creates pseudo "features" that could be mistaken for cultural features (Connor and Cannon 1991; Conner and others 1989; Timmons 2000). Fire-created features can result from burning deadfall, which causes soil oxidation in a pattern resembling a hearth or fire pit. In profile, these stains are crescent-shaped, with the thickest part of the crescent forming immediately underneath the deadfall. Treefalls can also leave basin-shaped imprints or displaced piles of rocks that resemble cultural features. Differentiating fire-generated features from cultural features is particularly important for studies that deal with the earliest use of fire by humans (James 1989), and some researchers are developing methods toward this end (Bellomo 1991).

Post-fire data particularly germane to the case study results discussed below were collected from various prescribed fire burn units on the Kootenai National Forest in Montana from 1996 to 1999 (Timmons and others 2000). Monitoring data document a variety of potential and actual fire effects on cultural materials and indicate that severity of effects results from the interplay of many factors, including material composition, provenience, fuel loads, duration and intensity of fire, moisture levels, and degree of heat penetration. Most important for consideration here were data relating to stump "burnouts," where the most dramatic effects from the Kootenai monitoring projects were observed. In the Dodge Creek prescribed burn unit, massive Douglas fir stumps that burned out left holes in approximately 0.4 percent of the burned area, resulting in numerous stump cavities up to 1.5 meters (5 feet) in diameter and depth, with root cavities extending out 5 meters (16.4 feet) (Timmons and others 2000). Within the boundaries of one 16-acre site approximately 688 stumps were estimated to be present. The Kootenai data also indicated that the age of the stumps affected their susceptibility to fire. In the Green Basin prescribed burn unit, the older and drier stumps were found to be more likely to burn out in a single event, while green stumps only burned partially (Hemry 1996).

Experimental Studies Dealing with the Effects of Heat on Artifacts, Ecofacts, and Datable Materials

Experimental studies of fire and heating effects can be divided into laboratory and field experiments. The latter can be further subdivided into those that attempt to replicate the conditions found in prescribed fires, and those that attempt to replicate the conditions found in wildland fires. Instances of the latter are extremely rare due to the danger of an experiment running out of control and becoming an actual wildland fire. For this reason, such experiments are rarely conducted. The only case of an "experimental wildland fire" documented in the literature was carried out in a grassland environment, where the grass was cut and the soil surface was exposed in an area surrounding the burning experiment to prevent its uncontrolled spread (Bellomo 1991). Such procedures are less practical in forested areas, and experimental studies conducted under these conditions, while still very useful, inevitably produce results that reflect the more sustained heat and longer burn times created by slash piles (Sackett and others 1994), and may not actually reflect the conditions occurring in a wildland fire, except possibly in cases where large fuel loads have accumulated.

Both experimental and post-fire studies have dealt with the effects of fire on various artifact types. The goal of the post-fire studies is simply to understand and recognize the effects of wildland and/or prescribed fires on these materials. The goals of the experimental studies, however, are not limited to the study of effects from these two types of fires, but rather extend their breadth of inquiry to include understanding and recognizing the effects of intentional heat treatment on archaeological materials. Flaked stone represents the most common focus of the latter type of study, as researchers have attempted to establish the means for differentiating intentional from unintentional heat treatment and also to understand how heat treatment changes the "workability" of particular types of stone.

Most experiments mimicking prescribed burns have attempted to replicate low-intensity fires rather than the high intensities characteristic of wildland fires. Comparisons of impacts between the two types of fires are valid. When considering subsurface materials, however, one must remember that soil serves as an insulator to mitigate the effects of fire, even fires of very high intensity. For this reason, even high-intensity wildland fires may not impact subsurface deposits—except in certain instances. Fires ranging from low to high intensity could yield similar subsurface effects due to this insulation.

Five experimental studies dealing with the effects of subsurface heating are particularly important for consideration. One dealt specifically with prairie fires (Picha and others 1991), two dealt with burning slash piles (Hartford and Frandsen 1992; Sackett and others 1994), and one dealt with moderate and high intensity fires (Pidanick 1982). The results of the prairie fire indicated negligible effects to subsurface artifacts because of only minimal heat penetration to subsurface deposits. The subsurface ground temperature showed a 2 to 4 °C (35.6 to 39.2 °F) increase during the fire, which would not be enough to damage archaeological materials or soils.

A study by Hemry (1996) in the Green Basin prescribed fire unit attempted to assess the effects of prescribed light intensity fire on groups of historic and prehistoric materials at varied depths and with exposure to a variety of combustible surface materials. The historic materials were placed in test holes designed to simulate a historic dump, while the prehistoric items (consisting of replicated mudstone and quartzite tools, and antler) were placed in small groups at four different depths and on the surface. A variety of fuel types were located on or over the cultural materials. Post-fire surface observations and excavations documented a variety of fire effects on items located on the ground surfaces and within the first 4 to 5 centimeters (1.6 to 2 inches) below the surface. The most severe effects were noted where a stump had burned out completely, to a depth of 80 centimeters (31.5 inches). A week after the experimental fire, a tree root was observed, still burning, approximately 3 meters (10 feet) away from its stump (Henry 1996).

Thermal Alteration of Cultural Materials and Features

Both experimental and post-fire studies have investigated the effects of fire on various types of artifacts and raw materials. Post-fire studies generally focus on documentation and explanation of the effects of natural or prescribed fires on these materials. While providing data that are useful in the interpretation of naturally induced fire effects, experimental studies also include investigation of the effects of intentional heat treatment. Flaked stone, in particular, has been a primary focus of many experimental studies, as researchers have attempted to differentiate intentional from unintentional heat treatment and also to understand how heat treatment changes the "workability" of particular raw materials. The results of previous studies that have considered the effects of heat on ceramics, chert, obsidian, ground and architectural stone, bone, paleobotanical materials, and chronometric samples are briefly reviewed below.

Ceramics—Given that ceramics are produced by exposure to heat, any subsequent refiring of ceramic materials may change attributes of appearance and technology. Refired ceramics may be difficult to analyze due to fire-induced changes.

Studies of thermal alteration to prehistoric and historic ceramics are thoroughly discussed in chapters 3 and 6, respectively. Post-fire studies that have considered ceramic materials describe sooting or smoke blackening as the most common fire effect (Eininger 1990; Jones and Euler 1986; Lent and others 1996; Lissoway and Propper 1988; Picha and others 1991; Pilles 1984; Schub and Elliott 1998; Traylor and others 1990). Those studies with a subsurface component note that subsurface ceramics are minimally affected by fire (Lent and others 1996), and that, in general, only those ceramics located immediately below the surface are impacted. The studies suggest that surface ceramics have the greatest potential for fire damage, and exhibit a range of effects including sooting, spalling, cracking, and oxidation.

The "direct effects" of heating are not the only factors to consider with regard to damage to ceramic artifacts. Chemical retardants are often used during fire suppression, and can have an effect on ceramic artifacts. Oppelt and Oliverius (1993) carried out a study of the effects of Firetrolä on prehistoric ceramics. Firetrolä is a foaming detergent used to extinguish forest fires; it is not the same chemical used in "slurry." Ceramic sherds were placed in experimental fire plots and covered with pine duff. As the plots burned, they were sprayed with different concentrations of the foam. The results indicate a negligible effect to sherds from the foam. Sherds were primarily blackened from oxygen depletion, which caused a reducing atmosphere. However, the duff covering, and not the foam, may have caused this condition. Sherds sprayed with a 1 percent concentration of foam exhibited heavier smudging than those sprayed with a 0.3 percent concentration. Sherds in the 1 percent foam group exhibited carbon impregnation to depths of 0.5 millimeters (0.02 in.) into the sherds. The only potential problem with the use of foam is that it may give some ceramics the appearance of being smudged, which could be mistaken for a product of the original firing process.

Chert—Chert has been the subject of numerous experimental studies, particularly because of its abundance at many archaeological sites, its desirable flaking qualities, and the frequency with which it was intentionally heat-treated by prehistoric peoples. The effects of heating on chert are discussed in detail in chapter 4. Post-fire studies that have considered lithic materials generally do not differentiate chert from other lithic materials. These studies have, however, produced some interesting observations that are applicable to chert as well as other stone tool source materials. Discoloration, fire blackening, and luster appear to be the most common fire effects that have been noted on lithic artifacts (Lent and others 1996; Schub and Elliott 1998). Patina develops on some materials (Traylor and others 1990), while other thermally altered materials exhibit crenated ("potlid") fractures and crazing. Obviously any of these effects could compromise interpretations of intentional thermal pre-treatment.

Obsidian—The effects of prescribed and natural fires on obsidian have recently become a "hot topic" due to the concern with the reliability of obsidian hydration as a dating technique. Thermal alteration of obsidian artifacts that have been through a fire is discussed in chapter 4, including the implications of fire-damaged obsidian for obsidian hydration. Unlike chert or other cryptocrystalline silicates, thermal pretreatment of obsidian does not improve its "workability." Thus any thermal effects observed on obsidian artifacts are presumed to be unintentional, resulting from accidental exposure to a heat source.

Ground Stone and Architectural Stone—The appearance of ground stone and masonry can be significantly altered by fire. These materials may take on the appearance of fire-cracked rock (FCR), which results when rocks are naturally or culturally exposed to high temperatures resulting in thermal alteration, including spalling, fracturing, and discoloration. Concentrations of archaeological FCR are often interpreted as thermal features such as hearths, stone boiling middens, or roasting pits. Ground stone or masonry thermally altered by an intense fire may be mistaken for FCR from thermal features. Stone from thermal features—such as hearths or stone boiling features—or other types of features may also be displaced due to the creation of holes or pits resulting from stump burnouts.

Ground stone and masonry have been the subject of a limited number of experimental studies. Those that have been carried out, however, provide general information regarding temperature thresholds for damage and visible effects of fire. If the rocks contain sufficiently high natural iron content and the right chemical composition, oxidation of their outer layers by fire may produce a reddish halo effect (Peter Bennett, personal communication 1997). This effect may be observed by breaking the rocks open, or by examining rocks already broken by thermal shock caused by exposure to heat. Evidence of thermal shock such as spalling and cracking is also an index of fire alteration (Lissoway and Propper 1988). Damage of this type apparently does not occur until temperatures exceed 300 °C (572 °F) (Pilles 1984).

A number of post-fire studies have documented thermal alteration to ground stone and architectural stone attributable to fire (Eininger 1990; Elliott and others 1998; Lent and others 1996; Lissoway and Propper 1988; Schub and Elliott 1998; Traylor and others 1990). Fire effects include smoke blackening, spalling, cracking, discoloration, and oxidation of surface materials. For architectural stone, the combination of fire effects and erosion may confound identification feature type and number of features from surface observation (Lent and others 1996).

An experimental study conducted by archaeologists from the Center for Environmental Archaeology and Texas A&M University investigated fire effects as site formation processes on artificial rock features in several different settings on the Kootenai National Forest (Thoms 1996). Subsurface basin, platform, and pile features intended to simulate thermal features typical for cultural sites on the Forest were built around both young (10-centimeter [3.9-inch] diameter) and maturing (30+ years old) ponderosa pines; each feature contained stream-worn cobbles and pseudo artifacts. Surface observations following the treatment of the sites by fire included the creation of a "tree well" or hole where one of the older trees burned. Field observations collected several months after the fire documented that rocks from the experimental feature were collapsing into the hole where they were redeposited in a pile some 40 centimeters (15.7 inches) below the surface. The archaeologists interpreted their preliminary results as indicating that "rock-rich" features adjacent to burning trees or stumps may become disarticulated and redeposited as "reconstituted" features that may, however, retain potential information (Thoms 1996).

Bone—Studies that address the effects of heat on bones, both human and animal, are usually geared toward understanding the changes that occur in bone at different temperatures. Bone is significantly affected by heat, even at relatively low temperatures (Bennett and Kunzmann 1985). Old bones (i.e., those likely to be encountered at archaeological sites) exhibit a slight darkening of the edges at 300 °C (572 °F), acquire a chalky appearance at 400 °C (752 °F), and become "severely" chalky at 500 °C (932 °F), resembling bone exposed to arid conditions for a great length of time. Shipman and others (1984) have noted changes in color, microscopic morphology, crystal structure, and shrinkage in bone exposed to fire. All three color components (hue, value, and chroma) become progressively more diverse as temperatures increase; changes in low and neutral values begin to occur at 400 °C (752 °F).

Because post-depositional processes can also affect bone color, changes in color cannot stand alone as indices of the temperature to which archaeological bone has been heated in the past. Fortunately, however, structural changes may be documented. When examined microscopically, bone tissues appear normal at temperatures below 185 °C (365 °F). An increase in tissue roughness occurs by 285 °C (545 °F), with tissue becoming glassy by 440 °C (824 °F). Tissue becomes frothy by 800 °C (1472 °F), and the frothy areas coalesce into smooth-surfaced nodules by 940 °C (1724 °F). Bone heated to temperatures higher than 645 °C (1193 °F) tends to exhibit larger crystals than bone heated to temperatures below 525 °C (977 °F). The most ambiguous results occur for shrinkage, where the mean percent shrinkage is not constant at different temperatures.

These data indicate that heat effects on bone range from minimal to extreme. The rate of temperature increase also affects how quickly bone is broken down. The more rapid the temperature increase, the faster bone is hydrolized, chemically altered, and destroyed. One can infer from these studies that subsurface bone probably will not be significantly altered due to the insulating effects of the surrounding sediments.

Pollen and Other Botanical Remains—Analysis of fossil pollen grains, or *palynology,* can be used to reconstruct the vegetation history of an area. It thus provides information about paleoecology that can be extremely useful for both cultural and natural resources managers. It is also sometimes used for archaeological cross-dating (Michels 1973).

Pollen analysis takes advantage of the fact that wind-pollinated species of trees, shrubs, and grasses release large quantities of tiny pollen grains (0.025-0.25 cm [0.01-0.1 in] diameter, less than 10^{-9} grams in weight). The grains are propelled by winds up to distances of 100 to 250 kilometers (62 to 153 miles). Throughout the year but especially during flowering season, pollen grains from the composite vegetation of a region accumulate on the ground as "pollen rain," depositing several thousand grains per square centimeter. Stratified sediments of pollen rain constitute recoverable records of past vegetation and, considered in sequence, can sometimes provide a relative dating technique for archaeological sites. Regional climatic change leaves traces in the pollen sequence by changing the relative composition of key floral species, thus each period in a pollen chronology has a "signature" that can be compared to the regional pollen spectrum.

Archaeologists collect samples for pollen extraction during excavation. First, a control sample of soil containing modern pollen rain is collected from a site surface for comparative purposes. Subsurface pollen samples are collected from undisturbed loci with clear archaeological contexts, such as within defined features or beneath fallen building stones. Within stratified sites, samples are collected from each stratum or level, highest to lowest, as pollen "columns." Occasionally, artifacts such as metates are given a "pollen wash" to secure a sample.

In order to "type" pollen grains, numerous attributes of the size, color, and the precise shapes of the walls of the grains are examined under binocular microscopy, at magnifications from 200 to 1000x. In the laboratory, samples are prepared for analysis in a variety of ways, depending upon the kinds of pollen anticipated—some species are more fragile—and the kind of soil matrix the pollen is extracted from. Generally, the pollen is sieved, washed, and stained. In order to be useful, pollen grains must be identifiable as to genus and, if possible, species. Fire effects to pollen can include consumption (as with any organic material, but less likely in below-ground contexts) as well as thermal alteration.

Macrobotanical specimens analyzed by archaeologists are preserved portions of plants. These can include pieces of formerly cultivated species such as corn, beans, squash, amaranth, and sunflowers, as well as other vegetative materials that were economically important (such as fibers used for cordage, matting, and clothing). Such specimens are extracted from soil samples collected during excavation, preferably from undisturbed features. The soil samples are processed by combining them with water. The heavier soils and rock fragments sink, while the floating "light fraction" is skimmed off with a strainer, placed on cheesecloth to dry, tied off, and bagged in paper. Once drying is complete, the specimens are classified according to species. In some cases, the heavy fraction is screened and any identifiable botanical fragments are also identified. Macrobotanical specimens damaged by fire can be consumed or so altered by exposure to heat and soot that identification is difficult or impossible.

The few fire studies that have been conducted on botanical samples have documented minimal damage to subsurface materials (Fish 1990; Ford 1990; Scott 1990). Palynological analysis of subsurface samples from the 1977 La Mesa Fire in Bandelier National Monument indicates that pollen grains in these contexts are not affected by "…even the most intense ground fires" (Scott 1990). Fish's (1990) pollen study in the wake of the Long Mesa Fire also attests that fires have minimal effects (if any) on subsurface pollen.

Although Fish concludes that the Long Mesa Fire event did not affect subsurface pollens, she provides a useful discussion of methods for evaluating potential fire effects on pollen samples. According to her interpretations, intense heat can damage pollen grains to the point that their diagnostic morphological features are unrecognizable, thus analysis should include a calculation of the proportion of grains too damaged for identification. Fire-altered pollen grains may take on a dark yellow-brown color, will not absorb the staining agent (thus obscuring morphological attributes), and will have thickened or swollen walls. Finally, pollen samples from fire-affected sediments may exhibit high ratios of charcoal fragments, as occurred in Fish's study. It is possible that charcoal generated by post-occupational fires may be indistinguishable from charcoal resulting from prehistoric cultural activities as reflected in archaeological pollen samples.

Ford's (1990) study of subsurface flotation samples from the La Mesa Fire sites demonstrates that these samples were not damaged by the fire, even though the site surfaces had experienced intense heating.

Ford also notes that archaeological charcoal may be more friable than recent charcoal, a characteristic that could potentially be used to differentiate fires resulting from prehistoric activities from those occurring as post-occupational natural fires.

Dendrochronology

Tree-ring dating, or dendrochronology, is a chronometric technique that has been applied with great success in the Southwestern United States and elsewhere (Michels 1973; Smiley and others 1953). Because the method involves counting the annual growth rings and matching them to the known master sequence for their species, the consumption of wood by fire may make it difficult or impossible to tabulate the rings. Robinson (1990) concluded that the La Mesa Fire did not significantly affect either of two tree-ring samples submitted for analysis from subsurface deposits. Unless a wood specimen is sufficiently damaged by fire, it still has the potential to yield an accurate date.

Radiocarbon Dating (^{14}C)

This dating technique is one of the most common and useful in archaeology. Although charcoal is not the only material that yields radiocarbon dates, it is certainly one of the most frequently available; other suitable materials include bone, shell, wood, and iron (Michels 1973). Destruction of perishable materials is the most harmful effect that fire can have on radiocarbon samples. Charcoal is often very fragile when recovered from archaeological contexts, thus it is more likely to be totally consumed during a later fire than other materials. As noted in Fish's 1990 study, however, mixing of modern and archaeological charcoal may occur at fire-damaged sites. This mixing could result in erroneously young dates for particular contexts if charcoal from a post-occupational fire is submitted for radiocarbon dating. Alternatively, contamination of the archaeological sample with modern charcoal could simply confound the radiocarbon assay.

Stehli's study of radiocarbon dates from sites burned over during the La Mesa Fire was inconclusive because no control samples from unburned sites of the same age were available for comparison (Stehli 1990). One of three radiocarbon dates run on archaeological charcoal collected from one of the burned sites appeared to be erroneously young (A.D. 1910). Without unburned control samples, Stehli could not determine whether this date reflected effects of the La Mesa Fire. The charcoal in the sample may, of course, have resulted from a post-occupation fire event.

Archeomagnetic Dating

This technique relies on the known variance of the earth's magnetic field through time (Michels 1973). The magnetic minerals in clays orient according to the polarity of the earth's magnetic field when clay is heated to a sufficient temperature, and retain this orientation when the material cools. This magnetic orientation is compared to an independently established known variation curve to derive a date for the sample, thus it is important to record the sample orientation before collection, and to collect the sample from a non-portable object (Rice 1987). Clay linings or hearth rocks containing magnetite and hematite in archaeological hearths or kilns and burned wall or floor plasters are ideally suited to this chronometric technique. The date obtained from the archeomagnetic assay reflects the last time that the sample was heated. The assumption for archaeological samples is that the last heating of the material took place sometime during the occupation of the site, and that the date obtained thus represents the date that pertains to the occupational history of the site. Reheating clay-containing features at sufficient temperatures during post-occupational fire events will reorient the magnetic minerals, thus significantly compromising the interpretive value of archeomagnetic samples taken from features in burned-over sites.

Results from archeomagnetic dating of material from hearths excavated after the La Mesa Fire indicated that although an erroneously young date was obtained from one set of samples, the problem could be compensated for, and an apparently accurate date was obtained from a second set of samples from the same feature (DuBois 1990). The subsurface heat probably did not reach a temperature that compromised the potential of the hearth to yield a reliable archeomagnetic date.

Obsidian Hydration

Of all the dating techniques discussed thus far, obsidian hydration (OH) has received the most attention in terms of fire effects. Although OH is not a heat-dependent dating method like archeomagnetism, the results can still be significantly affected by fire. This dating method measures the thickness of the hydration layer or band (sometimes referred to as a "rind") on the surface of obsidian artifacts, where water has been absorbed through a freshly broken surface (Beck and Jones 1994; Skinner and others 1997). The rate at which the hydration layer forms is influenced by several factors including chemical composition of the obsidian, temperature, and relative humidity (see Beck and Jones 1994 and Friedman and Trembour 1983 for a discussion of the effects of these variables). The band can be measured and used to provide relative or, more rarely, estimated chronometric dates for obsidian artifacts[1]. It is, however, extremely vulnerable to the effects of fire.

Several experimental studies have examined the temperatures at which obsidian hydration bands are modified in order to understand the effects of fire on band width (Bennett and Kunzman 1985; Green 1997; Skinner, Thatcher, and Davis 1997; Trembour 1990). Trembour's (1990) work with obsidian after the 1977 La Mesa Fire is one of the earliest studies to address the problem. He notes that the hydration band on obsidian becomes increasingly diffuse when heated, starting at about 350 °C (662 °F), and eventually is lost at about 430 °C (806 °F). Although the band may eventually reappear after cooling, it apparently does not return to its original thickness, remaining deep and somewhat diffuse. Other studies of the effects of heat on hydration bands have yielded similar results (Green 1997; Skinner and others 1997).

Obsidian artifacts deposited on or near the ground surface are the most vulnerable to thermal alteration. Previous studies considering the effects of fire on hydration bands in subsurface contexts have recorded minor damage, if any. Subsurface artifacts with damaged hydration bands have generally been recovered from strata occurring from 5-10 centimeters (1.97-3.9 in) below the ground surface (Skinner and others 1997).

Deal (1997) examined the effects of prescribed fire on obsidian hydration bands in an innovative field experiment. Using obsidian artifacts that had previously been sourced and hydrated, she placed specimens at and below the ground surface in a variety of contexts with respect to the fuels present (light, woody, and log) in two different prescribed burns. Temperature and duration of heat were measured throughout each fire event. Following the burns, the samples were resubmitted for hydration measurements at the same lab where the original measurements were taken. The results indicated that both exposure to elevated temperatures as well as long duration of heat exposure, even at relatively low temperatures, affect obsidian hydration bands in similar ways. For the fall burn, which had particularly significant results, Deal recorded a maximum ground surface temperature of 523 °C (973.4 °F) 2-1/2 hours after the flaming front passed over the obsidian specimens. The temperatures for this sample declined slowly, finally reaching 46 °C (114.8 °F) after 44 hours.

Case Study: Investigation of Subsurface Heating Effects at Bandelier National Monument, New Mexico

The Dome Fire of 1996 at Bandelier National Monument provided an opportunity to investigate the impacts of catastrophic fire effects on subsurface archaeological materials. The timing and duration of the wildland fire event were known. The severities at which affected sites were burned were calculated using information collected during the post-fire assessment of sites within the perimeter of the burn. These data, in turn, were used to select a sample of sites burned at varying severities (as well as an unburned control site) for testing through excavation. The Subsurface Heating Effects (SHE) study examined the extent to which fire impacted subsurface archaeological materials, and whether burn severities were reflected in the subsurface archaeological record.

The examination of subsurface materials from sites *systematically* documented as affected by different burn severities marked a significant departure from previously reported subsurface fire studies. Data from the post-fire assessment that began immediately following the 1996 Dome Fire allowed for classification of burned sites into light, moderate, and heavy categories; archaeological *and* ecosystemic data were collected and used in making site assessments. These data, in turn, were used to select sites for testing. Specific characteristics (such as stump burn-outs) that could have particularly serious implications for archaeological sites were also examined. Tested loci within the Dome Fire perimeter included one unburned control site, one lightly burned site, one moderately burned site, and two heavily burned sites. In addition, a site that had been through a recent prescribed fire (as well as several natural fires) outside of the Dome Fire area was selected for purposes of comparison.

The SHE study investigated a number of categories of information related to thermal alteration of subsurface cultural resources:

1. Thermal alteration of soils and other ecofacts, artifacts, and cultural features, including variations of observable changes at different intensities.
2. Correlation between measurable heating effects on archaeological materials and visible changes in soil or rocks or other materials with which they are associated.
3. Degree to which the subsurface heating effects observed in the wake of a wildland fire correspond to those reported from experiments that mimic prescribed burns.
4. Datable materials compromised by thermal alteration.

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[1] An estimated date is derived from the width of the hydration band combined with the rate of band expansion.

5. Potential for detecting ancient fires in archaeological excavations by visible correlates and/or consistent heating effects that may skew the results of materials analyses.
6. Correspondence of surface and subsurface burn severity data.

Thermal Alteration of Ecofacts and Cultural Materials

Investigation of changes in soils, artifacts, ecofacts, and other cultural materials began with examination of the stratigraphic profiles from each excavation unit to determine the depth of heat penetration from the Dome Fire. The fire, represented by Stratum I in all of the soil profiles from the burned sites, was characterized by a distinct layer of ash, charcoal, and burned organic materials. The thickness of the burned layer for each excavation unit varied from 2 to 15 centimeters (0.8 to 5.9 inches), but exceeded 8 centimeters (3.2 inches) at only one site, which also exhibited a small burned stump.

Ceramics recovered from the burned strata exhibited various degrees of sooting, spalling, oxidation, and crackled slips. Flaked stone artifacts exhibited sooting, spalling, crazing, luster changes, and residues. All of the ground stone artifacts affected by the fire were sooted except for one, which was oxidized. The heaviest fire effects recorded for ceramics and flaked stone were observed on artifacts recovered from LA 115152, a site that was moderately burned during the Dome Fire (fig. 7-1). An alligator juniper growing inside the structure at this site was completely consumed by the fire, including the root system. The burning roots allowed the fire to penetrate into subsurface deposits, affecting subsurface archaeological materials deep within the site.

Ecofactual data examined for the SHE study included pollen, faunal, and macrobotanical samples. Examination of pollen samples from burned and unburned contexts indicated that burned samples tend to have higher percentages of degraded pollen compared to unburned samples. A corresponding loss of pollen or a bias to specific pollen types were not apparent, however, in the burned samples. It was not possible to evaluate whether surface pollen was completely consumed by the Dome Fire because the surface pollen samples were collected 1 year after the fire, which allowed sufficient time for natural pollen to accumulate on the surfaces of the tested sites.

Subsurface macrobotanical samples also exhibited fire effects. The introduction of charred modern materials into the archaeological record for macrobotanical materials was the primary effect of both the Dome Fire and the prescribed fire. Samples from burned contexts also exhibited higher frequencies of vitrified charcoal. Fire-affected samples were primarily recovered from the upper fill of excavation units. Even though more charred remains were found in samples from the upper fill of moderately and heavily burned sites, however, these same samples still yielded fairly high proportions of uncharred remains.

Faunal data were recovered from two of the project sites. One site was unburned and served as the control site. The most severely burned bone in the project assemblage was recovered from the unburned site, and most likely resulted from contact with either burned roof material or a cooking fire.

At the second site (LA 3840), Dome Fire effects were confined to the upper stratigraphic profiles, although the site had been heavily burned. Faunal material was first encountered 16 centimeters (6.3 inches) below the ground surface, well below the levels affected by the fire. Fire effects were noted on faunal materials from this site, but they are attributable to contact with either burned roof material or a cooking fire.

Figure 7-1—Burn-out of stumps leads to subsurface damage on culturally sensitive sites. 1996 Dome Fire, Bandelier National Monument site LA 115152. Heavily burned site due to burn-out of an alligator juniper stump. Effects noted more than 1 meter below ground surface (bgs): artifact damage-smudging, etc., soil matrix oxidized and contaminated with modern charcoal, dating methods compromised, pollen and macrobotanical specimens damaged (Ruscavage-Barz and Oster 1999).

Correlation Between Heating Effects on Archaeological Materials and Visible Changes in the Surrounding Matrix

The matrices surrounding the cultural materials recovered during the SHE study were examined to determine whether observable fire effects could be correlated with effects on associated non-archaeological materials, such as soil and rock. Comparison of burned archaeological and non-archaeological materials from the tested sites indicated some correlation between the two categories of materials in terms of fire effects. Spalling and cracking of natural rock generally accompanied spalling and cracking of architectural material; fire-affected archaeological materials tended to co-occur with ashy soil, burned vegetation, and charred trees. Such co-occurrence vegetation and archaeological material damage is common throughout the Southwest (fig. 7-2).

Figure 7-2—Examples of spalling of sandstone due to heating during the 2002 Long Mesa Fire, Mesa Verde National Park, Colorado: (a) panorama, (b) close up (from Buenger 2003).

Subsurface cultural materials and corresponding matrices in the sample investigated for the SHE study generally exhibited fire effects within the first 10 to 15 centimeters (3.9 to 5.9 in.) of fill. Root and stump burnouts were the exception because they allowed the fire to penetrate subsurface deposits and burn deep underground. In these cases, the full range of fire effects were observed, including spalling and sooting of rocks, accumulations of ash deposits in root pipes, and damage to associated archaeological materials.

Correspondence Between SHE Study Fire Effects and Effects Noted in Experimental Fires

The results of the SHE study are consistent with other post-fire studies that have determined that fire effects are rarely found below the first 10 centimeters (3.9 in.) of fill at archaeological sites (Conner and others 1989; Hemry 1996; Lent and others 1996; Thoms 1996; Traylor and others 1990), unless a burned root mass or stump is present. As described above, fire effects were noted on materials within the first 10 to 15 centimeters (3.9 to 5.9 in.) of fill.

One site, LA 115152, proved the exception because the root system of an alligator juniper burned into a structure during the Dome Fire (fig. 7-3). Fire effects on natural and archaeological materials were noted throughout the structure, with the burned root system and ashy soil continuing well below the limits of the excavation. The site (LA 118345) affected by the prescribed fire, described in more detail below, also provided evidence of deep subsurface penetration by fire, again due to the fact that an alligator juniper provided a conduit.

Very few fire-affected artifacts were observed overall, with most found on the surface. Most of the burned subsurface artifacts from the SHE sites cannot attribute their alteration to the Dome Fire because they were recovered from levels too far below the ground surface to be impacted by natural or prescribed fires. Instead, these artifacts probably attained their burned appearance as a result of contact with burned roof materials or hearths.

Alteration of Datable Materials

Four different dating methods were tested for this project: archeomagnetism, dendrochronology, radiocarbon, and obsidian hydration. The results obtained from these methods were compared with the ceramic data to determine whether the dates obtained from the various methods are accurate or have been affected by the Dome Fire (or other post-depositional processes).

Figure 7-3—LA 118345, Bandelier National Monument site LA 115152. Site burned during a prescribed fire (Ruscavage-Barz and Oster 1999).

The only samples for archeomagnetic dating were obtained from a hearth at LA 3840, located approximately 1.11 meters (3.6 feet) below the ground surface. Since the Dome Fire was evident only in the first 5 centimeters (2 in.) of fill for this site, any anomalies in the archeomagnetic dates were not attributable to the Dome Fire.

Wood samples were collected from two sites for dendrochronology. Two wood samples from one site were recovered from deep levels unaffected by the Dome Fire. The samples from the other site, located outside the Dome Fire perimeter but affected by a low-intensity prescribed burn, were recovered from the lower fill of the structure and, likewise, were not impacted by the prescribed fire.

Radiocarbon (^{14}C) dates were obtained for four of the project sites. The radiocarbon dates from three sites were somewhat consistent with the ceramic dates, and were thus considered to provide reliable indications of the approximate dates that the sites were occupied. The remaining site did not yield any ceramics, thus the reliability of the radiocarbon dates could not be assessed. Most significant, even where modern charcoal had been mixed with archaeological deposits inside of a structure, the radiocarbon dates did not appear to have been compromised.

Twenty obsidian artifacts were submitted for obsidian hydration (OH). Although no chronometric dates were obtained from the samples, the widths of the hydration bands were compared to site dates obtained from ceramics and ^{14}C assays to determine whether hydration band width was consistent with site dates. The OH results are somewhat ambiguous and in most cases do not agree with site ages based on other chronological data. Band widths obtained for the samples range from 1.1 to 8.9 microns, which is a very wide range considering that most of the sites date to the A.D. 1300s and 1400s.

Band widths greater than five microns for obsidian artifacts from three of the sites suggested that the flaked edges of the samples were manufactured thousands, not hundreds, of years ago (Thomas Origer, personal communication 1998). If the obsidian samples were affected by the Dome Fire, band widths should have been thinner rather than thicker or the hydration bands would be missing (Green 1997; Skinner and others 1997; Trembour 1990).

Results obtained from dateable samples from the project sites indicated very little impact to these materials from the Dome Fire. Reliable dates, with the exception of obsidian hydration, were obtained from most samples, including those derived from extremely disturbed contexts. Thus the Dome Fire did not compromise the various dating methods employed, because most of the samples came from subsurface contexts that were below the zone of effect for the Dome Fire.

Potential for Detecting Ancient Fires, and Correspondence of Surface and Subsurface Burn Severity Data

To address the issue of detecting ancient fires in archaeological excavations, a structural site (LA 118345) located in an area for which a 200-year fire history was available was included in the SHE study sample. This site had been burned over during a prescribed fire in 1994.

The stratigraphic profile of LA 118345 was examined for evidence of earlier fires. No evidence of previous fires was apparent in either of the test units outside the structure. Within the structure, however, an oxidized soil layer containing burned duff below a level of clean unburned fill was encountered. This burned layer was encountered 20-26 centimeters (7.9-10.2 in.) below the ground surface, while the effects attributable to the prescribed fire effects ended 7 centimeters (2.8 in.) below the ground surface. The lower burned layer was therefore assumed to represent an earlier fire event. Two ^{14}C samples were collected from the earlier burned layer, producing calibrated dates of A.D. 1025-1290 and A.D. 1290-1425, respectively. These dates indicated that the fire event was not part of the 200-year sequence already known but instead represented a much earlier fire event.

Based on the stratigraphic position discussed above, the fire event appeared to have occurred after the structure collapsed. This interpretation conflicted somewhat with the radiocarbon dates because the dates from the fire event pre-dated radiocarbon dates obtained from materials near the structure floor below the roof fall level. The later fire event was not visible in the stratigraphic profile, and no other fire events were evidenced above the level of the roof fall.

The limited data from the SHE study suggested that ancient fires are difficult to detect from archaeological contexts. No ancient fires were detected either during excavation or in stratigraphic profiles at the other study sites, and perhaps the only ancient fires potentially recognizable in archaeological contexts would be catastrophic wildland fires rather than low intensity periodic fires like those believed to have characterized the landscape prior to the late A.D. 1800s.

The second question considers whether the level of burn severity determined by surface observations is reflected in subsurface deposits. The answer is no. The depths of penetration are similar at all sites, whether lightly or heavily burned. The only exceptions are attributable to the root burnout that occurred within one structure, and near another.

At LA 115152, there was no clear break between Dome Fire debris (e.g., ash, charcoal, burned organic materials) and archaeological sediments. This condition was a direct result of the burning root system, which carried the fire underground. If the root system had not ignited, then it is likely that only the surface of the site would have been impacted, similar to another SHE site (LA 3840) that was heavily burned on the surface but did not exhibit any fire damage to the structure interior. The evidence from LA 3840 indicates that surface burn severity is not reflected in subsurface archaeological contexts absent a root burnout.

Summary and Conclusions

One of the important lessons of the SHE study is that a significant difference exists between potential fire effects to surface versus subsurface materials. The effects that fire can have on surface archaeological materials ranges from negligible to extreme depending on the severity and residence time of the fire on the site. This contrasts sharply with the range of fire effects on subsurface deposits, which appear to be relatively protected from fire effects below the first few centimeters except when a burning stump and/or root system provide a conduit for heat penetration to subsurface cultural deposits.

The potential for damage caused by such "burnouts" was exhibited at two of the Bandelier SHE study sites impacted by wildland fire and prescribed fire, respectively. In both cases, the stumps and roots of large junipers ignited and burned underground causing significant damage to subsurface deposits. An alligator juniper growing in a structure at LA 115152 was totally consumed during the Dome Fire. The burning stump carried the fire into the root system inside the structure, heavily impacting the structure fill. Most of the root system was completely consumed, leaving root cavities lined with ash and charcoal that later collapsed, resulting in mixing of archaeological fill and modern ash/charcoal.

A less severe root burnout resulting from a prescribed fire occurred at LA 118345. The root system of a cut juniper stump ignited, even though the stump had been cut to minimize fire effects to the site. The root cavity extended well below the level of the structure floor. Fortunately, the stump was adjacent to the exterior structure wall and, when it burned, did not impact the structure interior. The evidence from this site demonstrated that prescribed fires, as well as wildland fires, can significantly impact subsurface archaeological contexts. Even though the stump had been cut to minimize potential fire impacts, it had been left as a "stub" rather than being flush-cut and/or treated to prevent ignition (for example, by covering with soil).

The evidence from the SHE study, and other fire effects studies discussed here, has significant implications for the interpretation of archaeological data from sites suspected to have been burned over in the past, as well as the management of cultural resources. Depending on the kinds of cultural materials and fuels present at a given site—as well as the specific characteristics of the fire or fires that have passed over it—not only the integrity of the site but the information potential of its contents may be destroyed or altered. Given the right conditions, severe fire effects may include heavy damage to subsurface deposits, long thought to be insulated from thermal and other fire-caused alteration.

The accumulations of fuels on contemporary landscapes have reached historically unprecedented levels, thanks to decades of aggressive fire suppression and exclusion. The potential for fires to destroy or seriously compromise the interpretation of the archaeological record has correspondingly increased. Cultural resources managers and field archaeologists would be well advised to include consideration of regional fire histories in environmental reconstructions, and data analyses. Understanding the role of fire as a site formation process is essential for every cultural resources specialist working in landscapes that have been touched by fire.

Postscript

These studies will be more than a decade old by the anticipated publication date of this volume. We believe that the results of this work stand the test of time quite well. We are proud of this pioneering effort. We hope it will be useful to future "pyroarcheologists."

John R. Welch

Chapter 8:

Effects of Fire on Intangible Cultural Resources: Moving Toward a Landscape Approach

Long before the Secretaries of the Departments of Agriculture and Interior signed the *Federal Wildland Fire Management Policy* in 1995, most land and resource professionals in the United States had recognized unprecedented fuel accumulations in western forests as management priorities. The *Policy*, its 2001 revision, the 2003 *Healthy Forests Restoration Act*, and the sequence of costly fire seasons that spurred these developments made it clear that fuels reduction would remain the driving issue in forest management in the United States for the foreseeable future (Franklin and Agee 2003). The central message embedded in this policy shift is that the foregoing century of fire suppression and other management practice has disrupted the balance among land, resource conditions and values, as well as the people who rely on public and Indian lands for livelihood, raw materials, and senses of place (see Karjala and Dewhurst 2003; Moseley and Toth 2004).

As the implications of enabling fire to reclaim its roles in wildland ecosystems continue to unfold, we are learning about how we value, view, and treat public lands, forests, fire, archaeological and historical sites, and associated human communities. The forest and fire management reorientation underway in the United States opens a window for looking at whether commonly applied standards and protocols for cultural resource conservation are adequate.

This chapter examines intangible cultural resources that are defined as conceptual, oral, and behavioral traditions providing the social context for artifacts and sites. Often derived from time-tested associations between ecosystems and human communities, intangibles are the fragile and often threatened or neglected linkages among geography, cultures, forests, trees, and people. Thus, intangible cultural resources warrant careful consideration in all stages of forest and heritage policy and practice, including wildland and prescribed fire and other fuels reduction programs.

Fire Policy and Standard Practice in Cultural Resource Management

Translating fire management policy into effective and balanced practice requires detailed understanding of local and regional ecosystems (Franklin and Agee 2003) as well as associated historical and prospective human roles. Initial implementations of the 1995 *Fire Management Policy* (updated in 2001) recognized the need for better coordination and collaboration with the local communities directly affected by fire programs on public lands (http://www.nwcg.gov/branches/ppm/fpc/archives/fire_policy/index.htm, accessed March 30, 2011). By 2010, thousands of communities had completed wildfire protection plans developed in collaboration with government agencies. These plans generally emphasize short- and mid-term fuels reduction and incident management. Although there are notable exceptions in the form of in-depth consultations concerning landscape-level fire effects assessments as well as fire management planning (see Burns and others 2003), there are few indications that consultation has widely permeated protocols and practices for re-establishing or sustaining fire-land-community relations.

The lack of sustained or widespread consultation regarding local communities' uses and values of forests limits our understanding of the varied ways in which human communities relate to wildland fire and public land management. Factors affecting relationships among communities, fire, and management range from ecosystem processes, global timber markets, and national policies to fuel models, community politics, and local patterns of forest utilization (Burns and others 2003). These relationships are becoming more complicated in western North America because of diminishing commercial timber reserves, increasing fuel loads, surging human occupation in and use of forests, global climate change, and escalating claims by Native Americans to government-to-government consultation rights and other recognitions of sovereignty (Field and Jensen 2005). This interplay of people, places, politics, lands, values, dynamics, and fire is attracting attention by researchers, managers, local community advocates, and leaders throughout the world (for example, South Africa National Parks 2006; Yibarbuk and others 2001).

For cultural resources, the most immediate and apparent result of the policy shift has been a substantial increase in the number of acres slated for "clearance" (that is, project compliance with relevant statutes and regulations) in preparation for fuels reduction by prescribed burning, hand, or mechanical thinning. Relevant measures are difficult to come by, but the 2007 *Healthy Forests Report* indicates that fuels reduction treatments have been applied to more than 138,000 km^2 (34 million acres) from the period of 2001 through 2009 (http://www.forestsandrangelands.gov/resources/reports/documents/healthyforests/2009/FY2009HFAccomplishments.pdf, accessed March 30, 2011. Through one of the dozens of *Healthy Forests Restoration Act* subprograms, as of early 2006, one region of the U.S. Forest Service had awarded about 130 stewardship contracts for fuels reduction and other treatments on 665 km^2 (162,000 acres) in the southeastern United States. Plans call for the expansion of this and other HFRA programs as technologies and markets are developed to utilize the surfeit of smaller diameter trees being removed through thinning. For the foreseeable future, legions of archaeologists will be engaged in cultural resource surveys covering terrain likely to be affected by forest and fuels treatments.

What are survey teams looking for and what are we finding? More to the point, what are we failing to seek and what are we missing? There are slight variations from region to region and agency to agency, but the general protocol for addressing cultural resources threatened by land alterations have remained much the same for the last three decades: identify, document, and avoid or minimize effects. Tools for finding, recording, and limiting impacts to tangible cultural resources have become more sophisticated in the digital era (Banning 2002). Legal, ethical, and practical developments have made it clear that intangible cultural resources deserve and require consideration (UNESCO 2006; Wild and McLeod 2008). Nonetheless, on-the-ground efforts to integrate wildland fire management and the conservation of intangible cultural resources have been limited and isolated.[1] Fire policy has shifted emphatically away from knee-jerk fire suppression. Most archaeologists and many other resource professionals recognize that artifacts and built features are merely the tangible manifestations of the cultural traditions and community values that are our ultimate concerns. Standard cultural resource management practice, however, continues to equate to finding, documenting, and providing limited protection for the physical dimensions of cultural resources. In other words, the importance of intangible cultural resources and the closely related needs for in-depth consultation are, except in a few isolated instances, being either downplayed or overlooked in a rush to reduce fuel loads and accommodate other policy mandates. Most land managers have started to see the forests through the trees; however, to extend the metaphor, only a few have caught glimpses of the cultures through the sites (fig. 8-1).

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[1] USFS operations in California may qualify as an exception to this general claim, but publications documenting these innovations have yet to appear.

Figure 8-1—Tangible cultural resource threatened by fire.

Approach, Scope, and Goals

This chapter suggests that we can and should do a better job of considering the full range of cultural resources in fire-related management contexts and offers some suggestions in this regard. The discussion considers communities and landscapes as the sources and repositories for values that drive management decisions and social systems. Communities and landscapes, along with the specific places and associated intangible cultural resources from which we derive our distinctive and sustaining identities, are the primary cultural resources that deserve foremost management consideration.

Cultural resources, the objects, places, and traditions significant in culture and history, exist in both tangible and intangible forms. Tangible cultural resources include sites, structures, districts, artifacts, and documents associated with or representative of cultures, processes, and events. Tangible cultural resources also include plants, animals, and other environmental elements as well as physical features, such as caves, mountains, springs, forest clearings, dance grounds, village sites, and trails—particularly as these may be associated with deities, spirits, ancestors, or ceremonies. Intangible cultural resources include conceptual, oral, and behavioral traditions, most of which overlap and are interdependent. Most tangible cultural resources are finite and irreplaceable if lost or destroyed; intangible cultural resources, although often vulnerable, are produced by each generation. Intangible cultural resources may be renewed and expanded through intergenerational transmission and various forms of creative endeavor (http://www.nps.gov/dsc/d_publications/d_1_gpsd_4_ch4.htm, accessed July 21, 2010). Most or all tangible cultural resources have intangible components in the form of associations and significance; many intangible resources have tangible components.

Implicit in the above definitions, however, is the truth that many cultural resources, especially intangibles, cannot be identified, fully documented, or have their significance assessed by archaeologists or other professionals without engaging representatives of the source culture (fig. 8-2).

Figure 8-2—Cultural resource protection crew assigned to the Cradleboard incident command team, White Mountain Apache Tribe lands, Arizona.

Fire effects on cultural resources, tangible or intangible, may entail consequences for personal and communal identities and their spiritual health. Information exchange is clearly implicated. Sustained institutional and interpersonal relationships are an essential basis for recognizing intangible cultural resources, determining the best and most appropriate means for their conservation and, perhaps most importantly, understanding these resources both in their own terms and in terms of management implications. Traditional ecological knowledge (TEK) has justifiably attracted most of the research attention directed toward the linkages among intangible cultural resources, fire ecology, and management (Berkes and others 2000; Raish and others 2005; Turner 1999). Identifying the full spectrum of cultural resources associated with a project area and assessing the full range of effects on cultural resources potentially associated with a project or program requires knowledge available only from the culture or cultures that create, use, and maintain connections to the resources.

No systematic attempt is made here to review previous studies on this subject. The reason for this is the broad range of relevant issues and subjects including, in addition to those already mentioned, American Indian philosophy and pre-contact environmental stewardship (Pyne 1982, 1995; Williams 2000), disaster sociology (Quarantelli 1998; Stallings 2002), community forestry (Baker and Kusel 2003), cultural property law (Hutt and others 2004), etc.—and the paucity of previous research focused on how and why fire mediates ties between people and place.

Instead of attempting to survey this vast terrain of concepts, practices, and policies, the primary objective of this chapter is to offer a framework of ideas and tools for supporting constructive interaction among representatives of local and management communities—groups that care about and have distinctive, yet often complementary perspectives on this and other land management issues. The discussion focuses on how to approach the effects of fire on intangible cultural resources by engaging local communities in identification and assessment. The ultimate goal is to enhance and expand land and fire management programs and policies respectful of and responsive to all pertinent cultural resources, as well as to the social, spiritual, scientific, economic, practical, and aesthetic values. Community consultations concerning intangible cultural resources provide an excellent point of departure for broader agency/tribe/public discussions of common goals, long-term plans, and best management practices.

Why Consider Fire Effects on Intangible Cultural Resources?

There are at least two broad reasons for considering the full spectrum of cultural resources in the context of land and fire management: (1) statutes and regulations most familiar to the management community; and (2) common sense, ethical concerns, and human rights issues. Legal mandates, especially as they relate to the complex relationships among Federal agencies and Indian tribes, were the original impetus for including a chapter on intangible cultural resources in this volume. Numerous Federal, tribal, State, and local statutes, regulations, court decisions, and policies recognize cultural resource values and set standards for their protection. These authorities generally require the identification and assessment of cultural resource values in the course of project planning and decision making (chapters 1, 9). The procedural requirements boil down to looking (and consulting) before you leap, rather than specific protections (Zellmer 2001).

Through four decades of experience with the National Historic Preservation Act (NHPA), the National Environmental Policy Act (NEPA), and other pertinent authorities, the parties involved in Federal land modification (legislators, applicants, land managers, oversight agencies, tribes, stakeholders, and courts) have negotiated widely recognized procedural standards in order to expedite projects and program deliveries. Although there are many good reasons for the use of standard protocols, one drawback is the difficulty of effecting positive change once standardization is in place. In the case of the "identify, document, and avoid or minimize effects" protocol, the uniformity has given rise to a checklist approach to cultural resource management that generally discourages individual and organizational sensitivities to novel or complicated situations. Streamlining environmental and cultural resource compliance processes too often results in steamrolling the often cumbersome issues linked to intangible cultural resources (Welch and others 2009b).

The second reason derives from common sense, ethical concerns, and human rights issues. If these concerns seem at first beyond the scope of a NEPA analysis or NHPA compliance process, it is worth recalling Congress' explicit purpose for NEPA: "to use all practicable means and measures… to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations" (Sec. 101 [42 USC § 4331]). Similarly, NHPA's first section aptly addresses tangible cultural properties as the physical manifestations of that which NHPA was created to protect. To paraphrase NHPA's core principles (www.achp.gov/nhpa.html, accessed July 21, 2010):

- History and culture are the foundations for national spirit, direction, and orientation.
- Cultural resources deserve conservation as a vital element of living communities.
- Preservation of irreplaceable cultural heritage serves national, educational, aesthetic, scientific, and economic interests.
- Collaborative partnerships among governments at all levels, corporations, institutions, and individuals are required to expand and enhance cultural heritage conservation.

When management decisions affect cultural resources, they also affect people and local communities—sometimes in direct and damaging ways. A combination of bureaucratic expediency and market forces has redirected NHPA purposes toward a comparably sterile cultural resource management emphasis on buildings, sites, objects, and undertakings (King 1998:6-19). Nonetheless, cultural resources—especially those linked to or reflective of the spirits and vitalities of distinctive communities—deserve protection, or at a minimum, careful consideration before being burned, altered, or appropriated for new uses. NHPA was not created specifically to protect intangible cultural resources, but the view that conceptual, oral, and behavioral traditions may be disregarded in the course of government-sponsored projects and programs is similarly indefensible. Both NHPA and NEPA provide conceptual and practical foundations for collaborations to address intangible cultural resource issues and concerns (table 8-1 lists pertinent Federal authorities requiring tribal consultations in the context of land and fire management).

Table 8-1—Some Federal authorities requiring tribal consultation in relation to land and fire management program planning and implementation.

Federal authorities	
Statutes and Regulations	***National Historic Preservation Act of 1966***
	(P.L. 89-665; 80 Stat. 915; 16 USC. 470; 36 CFR 800)—NHPA “Section 106” mandates Federal agency consideration of effects of projects on “historic properties” (places, structures, objects with historical significance). Requires Federal agencies to consult with potentially affected tribes on the areas of effect of undertakings, on the identification of properties, on whether an undertaking will affect a property, and on plans for avoiding or reducing adverse effects. 1992 amendments recognize rights of tribes to assume State Historic Preservation Officer (SHPO) functions for Indian lands and sites of cultural and religious significance as historic properties.
	National Environmental Policy Act of 1969
	(P.L. 91-190; 83 Stat. 852; 42 USC 4321; 40 CFR 1500, et al.)—NEPA establishes national policy for the protection and enhancement of the environment, including the preservation of “important historic, cultural, and natural aspects of our national heritage.” Requires Federal agencies to communicate with tribes on the significance of the impacts of projects and programs on tribal lands and communities. NEPA is often overlooked as a viable link between project planning, the human environment, and trust responsibility.
	American Indian Religious Freedom Act of 1978
	(P.L. 95-431; 92 Stat. 469; 42 USC 1996)—AIRFA establishes federal policy for preservation of American Indian, Eskimo, Aleut, and Native Hawaiian right of freedom to believe, express, and exercise their traditional religions, including access to and use of sacred sites and objects.
	Archaeological Resources Protection Act of 1979
	(P.L. 96-95; 93 Stat. 721; 16 USC 470; 43 CFR 7.5; 25 CFR 260)—ARPA requires Federal agencies to consult with tribes that may have cultural or religious ties to a site or other resource that may be affected by issuance of an ARPA permit.
	Native American Graves Protection and Repatriation Act of 1990
	(P.L. 101-601, 25 USC. 3001)—NAGPRA requires issuance of ARPA permit for intentional excavation of cultural items from Federal or Tribal lands and Indian involvement in permit decision; Requires tribal involvement in event of inadvertent discovery of cultural items.
Executive Orders and Other Authorities	***EO 13007 (5-24-96)—Indian Sacred Sites***
	Requires Federal land managing agencies to “(1) accommodate access to and ceremonial use of Indian sacred sites by Indian religious practitioners and (2) avoid adversely affecting the physical integrity of such sacred sites.” Further requires tribal consultation on policies and implementation.
	EO 13175 (11-06-00)—Consultation and Coordination with Indian Tribal Governments
	Establishes Federal policy of Regular and meaningful consultation and collaboration with Indian tribal governments in the development of regulatory practices that affect their communities and the avoidance of imposing unfunded mandates upon tribal governments; Requires Federal agencies to (1) be guided “by principles of respect for Indian tribal self-government and sovereignty, for tribal treaty and other rights, and for responsibilities that arise from the unique legal relationship between the Federal government and Indian tribes;” and (2) maintain “an effective process to permit elected officials and other representatives of Indian tribal governments to provide meaningful and timely input;”

Cultural Resources in Local and Management Community Context

Recognizing and understanding the diverse values embedded in and ascribed to cultural resources is a critical first step in providing for their protection and appropriate use. Putting this proposition into effect requires communication and cooperation among the individuals and communities concerned with one or a group of related cultural resources. Communities are defined here as groups of people who share interests and places. Two general community types merit distinction, definition, and discussion.

Local Communities

Local communities are most American Indian tribes and other place-oriented groups that derive elements of their world view, identity, and value systems through long-standing and ongoing attachments to their region of current or previous occupation or use. Local communities deserve attention because of growing recognition of management guidance and other benefits derived from collaboration with those willing to share knowledge of intergenerational experience with particular ecosystems. The place-based communities most relevant to this discussion are typically enclaves with variably porous boundaries defined by legal status, ethnicity, religious orientation, or some combination. Prominent examples include tribes, Hispanic villages, and communities defined by participation in irrigation systems or religions.

Management Communities

Management communities are clusters of offices and individuals having designated regulatory, policy, program, and trust responsibilities for ecosystems, public and Indian well-being as well as cultural resources. This community includes researchers, decision makers, and implementation and enforcement teams. Community is a useful and appropriate referent because these groups often have substantial interests—personal as well as professional—in establishing and sustaining constructive relationships both within their clusters and among people, forests, fire management, and cultural resources in specific geographical settings. Many biologists, hydrologists, archaeologists, foresters, soil scientists, enforcement officers, and decision makers develop and maintain long and deep individual associations with particular regions that complement their professional associations (Welch 2000; Nicholas and others 2007). A culture of professional stewardship is especially prominent within the U.S. National Park Service and the U.S. Forest Service. Both agencies are staffed by highly trained and skilled professionals—many of whom are following in their parents' footsteps—with profound personal attachments to public landscapes (Gartner 1999:2). These ties serve as powerful performance motivators for stewards and should not be trivialized. On the other hand, they should not be confused with the sense of place or connection experienced by American Indians and others to whom land and landscapes are inherited birthrights rather than acquired affinities.[2]

Differences in perspectives and interests frequently constitute barriers to communication and collaboration between local and management communities (Burns and others 2003). For better or worse, most communication opportunities occur in the context of management community planning driven by government program mandates and policies. The compliance checklist emphasizes quick planning and early project implementation. This expedited process may not allow sufficient time to define the full range of cultural resources or examine long-term means to safeguard their values, much less to integrate management and community interests.

Most chapters in this volume reflect the materials science approach that has dominated discussions on the effects of fire on cultural resources. The discussion here seeks to highlight prospects for transcending both the compliance and the materials science emphases. Although prioritizing consultation and collaboration holds promise, it does not, by definition, predetermine outcomes. A local community, for example, might see prospective fire effects on a sacred site or other cultural resource with crucial intangible values primarily in terms of threats to cultural traditions (Welch 1997). This perception could, depending on the values at stake, translate into preferences that fire either be excluded from the site in perpetuity or allowed to play its natural ecosystem role without regard to site contents or boundaries. Either approach would pose management challenges. Decision makers might see the issue primarily in terms of the proposed treatment's compliance checklist—what needs to be done to satisfy regulatory requirements? Researchers in the management community might view the situation as an opportunity to either learn more about the cultural traditions or, if inclined toward materials science, about the physical and chemical impacts of fire on artifacts, petroglyphs, or other site elements.

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[2] Another discussion might include *issue-oriented communities* as a third community type, defining these as individuals and organizations that derive their commonality from advocacy for one or more stewardship goals or practices. Although issue communities are important stakeholders in resource management, advocacy for both preservation and consumptive use is beyond the scope of further discussion here.

Much work remains to be done if we are to balance the compliance and materials science approaches to fire effects with community-oriented efforts to manage for the full range of fire effects on the full spectrum of cultural resources. One low-cost starting point is attention to vocabulary used in communications with local communities. Bureaucratic and compliance jargon such as "undertaking," "area of potential effect," and "mitigation" impede free flow of information from non-specialists. Common binary terminology—such as: site vs. non-site, prehistory vs. history, nature vs. culture—has persisted beyond most analytic utility and also often hinders collaboration between management and local communities. These false dichotomies and their underlying concepts tend to constrain rather than enhance relationships between managers and landscapes, landscapes and local communities, descendent communities and cultural resources, etc. Any language or program that defines cultural resources independently from local communities increases the likelihood of misunderstanding and conflict (Welch and others 2009a).

It is difficult to assess the depth or breadth of this terminological issue, and many proactive fire management programs are engaging local communities to achieve in-depth understanding of cultural resource issues. Nonetheless, two extensive bibliographies of fire effects on cultural resources (Halford 2001; Rude and Jones 2001) compiled into a joint publication of the Bureau of Land Management (Halford 2001) contain no uses of or references to intangible, sacred or traditional ecological knowledge (TEK). Only one reference was made to tribal communities and two were made to traditional fire use. The point is that neither the details of agency procedures for complying with statutes and regulations, nor the degree of pitting, cracking, and spalling on pot sherds are generally of interest to local communities. At the risk of oversimplification, what local communities care most about is the continued use and enjoyment of important places. In contrast to compliance and materials science, however, project and program planning are often important to local communities. Planning initiatives provide the basis for local community outreach on issues ranging from the protection of sacred sites to individual employment prospects. Landscape concepts and consultation provide good points of departure for engaging local and management communities' interests and goals along with those of multiple stakeholders (Burns and others 2003). It bears mentioning, however, that in the absence of decision maker willingness to terminate or modify a project or program that threatens intangible cultural resources, consultation cannot be expected to either satisfy a community concerned with the protection of the resources or lay the foundations for future collaboration.

Landscapes as Common Ground

In accord with Haecker (chaper 6), a landscape approach to fire effects provides a flexible framework for identifying and evaluating the significance of diverse cultural resources in ecological, historical, and community context. Landscapes are defined here as constellations of physical elements and symbolic associations with earth surfaces. Landscapes are culturally constructed and thus constitute one type of intangible cultural resource (Ashmore and Knapp 1999). This definition is distinct from the common use of landscape in forest and fire management planning contexts to refer simply to regions or groups of timber stands (Finney 2001). As is true for cultural resources in general, landscapes do not exist independently from local communities. In other words, without reference to historical and conceptual associations, landscape is space rather than place (Tuan 1977).

Because the identification of landscapes requires local community engagement, the landscape approach invites detailed considerations of how people have interacted with lands, plants, and animals through systems of meaning as well as through behavior and technology. Linkages among tangible cultural resources, local communities, ecosystems, and management initiatives, such as the *Wildland Fire Policy*, often seem elusive. Landscapes provide literal and figurative common ground (Zedeño and others 1997). Concepts and vocabulary underlying landscape approaches achieve greater coherence and relevance when related to local community perceptions and values. Many cultural resources are intangible, and most occupy or play roles in landscapes. A landscape approach thus provides tools for organizing and understanding intellectual and practical issues engaged by the topic of fire effects on cultural resources.

Zedeño and others (1997:126) suggest that landscapes are defined and characterized by three dimensions: formal, historical, and relational. The formal dimension is what can be seen, heard, tasted, or felt—the physical characteristics and resource properties of a landscape. The historical dimension is what has happened on and with a landscape through time—the sequential associations among places, resources, and communities. The relational dimension is what links material and conceptual realities—the social and symbolic connections that make landscapes meaningful and useful.

Thinking about landscapes in terms of formal, historical, and relational dimensions complements the more straightforward notion of landscapes as compilations of spatial-temporal-symbolic 'layers' that change through time in terms of formal and relational characteristics. This historical or developmental approach, which has become increasingly useful through geographic information systems (GIS), seeks to identify each layer in terms of places, resources, characteristics, values, and meanings as they represent local community perceptions and interests (Corbett and others 2006). More than one layer may be required to portray a landscape for a single community having evolving interests (for example, pre-reservation vs. late 20th century formal and relational dimensions). In the context of land and fire management, geography and local community-based mapping offers the common ground required to highlight connections among resource classes, local community resource uses, and prospects and limitations for fuel treatments and other disturbances (Lewis and Sheppard 2006). If cultural resources are to endure as functional pillars of community spirit and identity, their values (religious, social, economic, educational, and management) must be recognized, incorporated into planning frameworks, and engaged in pursuit of common ground objectives (Welch and others 2009a,b).

The fact that landscapes appear to easily accommodate cultural, historical and management perspectives may also be a prospective stumbling block: landscapes are difficult to define and delimit. Although never infinite, landscapes often eschew specific boundaries. This limitation raises philosophical questions, but these are often easily, if not exhaustively addressed in landscape approaches to land and resource management. In these contexts, geographical boundaries for plans, programs and actions are rigorously defined by pre-established jurisdictional and budgetary frameworks. If potential conflicts between local community landscape definitions and management community programs can be resolved, then applied research employing landscapes to integrate resources, communities, and values contribute to landscape theory, as well as more immediate management objectives (Karjala and Dewhurst 2003).

Beyond Compliance and Materials Science

Applying a landscape approach to cultural resource issues in fire management requires a departure from previous emphases on mitigation of fire effects on cultural resources in which effects and resources are defined primarily by the management community. Changes in laws, public opinion, and professional ethics have highlighted the inadequacies of compliance and materials sciences approaches for addressing local community concerns. The statutory and policy mandates relevant to these concerns reflect a growing responsiveness to issues raised and emphasized by American Indians and other local community representatives. Gaps are likely to persist between statutory possibilities and management realities. Regardless of where one turns for help, consultation with local community representatives remains one answer to pressing questions. Core subjects include the effects that land management programs and projects may have on cultural resources, as well as general interests in building understanding and partnerships in public land and resource management contexts.

Previous and ongoing research into the role of fire in the American West prior to the establishment of land and fire management agencies and policies has pushed fire effects on cultural resources discussion beyond the compliance and materials sciences approaches (Dods 2002). Investigations of local communities' uses of burning and accommodations to wildfire (Blackburn and Anderson 1993; Pyne 1982; Raish and others 2005) have highlighted the intimate links among cultures, landscapes, and fire. For example, according to Wukchumni scholar Hector Franco (1993:19), landscape burning was integral to the Yokuts economic and religious life: "Indian people, we talk to fire. We've learned through religious teachings that fire lives inside of us…. Fire was thought of in a very reverent manner." The abundant literature on American Indian use of fire also underscores the important point that landscapes are not today, and never have been in the past, static entities that can be preserved without major losses of resilience. Like the cultural resources they contain and sustain, the survival of many landscapes, including wilderness areas, as healthy and meaningful entities is dependent on respectful and considerate use by the communities of which they are a part.

The Sonoran Desert oases of Quitovac and Quitobaquito are good examples of complex habitats sustained by and integral to American Indian communities.

> Through burning, flood-irrigating, transplanting, and seed-sowing…O'odham families have nurtured a diversity of plant and bird species far greater than that for any areas of comparable size…. Yet after the last O'odham left Quitobaquito in the 1950s, a park superintendent decided to deepen the oasis pond, eliminate burning and irrigation for pastures and orchards, and halt any replanting of cottonwoods, willows, or other wild plants, native or non-native. As the oasis lost its dynamic nature, biologists began to notice declines in the endangered pupfish and mud turtle populations there….Whereas disturbance was once equated with threat by most conservation biologists and wilderness advocates, it is now recognized that some wild plants and animals require a certain level of exposure to fires, floods, or loosened soils (Anderson and Nabhan 1991: 29-30).

This account would be even more sobering if it included discussion of the effects of the disrupted management regime on the O'odham community for whom the oases are critical elements of group identity and history.

Careful consideration of the pre-management roles of fire in American Indian, Hispanic, and early Anglo communities is required for several reasons. First, use of fire reflects culturally based conceptions of landscapes, fire, stewardship, and of the links among them. Such conceptions must be included in management vocabularies as bases for communications with local communities and, perhaps more importantly, to afford glimpses of landscapes from distinctive, time-tested viewpoints. Second, pre-industrial use of fire has, in many world regions, profoundly shaped ecosystems, landscapes, and community and inter-community relations (table 8-2 lists uses of fire). It should not be a surprise, then, that management community restrictions on burning have angered local communities, alienated them from landscapes, and affected vegetation regimes, habitat, and other important resources. Management communities need to know the full range of factors that have shaped current conditions and must, as complements to relevant research (for example documentary, tree ring, and land use studies) consult local community representatives.

To focus and extend this line of argument, the history of Federal land management is too often a history of dividing people from places and resources critical in their material and spiritual lives. There is value in building upon many excellent examples of local-management collaborations through holistic approaches to land and resource conservation. Decision makers and researchers who think that local communities cannot be trusted stewardship partners are encouraged to review and emulate instances of community-focused efforts to sustain ecosystem health while providing for human needs (Agrawal and Gibson 1999; Berkes 2004; Coconino National Forest 1999; Maines and Bridger 1992; Netting 1993). Even where elders and cultural specialists holding location- or issue-specific knowledge or training are unavailable or unwilling to consult with management communities, local community interests are valid sources of management recommendations. The bottom line is that Federal and State lands are public lands, and we—trustees and beneficiaries alike—are obliged to seek better ways to balance, maintain, enhance, and perpetuate the diverse values embedded in these lands.

Steps and Stumbling Blocks in Inter-Community Collaboration

Each step in a landscape-oriented approach to the identification and assessment of links between fire management and cultural resources involves, at a minimum, an exchange between local and management communities. Generalized steps in the Federal land management compliance process are outlined below in terms of opportunities to recognize interests shared by local and management communities and to engage a landscape approach for exploring common ground and reaching agreement on management issues.

Several principles that serve to facilitate and enhance communications and collaborations deserve restatement. Each local community is unique, existing in its particular place and time because of historical processes operating on distinctive cultural and geographical substrata as well as current interests and goals. For this reason and because of the often contentious history of relationships between local and management communities, there is ample potential for improved collaborations based on the specification of common interests. Community forestry studies provide examples and discussions of the needs and benefits of refocusing

Table 8-2—Non-domestic uses of fire in pre-industrial communities (Raish and others 2005).

Non-domestic uses of fire
Clear land for agriculture fields and pastures
Replenish soil nutrients in agricultural fields
Kill woody species in rangelands and encourage grass growth
Increase wild seed production
Stimulate shoot formation – the production of straight shoots for basketry and other implements
Improve growth of both wild and cultivated tobacco and other plants
Kill and control varmints, vermin and flying insect pests
Drive and hunt game
Create diversions to facilitate raiding of or escape from enemies
Destroy enemies’ food stores, agricultural fields, homes, hiding places

land and resource management through attention to the interests and goals of local communities (Baker and Kusel 2003; Gibson and Koontz 1998; Henderson and Krahl 1996; Kelly and Bliss 2009; Kleymeyer 1994).

Consultation is defined here as an exchange of information and views as part of a good faith effort to reach agreement. Many specific issues associated with fire effects on cultural resources and landscape-level analyses have yet to be addressed. Stoffle (1998) provides a nine-step consultation program developed in the context of Department of Defense efforts to engage Indian tribes in processes prescribed by the Native American Graves Protection and Repatriation Act of 1990 and the executive order on Sacred Sites (13007). Burns and others (2003) offer a model for engaging diverse stakeholders, developing shared understandings, achieving a convergence of goals relating to how fire-dependent landscapes should look and function, and launching collaborations in pursuit of the goals. In November 2008, the Advisory Council on Historic Preservation (ACHP) released "Consultation with Indian Tribes in the Section 106 Review Process: A Handbook," http://www.achp.gov/regs-tribes2008.pdf (accessed August 2, 2010). This addition to NHPA guidance includes issue-by-issue interpretations as well as four summative recommendations and numerous useful suggestions. The four principal points are "Respect Is Essential; Communication Is Key; Consultation: Early and Often; Effective Meetings Are a Primary Component of Successful Consultation." The National Association of Tribal Historic Preservation Officers (2005) prepared *Tribal Consultation: Best Practices in Historic Preservation*, which provides specific approaches and tools for working with tribes within a NHPA framework. On the basis of these works and experience linked to forest and fire management, the suggestions here may be useful to representatives of management and local communities. Communication and the prospects for constructive collaboration can be enhanced by understanding and employing the following principles in consulting or otherwise interacting with local communities:

People First

- Build trust through respectful relationships. Even in the context of government-to-government relations, consultation occurs between individuals; there is no substitute for genuine personal attention to other participants and their perspectives. On the other hand, a professional, transparent, and respectful atmosphere for consultation based on a history of mutual trust is often more important than either the individuals involved or whether communications are face-to-face (NATHPO 2005:26). Without a combination of personal and community investment, consultation is usually unsustainable.
- Establish clear and open communications with at least one duly designated representative from potentially affected or interested local communities.
- Prioritize communications with representatives of those communities most affected by the project or program. In an ideal world, these will be the representatives most interested in and well informed about the consultation topic.
- Empower representatives to help set the definitions, priorities, times, places, media, and agenda for consultations. Document information for circulation to all consulting parties with a request for assistance in assuring that the record is faithful to the proceedings.
- Designate at least one individual who is not an official community representative to serve as the official keeper of consultation records and notes.

One Local Community at a Time

- Recognize commonalities and divergences among local communities and consider employing these to structure consultation processes.
- Make it possible for representatives of distinctive communities to have the exclusive attention of researchers and decision makers. Provide equal time for each local community in such settings.
- Avoid use of one community representative to assess or address issues of potential interest to a second, separate community.
- Avoid pursuit or engagement of multiple points of contact in order to identify individuals or organizations more likely to provide sensitive or accommodating information. It is reasonable to expect, encourage, and even insist upon a single official position on a particular issue from each involved community.

Deal Face Up

- In advance of face-to-face consultation, identify and respect the authorities, responsibilities, and goals of those participating in the communications. Avoid face-to-face meetings prior to the disclosure of the purpose and scope of the consultation, including policy and schedule mandates or limitations.
- Establish a respectful, but rigorous mutual understanding of mandates and prerogatives associated with the consultation process and likely outcomes. Acknowledge the costs associated with consultation and collaborate on means to reduce and share the financial and time commitments.

- Facilitate stakeholder access to all data being engaged in the decision process and in understanding the full range of issues and values at stake.
- Avoid the creation of any obligation on the part of stakeholders to assume agency duties or responsibilities without compensation, or to otherwise participate in the interactions if they are not ready or willing to do so.
- Provide for the appropriate acknowledgement—typically from the head of the agency—for any individual or community that assumes duties that contribute to the achievement of management community goals or mandates.

The Sooner the Better

- Engage stakeholders as early as possible in project planning or decision making. Avoid eleventh hour notifications and short time frame response deadlines.
- Request local community representatives' assistance in establishing procedural time lines and in anticipating likely contingencies.
- If the consultation requires additional time and a schedule extension is a possibility, collaborate in developing a new consensus-based schedule.
- Until consultation is completed, make sure that all parties are aware of the schedule for the next steps and of what actions will facilitate these steps.

Go to the Source

- Create opportunities for stakeholders to provide first-hand accounts of the cultural resources they care about, especially through the definition and description of landscapes. Knowledgeable leaders or technical specialists should be engaged as full partners or hired to assist in meeting the responsibilities of management communities in relation to large, complicated, or controversial programs or activities.
- Visits to project areas and other landscapes are useful contexts for consultation.
- Avoid privileging publications, experts not recognized by the local community, and stereotypes about the local community over group memory, self-perception, and self-representation.
- Get help as necessary, through training in cultural sensitivity or conflict resolution. If mistrust or conflict persists to the point of impeding communications, consider changing the focus of a consultation to procedural matters, such as the use of a professional facilitator or dispute mediator known or acceptable to the local communities.

Respect Tribal Sovereignty

- Recognize tribes' rights and privileges, recognized statutes, court decisions, and executive orders.
- Acknowledge Federal trust responsibility for the welfare and advancement of individual Indians and Federally recognized tribes. Federal agencies do not have special fiduciary responsibilities to State-designated tribes.
- Honor tribal requests for government-to-government communications. A tribe's elected leadership may designate its representation and insist upon documented delegations of authority from the head of the management or program agency. A Federal agency designee may, in turn, request documentation for the delegation of authority from the tribe's governing authority.
- Consider the benefits of developing memoranda of understanding or other agreements to guide consultations.

The adoption and application of these principles entails substantial investments in communications. Available resources may be inadequate, and any limiting factors should be disclosed to the consulting parties. On the other hand, such communication promises to provide significant and largely unprecedented benefits to those contributing to the dialogues, as well as to the ecosystems potentially affected by proposed programs or actions. Experience and study of consultation appears to be converging on the general formula that respect leads to trust, trust to collaboration, collaboration to success, and success to additional success (NATHPO 2005; Welch and others 2009b).

Summary and Recommendations

Approaching intangible conceptual, oral, and behavioral traditions as cultural resources requires open and sustained consultations between land managers and local communities having substantial experience with the lands under management. Proper consultation can facilitate identification of a full spectrum of values and their associated cultural resources, thus enabling the definition of landscapes and the assessment of fire effects on regional, site, and artifact levels. The broader and deeper understanding produced by consultation of this sort—perhaps in conjunction with participatory GIS or other forms of community mapping—promises to improve the planning basis for the conservation and treatment of forests and woodlands where fire plays a role.

Although much of this chapter may read like an ambitious recommendation, the following ten points summarize the discussion and offer specific guidance for addressing the effects of wildland fire on intangible cultural resources.

1. Unlike wildland fire, which exists independently from humans, intangible cultural resources attain definition and value only through and with groups that rely on them. The alteration or loss of cultural resources—whether through fire or another agent—can have profound and deleterious effects on the resources themselves, as well as on groups and individuals deriving elements of their identities and senses of place from these resources. It bears mention that many local communities regard wildfire effects on cultural resources as "natural" and often even preferable in comparison to prescribed burning or other management actions or land alterations. This perspective acknowledges fire as a powerful planetary element that demands respect and, in many instances, deference. Human endeavors and institutions, especially management communities, seldom receive comparable deference from local communities.
2. A landscape approach offers potent and flexible means for consultation, research, and planning in the broad context of fire effects. Applicable in both planning and post-fire incident scenarios, the landscape approach is intended to foster broadened, community-oriented consultation concerning the conservation of cultural resources in the context of public land management in general and fire and fuels management in particular (see Field and Jensen 2005). Management communities should make the most of landscapes and other common ground with local communities. The land and its health provide excellent points of departure and goals for stewardship collaborations. One visionary collaborative model involves local communities reclaiming their intrinsic roles as creators and sustainers of cultural resources; research communities gathering information to assess ideas and provide new perspectives; governance communities of decision makers working for the long-term interests of their constituents; and land managers serving liaison roles by fostering beneficial ties among these communities and the ecosystems that are the ultimate source of our health, wealth, and happiness (Kelly and Bliss 2009).
3. Federal land managers' statutory, regulatory and trust obligations are generally met and exceeded by a common sense, good neighbor policy of communication and collaboration concerning the consideration of the full range of cultural resources and potential effects in the course of planning for programs and projects (for example, forest management plans, prescribed burn plans, best management practices for fire suppression, etc.). Additional guidance concerning landscape-level approaches to the identification and consideration of cultural resources is available in National Register Bulletins 30 (*Guidelines for Evaluating and Documenting Rural Historic Landscapes*) and 38 (*Guidelines for Evaluating and Documenting Traditional Cultural Properties*).
4. Decision makers and researchers should embrace opportunities to serve local communities in addition to scientific truths or management objectives. Many of the sacrosanct and vitalizing practices and meanings that once bound people to their lands and to one another have been lost or degraded as local communities have been obliged to interact with their lands according to alien and alienating rules and concepts imposed by management communities. Approaching fire effects on cultural resources through emphasis on either compliance checklists or materials science typically results in self-limiting perspectives, criticism from local communities, and heightened potential for conflict. The results of this alienation, coupled with global climate change, continental-scale pest problems, and ever-increasing population pressure, are seen in the widespread disintegration of ecosystems, local communities and links among them. Local communities and landscapes deserve consideration as management priorities.
5. Wildland fires often create unique opportunities in cultural resource science, management, conservation, and inter-community collaboration. These opportunities are typically short-lived, as fire and its indirect effects often elevate and escalate the potential for vandalism and theft, watershed destabilization and loss due to rehabilitation activity. In general, the more recently created or used the cultural resource, the greater the potential effects that fire may have on the resource. This is true both because a more recently created or used site is more likely to contain fire-sensitive items and features and because such a site is more likely to be valued—in its immediate post-use or pre-fire condition—by individuals and communities. This is not to suggest that truly ancient sites are disrespected by local communities or should be disregarded by managers.
6. The embeddedness of cultural resources in landscapes is true both literally and figuratively. Tangible cultural resources are very often located within, and sometimes fully encapsulated by, soil systems. Soil systems are components of watersheds, and watersheds are almost invariably affected by post-fire processes involving sediment relocations. Activities associated with wildland

fire suppression, especially heavy equipment operations, often have direct, indirect and cumulative effects on cultural resources, the consequences of which too often include additional alienation between places, people, and the cultural resources that connect them.

7. There is value and unrealized potential in integrative consultations and studies focused on particular landscapes and ecosystems. Especially encouraging are efforts to connect or re-connect local communities to historical and management issues through research, education and outreach efforts focused on fire history, ecology, and management, as well as community response to catastrophe. Research has been completed on the use of fire by local communities, and this line of inquiry should be expanded to examine the impacts of fire on local history and culture.
8. Local and descendent community connections to cultural resources should be fostered and conserved for their intrinsic value, as well as for prospective management applications. It is arguable that local communities and the intangibles that give them identity and vitality are more important than the artifacts and features that many of us think of as cultural resources. Local communities are often endangered and require support and conservation. Without people who care about and sustain cultural resources—including landscapes—managers and researchers are concerned with the relatively sterile enterprises of minimalist compliance, materials science, and management driven by either internal value systems or second-hand interpretations of local community interests and public values. The inclusion of local communities and other stakeholders as partners in public land and fire management opens the door to a search for understanding and truths regarding the critically important relationships among landscapes, history, culture, and management.
9. As one means for integrating practical and legal mandates, fiduciary principles espoused by institutional and financial trustees offer a guide for expanding considerations of fire effects on cultural resources beyond basic management and pro forma compliance, toward true stewardship. All employees of public land management agencies share the burden of upholding the public trust, the doctrine of fiduciary responsibility for the maintenance and improvement of the terrain and resources under their control (Dunning 2003). In addition to general duties as public trustees, all U.S. Federal officials share specific fiduciary responsibility for the welfare of American Indians (Chambers 1975; Welch and others 2009b). American Indian communities and individuals often depend on land-linked cultural heritage for everything from raw materials required for religious practices to the foundations of group identity and moral guidance (Basso 1996; Friedlander and Pinyan 1980). This truth also applies to most place-based non-American Indian communities.
10. NEPA, NHPA, and fiduciary principles converge on the mandate for public land managers to harmonize their programs with local interests and long-term ecosystem health. One criterion for assessing land management is the degree to which policies and practices strengthen land-linked communities and enhance their ties to lands and other resources. A second criterion is the degree to which a management policy or practice results in the maintenance or enhancement of the value of lands as trust assets, as evaluated by the beneficiaries. Fiduciary obligations to the public at large and American Indians in particular suggest the need for long-range planning and the identification and evaluation of all significant cultural resources potentially affected by management decisions and actions. There are, of course, many regional and agency interpretations of what these obligations mean, and it is useful for practitioners to understand both legislative intent and the political and bureaucratic forces that have shaped actual practice.

Concluding Thoughts

Fire is a unique and powerful element of the Universe, existing as both tool and symbol in all cultures. Given our interests in understanding the world, protecting ourselves, and harnessing fire, the enduring fascination with fire is little wonder. Nonetheless, in the face of countless lessons learned about fire's destructive force, and innumerable billions spent on subjugation crusades, fire continues to defy mastery. Fire thus serves as a catalyst for change and a sometimes cataclysmic reminder to local and management communities of the mandate to seek harmony with ecosystem processes. Many local communities have heeded this reminder, incorporated fire's lessons into cultural resources, and embedded themselves in fire-dependent landscapes and ecosystems since time immemorial. Management community representatives and researchers are urged to consider the benefits of protecting local communities and their landscapes as cultural resources. Once people and the places they care most about are safe, the possibilities increase for learning what lessons they may offer concerning ecosystem disturbance, resilience, and balance, as well as the consequences when these are disregarded or exceeded.

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Chapter 9:

Implications of Fire Management on Cultural Resources

> *It is not what you find, but what you find out.*
>
> David Hurst Thomas

Previous chapters in this synthesis have identified the important fuel, weather, and fire relationships associated with damage to cultural resources (CR). They have also identified the types of effects commonly encountered in various fire situations and provided some guidance on how to recognize damages and minimize their occurrence. This chapter describes planning processes and actions that can be used to manage the effects on cultural resources in different fire and fire management situations.

Three reoccurring themes have emerged in this synthesis: the need to identify, evaluate, and mitigate the impacts of fire and fire management activities on cultural resources. The most critical point of this approach is the need to **identify** the values at risk. The previous chapters have provided a clear idea of the scope of cultural resource elements—both tangible and intangible—that could be lost if not properly protected and what may cause the most harmful effects to each. This report has assessed fire's effects on cultural resources of many types, but for fire managers there may still be questions about what is actually at risk. Each resource was discussed in detail, identifying not only its physical properties but also its cultural significance. The values of these resources were identified through field surveys, georeferencing techniques, and consultations with local community members and tribal liaisons (chapter 8).

What determines the value of each element? Through **evaluation**, using the matrix process detailed later in this chapter, we are able to define not only the physical properties or significance of each element but also management and inventory techniques. These evaluations also often provide a context for future desired conditions for the site as well as the priority for comparison to other elements. Specifically, the matrix identifies values at risk versus fire behavior *and* management actions. The *Risk Management* section below and also the *Introduction* (chapter 1) define direct and indirect effects of fire and operational activities on cultural resources. Other chapters allude to operational effects through examples. Simply stated, operational effects are effects on cultural resources caused by fire suppression activities such as digging line, dropping retardant, cutting down trees, or other tactics. In fire management activities, particularly fuel treatments and restorations, the evaluation process involves a number of iterations where expected fuel consumption and fire behavior are evaluated for their potential impacts on CR and prescriptions are modified to minimize adverse effects and the need for subsequent mitigation.

Mitigation is the final step in managing cultural resources because it is not possible without identification and evaluation. Careful planning and advance knowledge of the types of cultural resources commonly encountered on a management unit can minimize negative effects to CR. However, new cultural resources are often discovered following fire. If we do not know what is there, we cannot create a means to evaluate what is important to preserve, or plan how to best protect these resources from damage or destruction. Mitigation, in this context, are the preventative measures that both cultural resource specialists and fire managers can use to limit direct and indirect effects of both fire and fire management activities. Mitigation of fire and suppression effects on CR has been discussed in previous chapters and is discussed in the sections below as an essential step for both planned and unplanned fires.

The objective of this chapter is to provide an integrated summary of the potential impacts for fire-related activities within a framework useful for managers. It presents additional information for both cultural resource specialists and fire managers to help them understand the resources they are trying to preserve, how they are damaged, and to create processes to better preserve them.

Planning

The management of cultural resources is becoming an increasingly important concern for managers of Federal, State, and tribal lands. Numerous laws, regulations, policies, and guidelines that address cultural resource management have been developed over the last 100 years. Section 106 of the National Historic Preservation Act (P.L. 89-665, as amended, P.L. 91-423, P.L. 94-422, P.L.94-458 and P.L. 96-515), along with its regulations (35CFR800), require cultural sites to be evaluated for their potential to be eligible for listing in the National Register of Historic Places. The law also directs Federal agencies to assess the effects of a proposed project on any eligible properties. Past and potential fire impacts to artifacts and features are critical in assessing both eligibility and effects. Managers must, therefore, be able to integrate the application of an existing regulatory framework with the knowledge of potential impacts to these irreplaceable cultural resources.

Effective cultural resource management begins with strong management commitment, good inventory data, solid planning, and effective monitoring. General or land and resource management plans (LRMP) define the mission and strategic direction for a unit of land. These broad-scale plans typically identify the pertinent laws and authorities associated with the creation of the management unit, its geographical location, roles and responsibilities, stakeholders and partners, important laws governing the management of the unit (e.g., in the United States: National Forest Management Act, Federal Land Policy and Management Act, Endangered Species Act, Clean Air Act, Clean Water Act, National Historic Preservation Act, etc.), the resource goals to be promoted by the plan, the values at risk, and the sources of those risks (fig. 9-1). Ideally, LRMPs also clearly describe the types of vegetation, the role of fire regimes, and the historic and prehistoric uses of the land. Similarly, cultural resource management plans (CRMPs) identify the pertinent laws and policies governing the protection of historic and prehistoric heritage resources, roles and responsibilities, and key contacts such as the State Historical Preservation Officer and indiginous community leaders. They also identify the cultural resources (CR) including cultural landscapes; the types of sites; known or probable resources and their location, as appropriate; as well as the threats or risks to the CR. Some sites may be well known (lookouts, ranger stations), while locational information of other sites (prehistoric camp sites) is exempt from public disclosure to protect the resource from vandalism (Christensen and others 1992). CRMPs also identify the state of knowledge and the CR practices and standards for inventorying, monitoring, stabilizing, and restoring resources as well as measures for minimizing and mitigating negative impacts associated with other management activities. Likewise, fire management plans (FMPs) define pertinent laws and policies, authorities and responsibilities, goals, options, and constraints facing fire management. FMPs typically include descriptions of historic role and use of fire in the management unit; elements of the fire environment including vegetation/fuels, terrain influences, and historic fire weather; fire occurrence and behavior; the values at risk; and resources protected. The standard focus of FMPs includes public and fire fighter safety; natural, air, and cultural resources; infrastructure, and wildland urban interface. FMPs describe appropriate actions for fuels treatment, restoration, and wildfire suppression based on current knowledge and practices. Both the cultural resource management plan and the fire management plan provide direction to the LRMP and draw direction from it. All three are part of an integrated approach to effective planning and stewardship of natural and cultural resources. Fire management and cultural resource plans are integrated with land and resource management plans to form the basis for proposed activities. Actual activity plans require interdisciplinary integration of other resources and processes. Assessment of actual

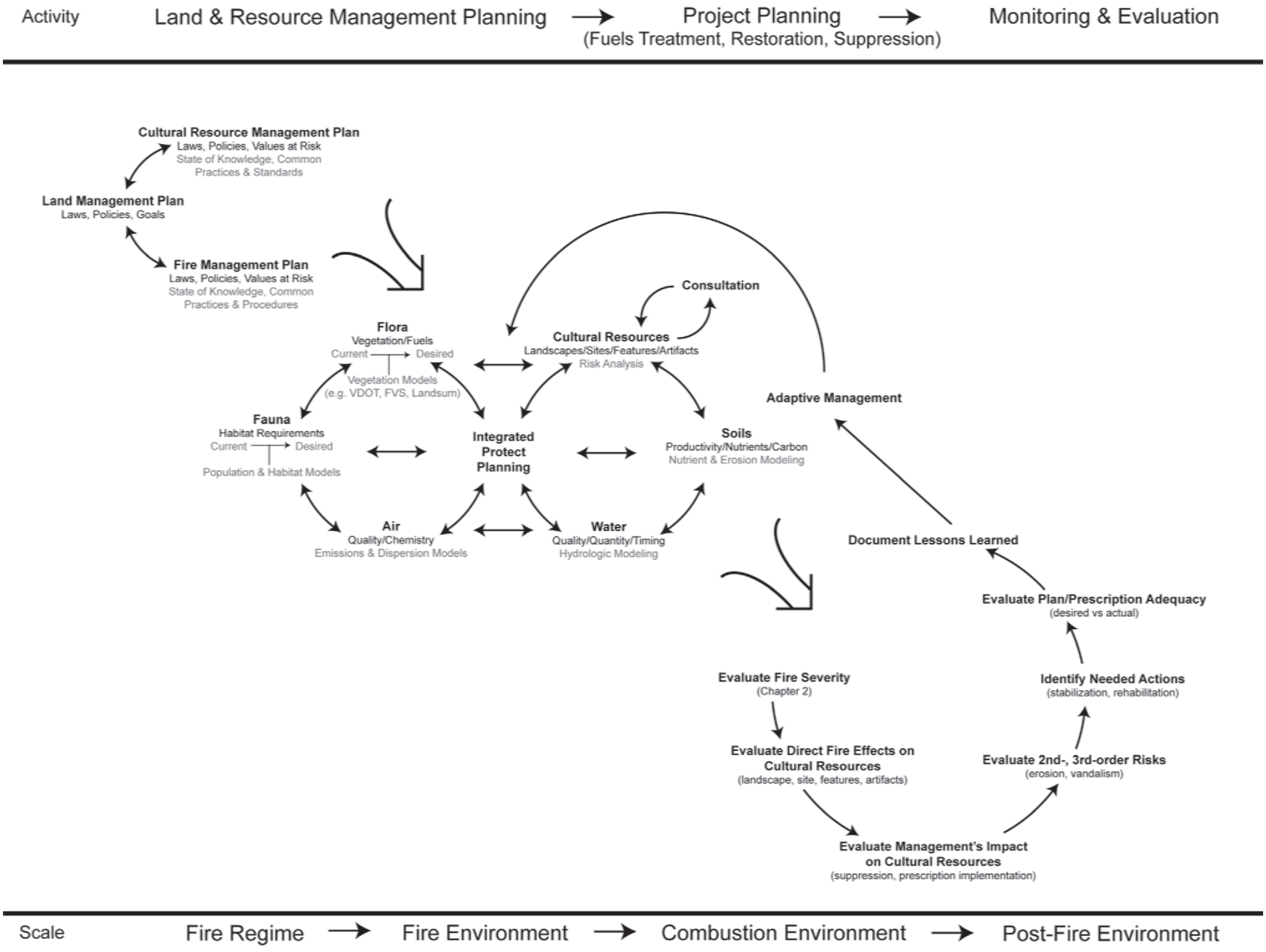

Figure 9-1—Schematic of the planning process as it relates to cultural resource (CR) protection.

and potential impacts on CR following action (fire) requires inventorying, monitoring, and interdisciplinary assessment. These support critical evaluation of preexisting plans and procedures, documentation of lessons learned, and refined knowledge in support of adaptive management.

Well written integrated LMPs, CRMPs, and FMPs provide a foundation for designing and implementing projects that achieve their shared-collective goals. Integrated project planning addresses the effects of proposed actions on flora (Brown and Smith 2000; Steffan and others 2010; Zouhar and others 2008), fauna (Engstrom 2010; Smith 2000), air (Sandberg and others 2002), soil and water (Neary and others 2005), cultural resources (chapter 1), communities (Aplet and Wilmer 2006; Daniel and others 2005; Jakes and others 2007; Shlisky and others 2007; Wells 2009), and infrastructure. Integrated project planning involves an iterative process of evaluating trade-offs between competing goals and objectives to arrive at the best alternative for a multiple of resources (fig. 9-1). It is an interdisciplinary collaborative effort involving stakeholders (Jakes 2008; Kaufmann and others 2009; McCaffrey 2006; Sturtevant and Jakes 2008). Fire managers need to consider all significant and sensitive CR and to be proactive to minimize potential damage. Active involvement of CR specialists in the planning and conducting of fire management activities is integral to meeting CR goals and objectives (table 9-1).

Following fire, CR specialists need to evaluate the fire's severity and its impacts on the cultural resources. (Chapter 2 provides guidelines for evaluating fire severity.) Fire's impacts may be the direct result of heating or the deposition of chemicals released during the combustion process (soot, tars, adhesions, etc.). Other chapters in this publication provide guidance on determining the direct effects of fire on ceramics (chapter 3), lithics (chapter 4), rock art (chapter 5), materials of the historical period (chapter 6), and subterranean structures (chapter 7). Evaluation of the effects of fire on CR requires that the CR specialists consider the combustion environment, i.e., the local small-scale environment juxtaposed around each site or artifact as it is at this scale that the direct effects occur (chapter 2).

In addition to evaluating the direct effects of fire on cultural resources, CR specialists need to evaluate the impact of fire management activities (fig. 9-2b) (broken bedrock mortar) and the potential for second- and third-order effects such as the potential for post-fire erosion (Allen 2001; Lesko and others 2002; Johnson 2004; Kelly and Mayberry 1980; Neary and others 2005) and for vandalism (Christensen and others 1992; Davis and others 1992a,b; Downer 1992; Higgins 1992), respectively. Erosion potential is a function of the terrain, geologic parent material, fire severity, and expected post-fire weather, principally precipitation (Neary and others 2005). Effective evaluation of erosion potential and the need for post-fire stabilization and rehabilitation requires an interdisciplinary effort. Following planned (e.g., fuels treatment, restoration, prescribed burning, etc.) and unplanned (e.g., wildfire

Table 9-1—Advance planning–preparedness: A U.S. Federal lands example.

Proper cultural resource planning is the best way to respond to any planned or unplanned fire. There are several steps that can prepare for making decisions about cultural properties:

- The Cultural Resource Specialist prepares a GIS layer with locations of known eligible and unevaluated properties, where wildfire management decisions dictate necessary site protection.
- The Cultural Resource Specialist prepares a GIS layer based on the likelihood of cultural properties using a predictive site model. In lieu of a GIS layer, the Forest will utilize a hard copy map of site probability.
- The Cultural Resource Specialist, in cooperation with a Fire Specialist, prepares Site Protection Plans (SPPs) that identify the appropriate protection measures for various cultural property types. As these plans are developed, they can be provided to the appropriate Historic Preservation Office, either the State Historic Preservation Office (SHPO) or the Tribal Historic Preservation Office (THPO) for their review and comment.
- The Cultural Resource Specialist provides instruction during any forest Wildland Fire Decision Support System (WFDSS) training on the Federal laws and Forest Service policies regarding the protection of cultural resources. The training will include the procedures for cultural resources protection.

suppression) actions, a formal review of the prescriptions, plans, and execution should be conducted. Lessons learned should be formally documented to provide a basis for a formalized adaptive management process that leads to improved management of future projects (fig. 9-1).

Risk Management

Cultural resource and fire managers should assess potential risks when evaluating the effects of wildland fire, prescribed fire, fire use and fire suppression on cultural properties. These risks include the direct, first order impacts from the fire itself as well as suppression activities, and the indirect effects such as erosion potential (chapters 1 and 2).

Direct effects that occur as a result of the fire itself include the combustion of burnable cultural materials (wood, shells, paints, glazes) and physical and chemical changes in materials (spalling, charring, calcification, crazing, melting, heat and chemical alteration). Direct effects are the result of the physical and chemical processes associated with combustion. In contrast, indirect effects occur as a consequence of the direct effects, and are of two types: human responses and biophysical responses (chapter 1). For example, from April to June, 2007, a series of fires collectively named the Bugaboo Fire burned over 600,000 acres (2,400 km^2) in the Okefenokee National Wildlife Refuge, Osceola National Forest, and adjacent lands. Hundreds of miles (kilometers) of fireline were dug by tractor-plow and hand crews, exposing and damaging numerous CR sites and features. Over 100 new sites were discovered on 407 kilometers (253 miles) of fireline on the Osceola National Forest alone (Lydick and Donop 2009). Cultural resources may be affected directly by suppression activities (hand and mechanical fire line construction (figs. 9-2, 9-3), retardant use (Reed and others 2007)

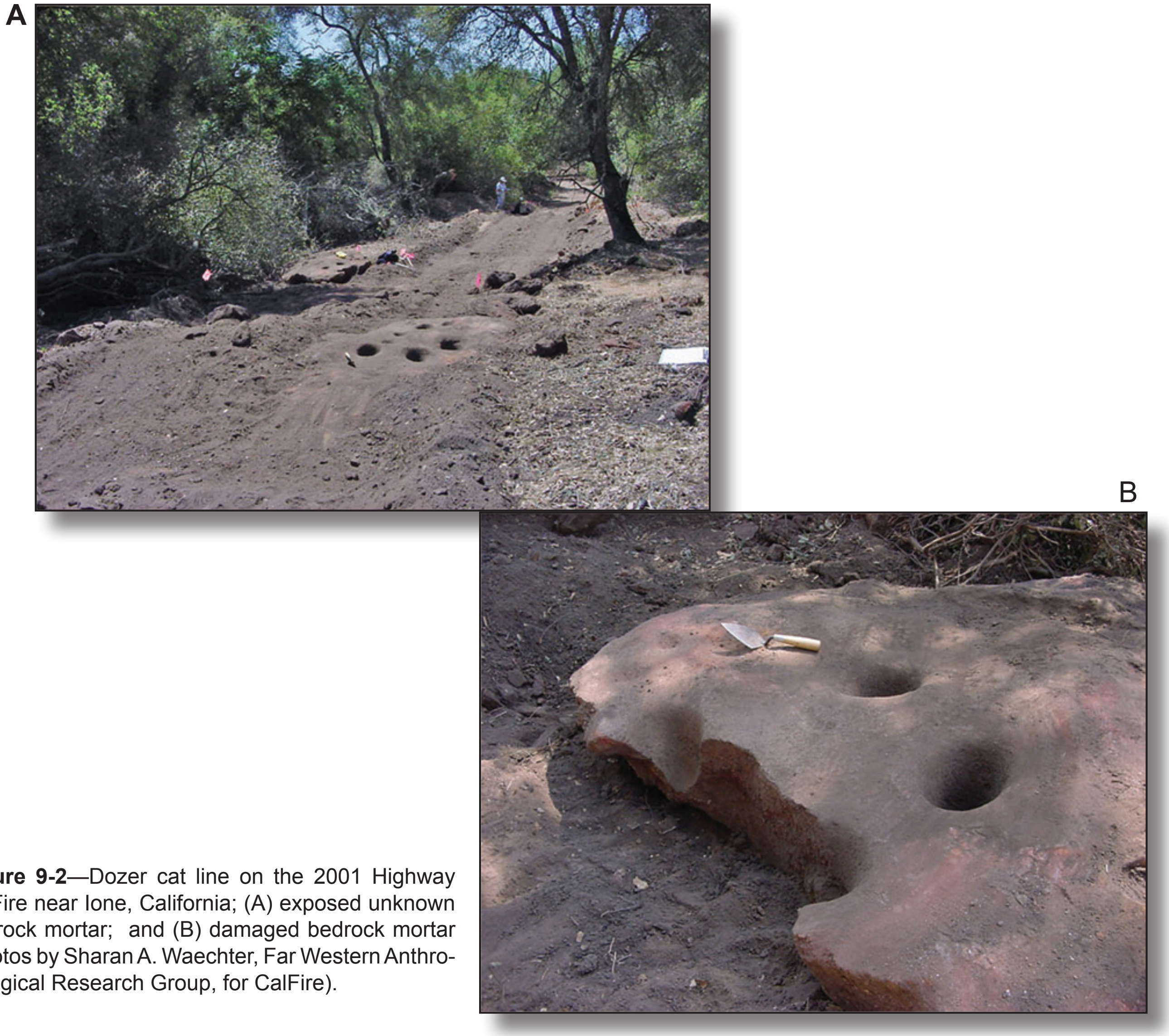

Figure 9-2—Dozer cat line on the 2001 Highway 88 Fire near Ione, California; (A) exposed unknown bedrock mortar; and (B) damaged bedrock mortar (photos by Sharan A. Waechter, Far Western Anthropological Research Group, for CalFire).

and rehabilitation activities. It is generally concluded that fire suppression activities during wildland fires and post-fire site rehabilitation treatments present the most consistent adverse impacts and pose the greatest risk to cultural properties. The indirect effects of fire include exposure of surface cultural properties to erosion and to increased visibility. The removal of vegetation and surface litter can expose cultural properties formerly not readily visible to the eye, therefore making them more vulnerable to looting (Christensen and others 1992). Post-fire erosion on steep slopes of severely burned areas can occur after intense wildland fires have destroyed most of the pre-fire vegetative canopy, causing the horizontal displacement of surface cultural materials (Allen 2001; Johnson 2004; Lesko and others 2002; Timmons and others 1996). A fire can leave standing vegetation that becomes vulnerable to blow down and can impact both surface and subsurface cultural properties.

The elements of risk for adverse impacts to cultural properties can only be assessed in a rather detailed analysis that takes into account multiple factors. One set of factors relates to the type of cultural features and artifacts (elements) involved and the relative location of those cultural properties on the landscape. Often the locations of features or sites are known before hand. Often such CRs are discovered through pretreatment or post disturbance surveys, Usually the types of resources to be expected in an area can be anticipated, (sidebar 9-1), but sometimes new discoveries are made. Another set of factors relates to the interaction of the environment with fire. As the previous chapters describe, not all cultural properties will respond to fire in the same way. How a cultural property will react to fire depends on its material composition (organic/inorganic), its provenience (surface/subsurface), existing fuel loads (grasses/heavy deadfall), fire intensity (high/low), duration of heat, soil heat penetration, and fuel, soil, and duff moistures.

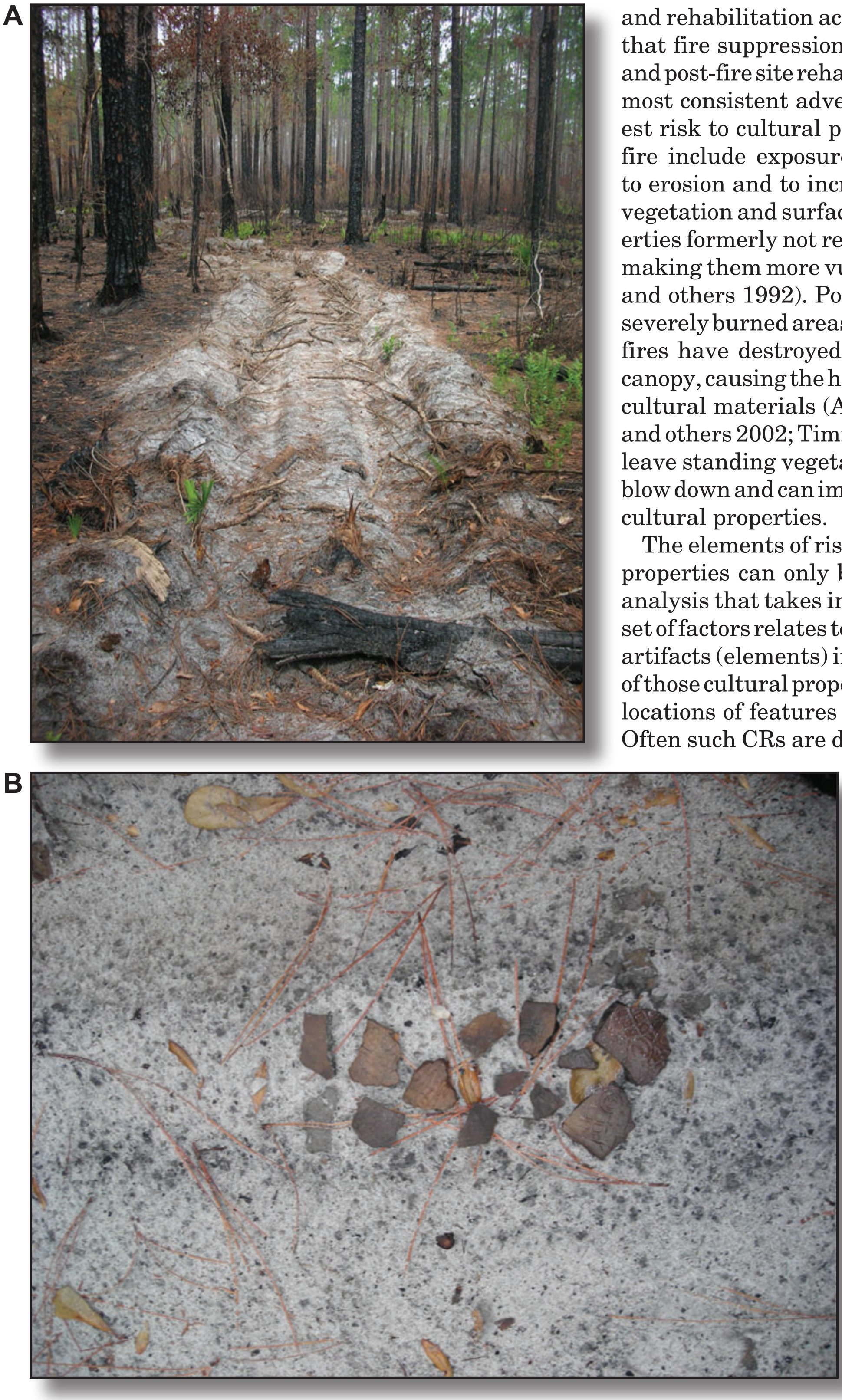

Figure 9-3—(A) Fireline on 2007 Bugaboo Fire, Osceola National Forest; (B) Pottery sherds impacted by tractor-plow fireline construction.

Sidebar 9-1—Observing and Conserving Cultural Features

Archaeologists become familiar with the types of resources in their particular area: the known sites, common features, types of artifacts, and the raw materials used in their geographic area. When CR specialists are deployed on fire assignments to new areas they need to come up to speed quickly by interacting with local specialists. Wildland fire suppression forces commonly get deployed all around the country where they encounter historic and prehistoric cultural resources. Old buildings, rock art panels, railroad trestles and other highly visible features are easily recognized as such and alert firefighters to the need to take special caution and solicit input from CR specialists. However, many CR are subtle and not easily recognized by the untrained eye. There have been instances where fire crews have “collected” artifacts and a number of examples where CRs were inadvertently damaged. Education and training can minimize these damages. Line scouts and crew bosses need to learn to spot features and minimize potential damage. The following examples illustrate the types of CR one may encounter.

A

Figure 9S-1a—Prehistoric hunting blind (photo by Becky Timmons, USFS Kootenai National Forest). The linear structure and stacked-rock nature of this feature identify it as a cultural resource.

B

Figure 9S-1b—Archaic stone hearth (note circular pattern of rocks) revealed by forest floor consumption during prescribed burning (photo by Becky Timmons, USFS Kootenai National Forest).

C

Figure 9S-1c—A slab-lined basin (prehistoric cooking pit), normally with just the tips of the walls above the surface. Erosion post-fire partially deflated the feature. The 2002 Mustang Fire burned up to the edge of the feature, which is now undergoing further deflating (lower right area in photo) (photo by Clay Johnson, USFS Ashley National Forest).

D

Figure 9S-1d—Trash dumps are commonly found in rural locations and may indicate a historic site such as this garbage dump site from a World War II prisoner of war camp near Monticello, Arkansas (photo by Don Bragg, USFS Southern Research Station).

E

Figure 9S-1e—Features such as this hand-dug well on an old homesite near Monticello, Arkansas, are easily recognized as man-made. In old mining districts such shafts are also common features that should be avoided for both safety and CR reasons but should alert fire fighters to be aware that other CR may be near-by (photo by Don Bragg, USFS Southern Research Station).

F

Figure 9S-1f—This rock circle on the south flank of Grand Mesa in western Colorado was one of three such rock circles on a very low ridge in the pinyon-juniper. Rocks were cleared on this lava rock ridge to make a circular space. An excavation nearby showed occupation going back about 5,000 years. One flake was found in the interior (photo by Sally Crum, USFS Grand Mesa-Uncompahgre National Forest).

G

Figure 9S-1g—Overhanging rock shelves such as this overhanging sandstone on the Uncompahgre Plateau rock often formed rock shelters for native people. Care should be taken to minimize soil disturbance without guidance from a CR specialist (photo by Sally Crum, USFS Grand Mesa-Uncompahgre National Forest).

H

Figure 9S-1h—Wickiups are common features throughout the western United States. What may at first glance appear to be a random jack-straw of natural fuels may be an archaic hunting camp site (photos by Sally Crum, USFS Grand Mesa-Uncompahgre National Forest).

The previous examples are but a few of the near infinite things fire managers may encounter in the field. The first and foremost rule of fire is safety first. Next comes protecting the resource, including cultural resources. A few simple rules can guide actions:

- If it looks like a good place to camp then someone has likely camped there in the past, perhaps for hundreds of years.
- If there is a majestic view, you are not the first to marvel at it.
- If something looks “out of place” or “unnatural,” it may deserve greater scrutiny.

However, non-specialists should not pick up, overturn, dig at, or otherwise disturb suspected CR. Important archaeological information can be lost just by picking up an artifact, even if it is put back down afterward. There is a good chance that he or she is on a previously recorded cultural site, where the artifacts have been recorded and are being monitored; these sites also should not be disturbed. There is also a good chance that the site is previously unrecorded. It is common to find previously unknown CR following a fire. If you find something that looks interesting:

- Leave it right where it is;
- Get a GPS location if possible;
- Take a photograph if possible; and
- Contact the local resource advisor or cultural resource specialist assigned to the fire.

Wildland Fire Management Recommendations

The protection of cultural resources during wildland fire is more challenging than for a prescribed burn. Treatment options available to mitigate the direct impacts from wildland fire include use of water, retardant, and fire shelter material. Retardant and water drops on sensitive cultural sites are possible; however, the use of retardant has some effects on cultural properties that should be considered (Reed and others 2007) (sidebar 9-2). Some areas can be protected by judicious backfiring operations that are designed to protect designated cultural properties from the direct onslaught of the fire. MIST (Minimum Impact Suppression Techniques) suppression methods can help to minimize suppression activity impacts:

- Cold trail and wet line versus mechanical and hand line construction
- Alternative mechanized equipment (rubber tired skidders versus tracked skidders)
- Minimal scraping and tool scarring during mop-up activities
- No piling of burned and partially burned fuels
- Avoidance of camping in meadows and along streams or lakes, as there is a high probability for buried cultural properties

Sidebar 9-2—Effects of Fire Retardants on Cultural Resources

Fire retardants, particularly those dropped by aircraft, are an integral tool in fire management. While retardants can be critical to fire suppression success (fig. 9S-2a), they pose a threat to cultural resources (Reed and others 2007) (fig. 9S-2b,c; table 9S-2.1). Retardants are fertilizer-based salts (commonly diammonium phosphate or ammonium sulfate) that contain corrosion inhibitors and, typically, iron oxide, which can be absorbed on porous surfaces leaving long-term staining. The salts can alter moisture relations causing shrinking and swelling that can damage the surface. Phosphates in some retardants can affect archaeological analysis of prehistoric occupation of a site. The fertilizer salts are corrosive to many metals.

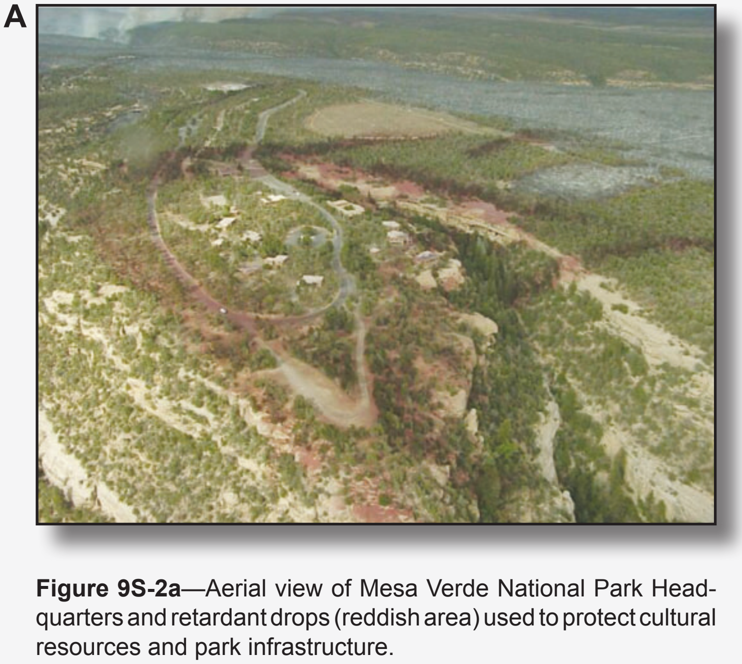

Figure 9S-2a—Aerial view of Mesa Verde National Park Headquarters and retardant drops (reddish area) used to protect cultural resources and park infrastructure.

B

Figure 9S-2b—Spruce Tree House, Mesa Verde National Park, illustrating effect of retardant on sandstone cliff-face, note Burned Area Emergency Rehabilitation (erosion mats) to protect cliff dwelling from water and debris coming over the overhanging edge of the alcove.

C

Figure 9S-2c—Close up of sandstone wall, showing the coverage of slurry coating. Dried slurry is hard, difficult to remove, long lasting, and accelerates weathering.

Table 9S-2.1—Summary of findings on rehabilitation of sites impacted by fire retardant.[a]

<table>
<tr><th colspan="4">Retardant cleaning procedures
Begin with least invasive method</th></tr>
<tr><th colspan="2">Recommended</th><th colspan="2">NOT Recommended</th></tr>
<tr><td colspan="2">• Dry brushing
• Hand brushing w/ water
• Hand brushing w/blkaline surfactants
• Poulticing</td><td colspan="2">• Power washing
• Sandblasting
• Acid based washes</td></tr>
<tr><th>Sandstone</th><th colspan="2">Painted wood</th><th>Metals, glass</th></tr>
<tr><td>• Pre-soak w/ water
• 10% borax solution (surfactant)
• Gentle circular brushing w/ natural fiber
• Rinse w/ water
• Repeat where necessary</td><td colspan="2">• Pre-soak w/water
• Brushing w/ mild detergent
• Rinse</td><td>• Wipe or sponge w/ mild detergent
• Wipe dry</td></tr>
<tr><th colspan="2">Summary of retardant investigations</th><th colspan="2">Strategies for retardant impacts mitigation</th></tr>
<tr><td colspan="2">• Retardants pose potential risks to health, safety & cultural properties.
• Retardants will not wash off naturally; they require intervention to remove, particularly on vertical surfaces
• Mitigative measures were tested that effectively removed retardants without further damage to cultural resources</td><td colspan="2">• Assess impact - resource type, retardant type
• Research retardant type and MSDS
• Evaluate risk to resources
• Mitigate impacts where necessary
• Map affected areas
• Establish monitoring system
• Consider integrating potential suppression impacts into Fire Management Plan</td></tr>
</table>

[a] Corbiel, Don. 2002. After the fire: Investigating fire suppression impacts on historic resources. Lessons learned from the Long Mesa Fire of 2002. Washington, DC: U.S. Department of the Interior, Bureau of Land Management. PowerPoint presentation. 59 slides. Online: http://www.blm.gov/heritage/powerpoint/Fire_Corbeil/Impacts%20to%20Historic%20Resources_2_files/frame.htm.

In particular, some suppression tactics should be carefully considered in areas of known cultural properties as they have a greater potential for adverse impacts, such as:

- Use of fire line explosives
- Allowing the burning of trees, snags and stumps
- Repair of soil compaction by scarification

Disturbance by fire suppression activities can be mitigated to some extent by conducting pre-fire cultural resource surveys and careful planning of fire suppression strategies in areas of cultural properties. Fire Management Plans are designed to analyze specific management areas/response zones in order to identify:

- Appropriate management response strategies for each fire management unit or fire management area;
- Acceptable fire suppression tactics;
- Strategic priorities;
- Resource values and suppression cost factors;
- "Must meet" criteria;
- Fire intensity, size, duration, and seasonal constraints;
- Areas/conditions where firefighter safety is compromised;
- Objectives/desired conditions/standards and guides; and
- Risk analysis process and parameters.

It is vital to integrate cultural resource values into these plans by providing management level information about cultural properties. Some general information to include in Fire Management Plans might be:

- Identification of significant cultural resource values at risk on large-scale maps, along with their National Register eligibility status;
- Assessment of risks to cultural properties;
- Options to reduce risks to vulnerable cultural properties, such as reduction of fuel loads, careful construction of fire lines, etc.;
- Benefits and impacts on local cultural properties as outlined in any fire guidelines, such as MIST, that may exist;
- Tribal communications protocol to be used during wildland fire suppression;
- Documentation of known issues as compiled with interested stakeholders;
- Identification of training courses recommended for cultural resource specialists that would prepare them for fire positions such as fire line locators, heavy equipment supervisors, rehabilitation team members, and resource advisors;
- Outlining cultural resource training for site protection issues for fire suppression personnel;

During fire suppression activities, several steps can be taken to further protect significant cultural properties. For example, in the United States when a fire has been declared on Federal land a wildland fire, a Wildland Fire Decision Support System analysis is prepared. This document addresses how specific fire suppression tactics will meet the guidance provided in the Fire Management Plans, including the following recommendations:

- Using any cultural property information available (GIS) to determine the cultural properties within and adjacent to the fire. Identify and map the location of significant cultural properties at risk for field reference. The status of eligibility for each site should be tracked. Traditional cultural properties should also appear on the map, if possible.
- Immediately assigning trained cultural resource specialist to fires where there are known cultural properties so that they can get out ahead of any large equipment.
- Organizing cultural resource specialist teams that are made up of qualified archaeologists and tribal representatives.
- Using the local cultural specialists to advise the archaeologist assigned to the fire if they are not local.
- Considering the location of fire camps to assure that cultural properties are not impacted.
- Including cultural resource information as part of the Wildland Fire Decision Support System.
- Encouraging cultural resource specialists to work with large equipment operators and line scouts.
- Encouraging cultural resource specialists to brief suppression crews and other field personnel.
- Ensuring that cultural resource specialists keep detailed notes on areas covered and cultural properties located and damaged.
- Consulting with State historic preservation offices following the protocol agreed upon.

Prescribed Fire

Prescribed fire is used to manage both vegetation and fuels for the purpose of restoring ecosystem processes, with several goals in mind: (1) biomass reduction, (2) site preparation for regeneration of conifers and shrubs, (3) rejuvenation of shrubs and grasses, (4) enhancing germination and growth of forbs, and (5) suppression of in-growth species. Prescribed fire may also be used to reduce fuels that could endanger buried cultural resources in the event of a wildland fire.

Prescribed fire severity varies depending on the prescription (such as, whether the fire is intended to be non-lethal, mixed-severity, or stand-replacing; light, moderate, or deep depth of burn). An earlier section of this publication (chapter 2) describes the physical process of combustion, the effect of different severities of burning on damage to vegetation, heat transfer to the soil surface, the subsequent transfer of heat downward into the soil, and potential impacts to cultural resources. It is the combustion process; along with the subsequent generation of heat, that directly damages cultural properties above, on, and below the soil surface. Above-ground materials may be directly consumed or irreversibly altered by the heat produced by the fire. Cultural materials found on the soil surface are exposed and vulnerable. Cultural resources within the soil are less likely to be changed unless heavy accumulations of surface fuels or organic soil are burned. Assessment of risks involved when using prescribed fires includes not only the potential damage of the fire to the cultural material, but also the trade-offs with other resources and the potential for escaped fires.

Cultural properties with heavy fuel loads in the form of coarse woody debris (deadfall, stumps, logging/thinning slash), thick dry duff, and dense standing vegetation may be at risk from prescribed fire. All fuel elements in the fuel bed should be considered for their potential to cause damage. For example, rotten and partially rotten logs easily sustain combustion at moisture contents well above those of solid fuels. In a study of fire in lodgepole pine forests in eastern Oregon, Agee (1981, as cited in Agee 1993) noted that even under moderate fire weather, partially decayed logs (decay class 3-4) can be the primary corridors for fire spread. Even logs with relatively high moistures (40%) will serve as corridors to carry a ground fire. The depth of heat penetration varies with the volume of coarse woody debris, whether combustion is primarily by flaming versus smoldering combustion and soil moisture (chapter 2). Temperatures associated with flaming are often two- to three-hundred degrees higher than those of smoldering, and high soil moisture presents a barrier to high heat penetration (Campbell and others 1994, 1995). In one study research, Agee (1993) found that a log smoldering for 3 hours registered a temperature of 100 °C (212 °F) at the mineral surface while the temperature of the soil under the log at 5 cm (2 in.) was only 50 °C (122 °F).

The most dramatic effects from fire will occur around stumps (sidebar 9-3). Thermocouple measurements confirm high temperatures from burning stumps at 1500 °C (2732 °F) (Traylor and others 1979). In one study Timmons and others (1996) observed burning stumps in the Green Basin Prescribed Burn in northwestern Montana. Stumps that were 30 years old did not burn, but the 45-year-old stumps burned completely. The older/drier the stump was, the more likely it was to burn out in a single event, whereas the green stumps only partially burned (Timmons and others 1996). In another study, observations at a prescribed burn in northwestern Montana revealed many of the Douglas-fir stumps left from 80 years of logging were rotted and massive in size. In a 1-acre sample plot placed in a relatively open forested landscape, 43 stumps were counted. Around 688 stumps were estimated within the boundary of a 16-acre (0.06 km^2) buried prehistoric site. Even in the light intensity spring burn conducted on the site, approximately 20 stumps within the 1-acre plot burned out. The results were stump cavities as large as 1-½ meters in diameter and depth, with root cavities extending out 5 meters (16.4 ft). If there were hearth or stone-boiling features that intermingled with the roots, the feature would collapse and artifacts dropped in the profile (fig. S-3b,c). Holes created by the burned out stumps comprised approximately 0.4% of the burn area.

In a field experiment, simulated “fire-cracked rock features” were placed next to stumps in a prescribed burn area. The lithic features located adjacent to burned out stumps were disarticulated and redeposited (Timmons and others 1996). It is also quite possible that an artifact could be thermally altered if located directly against the stump. However, as little as 0.8 centimeters (2 in.) of soil between the artifact and the stump would likely insulate it from the heat given off from the burning stump. While we cannot rule out the possibility of artifacts or even features being adversely affected by a burning stump, we have greater control of the percentage of stumps that are burned in a prescribed fire than we would if wildland fire burned through the accumulation of heavy fuel loads. Not only would wildland fire impact a greater percentage of the site, but would also increase the severity of impacts to the artifacts (fig. S-3b,c).

A slow, creeping fire, smoldering in thick duff also has potential to adversely affect cultural properties, as does heavy accumulations of standing vegetation. Total removal of duff may also expose surface features and artifacts to erosion and vandalism, due to increased visibility. Careful planning and monitoring of prescribed burns will reduce the potential for adverse effects and identify the need for subsequent rehabilitation measure, like those used following wildfires. Mitigation measures, such as mulching or concealment may be required to reduce the potential for erosion and vandalism, respectively.

Sidebar 9-3—Stump Burn-Out: Feature Damage

Stratigraphy, the laying down of layers over time, is an important factor in archaeological interpretation; undisturbed artifact or feature depth is related to time since the cultural resource was last used or deposited. Trees often grow in close association with cultural resources. Midden soils and wind-blown loess soils create favorable habitats for establishment and growth of woody plants, which eventually die. Wind-throw trees can result in ripping the root ball out of the ground creating a mound and depression microsite and redistributing cultural materials. The stump, whether occurring naturally or because of historical logging, eventually decays (fig. 9S-3a) leading to a fuel capable of sustained flaming and smoldering. The subterranean character of stump holes and root channels (fig. 9S-3b) creates the opportunity for sustained extreme heating potentially damaging surface and subsurface artifacts and features. This can be a confounding site formation effect for archaeologists (chapter 7; Conner and Cannon 1991; Conner and others 1989; Timmons and others 1996). The residual hole left after burning can collapse, redistributing cultural materials (fig. 9S-3c). Mop-up during fire suppression poses additional hazard to artifacts through rapid quenching or mechanical disturbance.

A

Figure 9S-3a—Rotten stump 40 years after partial cutting of the forest.

B

Figure 9S-3b—Burned-out stump hole revealing collapsed rocks.

C

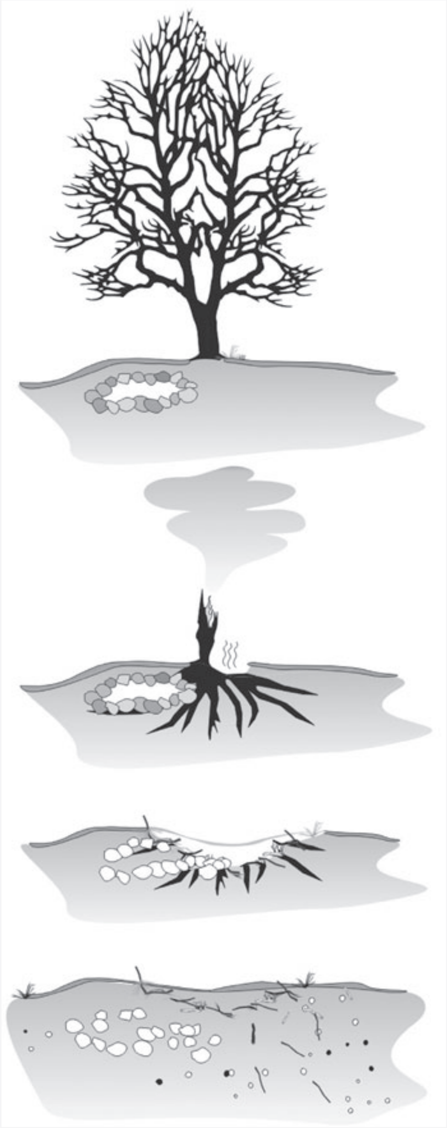

Figure 9S-3c—Stump burn-out and cultural resource damage. Trees commonly grow in or adjacent to features as in this illustration of an archaic hearth. Root expansion during the tree's life can displace artifacts. Subsequent burn-out of the stump and roots can cause collapse and redistribution of artifacts as well as affect dating techniques.

Prescribed Fire Management Recommendations

The risk of negative impacts from prescribed fire to eligible or potentially eligible cultural sites can be minimized through proper planning. The planning, implementation, and monitoring of prescribed burns are best accomplished through applying a team approach of cultural resource specialists and fire managers.

Cultural Resource Specialists:

- Conduct project inventory to identify cultural properties and obtain the necessary clearances (legal compliance) for the proposed burn area in order to assess project effects to cultural properties. The inventory should include ethnographic (tribal) information about cultural properties (as associated with cultural sites) and treaty rights-related resources (as associated with plants, etc.). Consider all cultural sites with surface artifacts or features as sites at risk and design specific protection measures accordingly.
- Provide cultural information (location, provenience, site description, areas of high potential for resources).
- Consult with American Indian Tribes and First Nations regarding the project intent and dates.

Fire Managers:

- Determine the type and loading of fuels in order to obtain estimates of potential fuel consumption and surface and subsurface temperatures and work with cultural specialists to determine how these combinations could affect cultural materials.
- Identify the fuel models and vegetation types to help determine the potential heat that may be generated under different fuel moisture, weather variables, and ignition patterns.
- Formulate a burning prescription and work with cultural specialists to ensure that all significant cultural properties are protected. Carefully consider burning strategies that might reduce potential effects. For example, a head fire might cause fewer effects to artifacts on the ground surface than a cooler, slower moving backfire with a longer residence time (chapter 2).
- List all burn preparation needs in the burning plan and ensure that they are implemented before burning.
- Brief all fire support personnel on the objectives of the burn and engage the cultural specialists to discuss the proper protection of cultural properties and materials.

Removal of heavy fuels is the most useful preventive measure for lessening the impacts of fire on surface cultural materials. This includes deadfall, snags, and heavy brush, all of which have the potential to burn hot. Light fuels such as grasses and thin duff will usually produce low heat and residence time resulting in minimal impact on the surface. Under common prescribed burning conditions grass fires typically result in smoke-blackened artifacts and features, which retain their interpretive potential after they are affected. While heavy fuels are the greatest threat to surface cultural materials, stumps and roots present the greatest potential source of heat penetration into undisturbed sub-surface cultural deposits. A trained cultural resource specialist should determine the best treatment measures, which might include:

- Avoid burning heavy fuel accumulations; if present, remove the concentrated fuels from the sensitive sites. Trees, snags, and large shrubs should be removed from cultural resource sites when they are identified as having the potential to adversely impact the resource. Particular care should be directed to the location and burning of any slash piles.
- Hand removal of any fuel source may be necessary. Some resource types such as pictographs, petroglyphs, bedrock mortars, and milling features may be damaged by the presence of even light fuels.
- Treat stumps by wrapping them with fire resistant-reflective fabric; application of water, retardant, or foam; or bury stumps with soil, rocks, or similar material to prevent ignition during a fire. Accelerating stump decomposition with substances designed to accelerate decomposition, or mechanical treatment of stumps by drilling or scoring may be helpful. However, physical removal of a stump by mechanical means could have as much or more impact than the fire itself.
- Remove standing, dead trees from sensitive cultural resource sites to prevent tree tip-up.
- Isolate vulnerable cultural properties from the fire by creating foam barriers, building carefully prepared hand lines, and establishing hose-lays.
- Remove deadfall from sites, particularly from surface features. When planning for prescribed fire, it is in the best interest of the resource to minimize the ignition of trees, deadfall, and stumps.
- All trees, shrubs and brush growing in and near cultural features should be assessed and removed as appropriate. Planning for removal of live vegetation should include consideration of whether erosion would be accelerated when trees and large shrubs are removed or whether exposure of the feature to looting outweighs any potential benefits. It would not be appropriate to worsen erosion or looting hazards while attempting to control potential fire impacts.

Fire Rehabilitation

Fire rehabilitation activities following the fire should receive the same level of attention as that used in designing the implementation of a prescribed burn (sidebar 4). A cultural resource specialist should be involved in the development of rehabilitation plans to identify site-specific mitigation measures for cultural properties. Mapping the location of post-fire treatment areas and specific rehabilitation activities for cultural sites will help assure avoidance of any further damage to resources. Individual cultural resource site records should be updated to reflect any changes that occurred as a result of the rehabilitation activities.

Fire Rehabilitation Recommendations

Caution should be exercised when implementing post-fire treatments (Robichaud 2009; Robichaud and others 2000) to avoid damage to cultural resource sites. Physical treatments common as rehabilitation measures include aerial or ground application of mulches, straw wattles, reseeding (preferably with native species), mechanical revegetation, construction of contour trenches, and water barring. Recommendations for mitigating potential adverse effects during rehabilitation should be specific to cultural sites, outlined in formal *Determinations of Effects*, and reviewed by the State historic preservation office or the tribal historic preservation office. Recommendations should be implemented as soon as possible to prevent resource loss due to erosion and looting. Some recommendations to consider are:

- Backfilling stump cavities to prevent collapsing of sediments around features. The locations should be carefully documented for reference by future cultural resource specialists.
- Reseeding of devegetated areas with vegetation that does not contribute to vertical displacement of buried cultural materials.
- Installing log diverters to redirect the flow of water away from vulnerable areas of a site.
- Removing standing, dead trees inside of features to prevent tree tip-ups caused by falling and possible later ignition by fire.
- Consulting with a rock art conservation specialist to assist in identifying appropriate treatment.

In the United States, recommendation options may be compiled and agreed to by the agency, the State Historic Preservation Office, the Advisory Council on Historic Preservation, and interested tribes in a Programmatic Memorandum of Understanding (PMOA). A PMOA can be negotiated on a local forest or regional level as tiered to any national PMOA. At present there is a multi-agency effort to produce a national PMOA on Wildland Fire Management and Cultural Resources.

Fire Use

In the United States, some naturally ignited fires are allowed to burn under specified, prescriptive conditions in order to meet resource objectives. As such these fires pose some challenges that are somewhat unique. Such fires are typically in more remote areas and often within legally designated wilderness areas where mechanized fire suppression is limited. In contrast to wildfires that are suppressed as quickly as practical, such resource benefit fires may be allowed to burn for weeks or months. In such situations planning for cultural resource protection is more similar to that of a prescribed fire in that there is a greater opportunity for planning and coordination. The remoteness of the resource changes the risk factors, such as those posed by heavy equipment, but also changes the monitoring and rehabilitation opportunities requiring both fire managers and the cultural resource specialists to adapt their practices (sidebar 9-5).

Fire Use Recommendations

The use of cultural resource data to support wildfire planning has traditionally been a management issue. The disclosure of cultural resource data has typically been such that the release or exchange of information with wildfire staff is cumbersome and at times nonexistent. Protection of cultural site location information is mandated by the Archaeological Resource Protection Act. It is exempt from public disclosure, but can be made available to other agency personnel on a need-to-know basis, which includes information needed to protect a cultural site. The lack of information including site location, site probability, and fire susceptibility can impact planning for wildfire decisions and prescribed fire projects.

CR data, along with other datasets, are needed on an interagency basis to support national applications, planning, and wildfire suppression efforts. To facilitate the collection and standardization of these datasets, the Federal agencies are developing a wildfire geodatabase (Wildland Fire Distributed Information System) that would pull cultural resource data from various sources and make it available for wildfire response teams. This is not intended to store or create a national dataset of site specific locations but provide generalized locations that include material types (for information on susceptibility to fire) and site depths.

In the United States, an application that will use these data is the Wildland Fire Decision Support System (WFDSS) (Noonan-Wright and others, in press). WFDSS runs Finney's fire spread probability model (FSPro) (Finney and others 2011) that calculates the probability that a given area will burn based on thousands of simulations of historic fire weather. This probability layer is then intersected with multiple data

Sidebar 9-4—Protecting Cultural Sites From Erosion

Burned Area Emergency Rehabilitation (BAER) is frequently used to protect cultural sites from further damage from erosion. Fire management agencies have guidelines for BAER practices, which often need modification in cultural resource areas. BAER teams working in CR areas should have CR specialist on the team to direct rehabilitation efforts and site documentation for future monitoring.

A

Figure 9-S4.a—Burned Area Emergency Rehabilitation work to protect a rock shelter following the 2002 Mustang Fire, Ashley National Forest, Utah. Straw wattle (foreground) was used as a runoff barrier to protect the rock shelter from water coming in from the side, which could result in erosion damage. An erosion blanket (brown patch in mid-ground) was used to protect the floor of the rock shelter from water flowing off of the overhanging ledge (Johnson 2004a,b) (photo August 2002, by Clayton Johnson, USFS Ashley National Forest).

B

Figure 9-S4.b—A prehistoric rock shelter shown in figure S4.a with treatments to reduce further erosion. Protection for archaeological sites must be designed to keep erosive and debris flows away from the site, and to reduce erosion on the site without further disturbing the features. Log erosion barriers are not recommended on a cultural site as they raise the risks additional damage due to mechanical disturbance and future fire damage. Note deposited sediments against straw wattle erosion barrier (lower right corner of photo) 10 months after BAER placement (Johnson 2004a,b) (photo May 2003, by Clayton Johnson, USFS Ashley National Forest).

C

Figure 9-S4.c—Hand mulching with straw was effectively used to protect an archaic pueblo site burned over in the 2002 Rodeo-Chediski Fire, Apache-Sitgreaves National Forest, Arizona (photo courtesy of Barbara Mills, University of Arizona).

D

Figure 9-S4.d—The mulching was successful, as observed in 2004 at the pueblo site, shown in figure S4.c, 2 years after the Rodeo-Chediski Fire (photo courtesy of Barbara Mills, University of Arizona).

Sidebar 9-5—Structure Protection

Many cultural sites consist of stone, adobe, or wooden structures (log cabins, old barns, mining buildings, historic lookouts, etc.). There are three main mechanisms whereby such structures may be damaged in wildland fires: ignition from a wind-blown ember (fig. 9S-5a,b), flame contact from the burning of surface fuels too close to the structure (fig. 9S-5c), and radiant heat from an intense surface or crown fire (fig. 9S-5d,e). Spotting distance increases with the intensity of the fire and wind (chapter 2). Spotting up to a kilometer is common and spotting up 2 kilometers occurs under ideal conditions. Sprinkler systems, fire retardants, and wrapping (fig. 9S-5f) are routinely used, often in combination, to protect historic structures (fig. 9S-5g).

A

Figure 9S-5a—Historic cabin burned from ember-caused ignition.

B

Figure 9S-5b—On the evening of July 29th, 2002, historic residences burn during the Long Mesa Fire, Mesa Verde National Park, Colorado. On the evening of July 29th, embers from the blaze landed on rooftops and entered into attic spaces. Three residences were lost along with other infrastructure.

C

Figure 9S-5c—Damage to a sandstone wall caused by direct flame contact during the 2002 Long Mesa Fire, Mesa Verde National Park, Colorado.

D

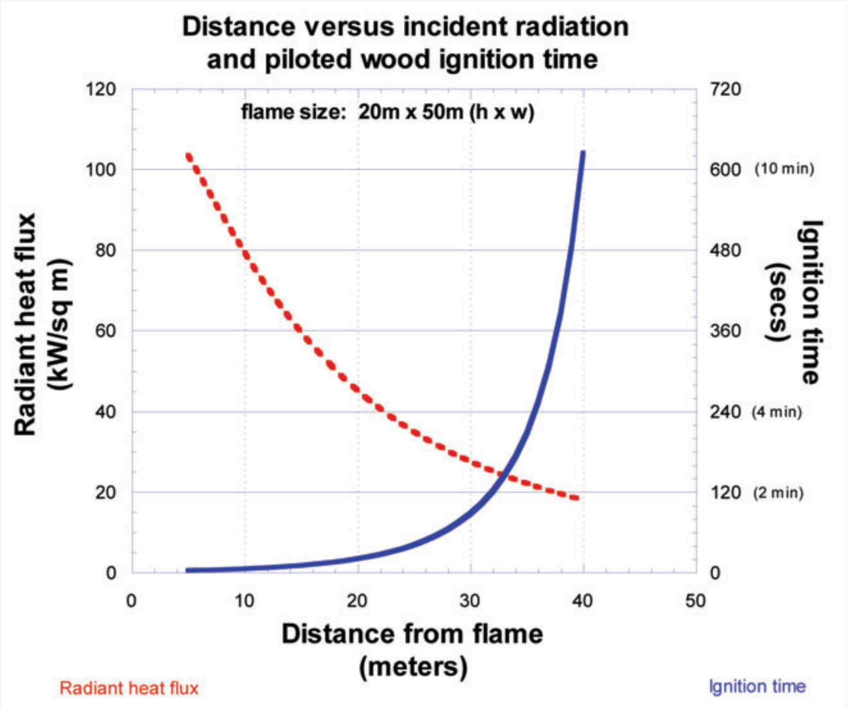

Figure 9S-5d—The radiant flux from an intense crown fire decreases exponentially with distance. Correspondingly, the exposure time to ignition increases exponentially with distance from the flame-wall. Because fine canopy fuels burn out quickly (<2 minutes), peak intensities can not be sustained long enough to ignite wooden structures at a distance greater than about 30 meters (~ 100 ft.) (Cohen 2000).

E

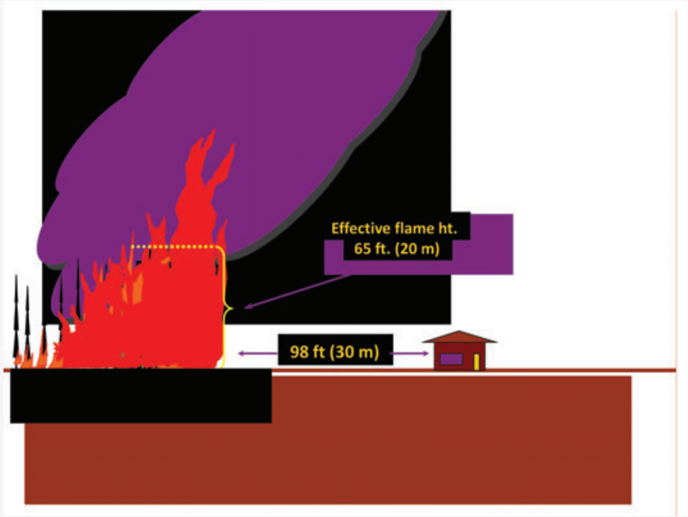

Figure 9S-5e—Modeling can be used to predict the distance from a structure that fuels need to be treated to protect structures from direct flame ignition.

F

Figure 9S-5f—Crews commonly wrap back country structures with fire shelter cloth to minimize structure ignition.

Figure 9S-5g—Little Snowy Lookout following foil-wrapping and pretreatment with aerial retardants.

layers such as structures, roads, ownership, and other significant values at risk in the Rapid Assessment of Values at Risk model (RAVAR) (Calkin and others 2008, 2011; Thompson and Calkin 2011). A report is generated detailing the probability that these resources will be impacted by the spreading fire. The fire's risk to a cultural resource feature class can be a component of this report. To support the WFDSS analysis, the cultural resource layer will consist of several attributes that provide basic information about sites so that fire staff will have a basic understanding about the condition of the site, the fire sensitivity of the site, and possible management mitigations or avoidances to better protect the site.

Another tool for fire planning is a decision-making matrix, developed for the National Park Service that is being used as a planning tool to convey essential information regarding cultural resources, their contexts, values, and the activities needed to identify and manage them within fire situations. Inventory strategies, management objectives, and treatment options can be designed to plan for fire events by defining cultural resources and their components. This allows specialists to see, at a glance, a summary of what resources are present and how they may be effectively managed and protected. By looking at the historical context of a landscape, surveyors are able to examine historic techniques that may influence management tactics for the future. By using generalized language to describe resource types, security can be maintained to protect actual site content while still giving enough information to allow for effective management decisions within and around the resource sites.

In addition to categorizing resources, the matrix places resources in multiple contexts; defining what elements are at risk, what needs protection, and the integral characteristics to be preserved. Creating a risk matrix also compels administrators to identify possible risks directly or indirectly caused during and after management, ranging from artifact displacement to complete obliteration in some cases. The matrix also calls for inventories of sites and suggestions of future inventory methodology, associating temporal data with each resource. After compiling what resources are within the specified area, land management decision makers and cultural resource specialists collaborate to create appropriate management objectives to achieve a desired condition. When the objectives are established, several treatment options are proposed to obtain the desired conditions, and managers use the best research available to choose the best treatment alternative to implement. Table 9-2 is a specific example of the matrix provided by Great Smokey National Park where cultural resources from both the prehistoric and historic periods and major resources which must be preserved in fire and vegetation management activities.

Summary

A large amount of data is becoming available concerning various dimensions of cultural resource management. These data include detailed information on the different cultural resource materials and how they are changed by fire. The behavior of fire and associated combustion processes are well understood, as are impacts of fire on vegetation, soil, and water. The direct and indirect effects of activities associated with wildland fire have been well defined. There is immediate need to bring together the wide array of information into a format that managers can use while fighting wildland fire or for planning burns. The information should be synthesized into a workable set of guidelines for protection of cultural resources. Integration of cultural guidelines with Fire Management Plans, MIST Standards, emergency discovery plans, and fire management handbooks is critical.

Table 9-2—Matrix for evaluating potential impacts of fire management activities on cultural resources. Example from the Great Smokey National Park. Matrix developed by Robert J. Jackson, Pacific Legacy.

Historic context[a]	Resource type[b]	Properties at risk[c]	Elements[d]	Risk conditions[e]	Inventory method proposed[f]	Management objective desired condition	Treatments alternatives/options
Archaic Prehistoric	Res. procurement camp	Lithic scatters/flaked stone	Chert	Displacement from ground disturbance	Documents search, predictive modeling, shovel tests in low slope areas and gaps	Map, maintain site stability and data potential of site components	Remove heavy fuels
	Base camp	Ground stone	Quartz	Breakage from heavy equip./heating	Documents search, predictive modeling, shovel tests in low slope areas and gaps	Maintain cool surface temp	Reduce duff consumption
		Fire cracked rock	Granite	Confounding of thermal dating		Avoid crushing artifacts	Line w/o mineral soil disturbance
		Charcoal	Sandstone	Mistaken raw material type/discoloration		Maintain context	No heavy equipment
		Steatite vessels	Steatite	Contamination from new charcoal		Map locations	Reduce subsurface burning
			Charcoal	Displacement from erosion		Avoid charcoal contamination	Post burn stabilization
Euro American farming	Homesteads	Houses, furniture and household goods, outbuildings, apple houses/storage, yards, springhouses, ornamental/food plants, trash	Wood, stone, metal, rubber, plastic, glass, brick, cloth, cement, ceramic, leather, living exotic plants	Breakage from heavy equipment/heating	20 of the 30 known homesteads have been recorded. The last 10 should be revisited and recorded.	Case by case assessment due to high number of sites and different mgt. objectives by park district	Remove adjacent fuels, maintain greenways, burn during high soil moisture season, engine nearby and monitor during burn, sprinklers, wrap in fs cloth
	Fields/Pastures	Fences, rock walls, cultivated species, trash	Wood, stone, metal, rubber, living exotic plants	Artifact displacement from erosion		Case by case assessment due to high number of sites and different mgt. objectives by park district	Mow and wet line fences, monitor during burn and extinguish.
	Roads	Earthwork features, rock walls, vehicles, bridges, trash	Wood, stone, metal, rubber, plastic, glass, cement, ceramic, leather, living exotic plants	Loss of features/Ground disturbance and erosion	Historic maps checked to determine roads that have not been recorded.	Case by case assessment due to high number of sites and different mgt. objectives by park district	Fuel removal or monitor on case by case basis
	Orchards	Fruit and nut trees, wooden fences, rock walls	Wood, stone, metal, glass, living exotic plants	Loss by burning of cultivated plant spp.		Case by case assessment due to high number of sites and different mgt. objectives by park district	Rake around trees, monitor during burn

[a] Historic contexts are the themes, activities, events or time periods that are represented by cultural properties.

[b] Resource types are categories of physical objects or properties that share common attributes, elements, and usually functions.

[c] Properties at risk are those that have cultural value and are likely to be damaged by fire activities.

[d] Elements are the basic building blocks or constituents that make up a resource.

[e] Risk conditions or activities are the project actions that could damage elements of resource types.

[f] Inventory method is the manner in which these properties should be located and recorded or revisited.

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Glossary

adaptive management. The process of implementing policy decisions as scientifically driven management experiments that test predictions and assumptions in management plans. Adaptive management provides for scientifically based decisions when the results of management actions are uncertain.

Advisory Council on Historic Preservation. (United States) An independent Federal agency with statutory authority to review and comment on Federal actions affecting properties listed in or eligible for the national Register of Historic Places, to advise the President and the Congress on historic preservations matters, and to recommend measures to coordinate activities of Federal, State, and local agencies. Its members include Cabinet-level representatives from Federal agencies and presidential appointees from outside the Federal government.

anthropology. The scientific study of the human condition, past and present, including cultural, biological and physical adaptations over time and in various natural and social environments. Anthropology includes the specializations of archaeology, cultural anthropology (including ethnography, ethnology, and applied anthropology), linguistics, and physical anthropology. An anthropologist is a scientist with advanced training in any of these sub disciplines.

archaeological resource. Any material remains or physical evidence of past human life or activities that are of archaeological interest, including the record of the effects of human activities on the environment. They are capable of revealing scientific or humanistic information through archaeological research.

archaeological site. Any place where there is physical evidence of past human occupation or activity. Physical evidence may consist of artifacts, features such as agricultural terraces and hearths, structures, trash deposits, or alterations of the natural environment by human activity.

archaeological survey or inventory. Type of fieldwork used to discover and record surface remains of cultural resources.

archaeology. The scientific study, interpretation, and reconstruction of past human cultures from an anthropological perspective based on the investigation of the surviving physical evidence of human activity and the reconstruction of related past environments. Historic archaeology uses historic documents as additional sources of information. An archaeologist is a scientist professionally trained to conduct such studies. Archaeology is a sub-discipline of **anthropology**.

Archaeological Resources Protection Act of 1979 (ARPA). Established **antiquities permit** system for excavation of archaeological resources, and civil and criminal penalties for illegal excavation.

artifact. Any object used or manufactured by humans. Archaeologists study artifacts created or used by people who lived in the past.

aspect. The cardinal direction that the slope of a land surface faces.

association. The relationship between a historic event, activity, or person and a cultural resource.

back fire. A fire set in front of an advancing wildfire intended to remove fuels meeting management objectives to stop, turn or control the advancing front of the wildfire.

biomass. The total quantity at a given time of the living or dead organisms on a unit land area; often used synonymously to refer to the harvestable woody vegetation, especially when considering the harvest of small diameter trees to be used as chips for fuel.

blackening. the presence of carbon deposits on the surface of a specimen formed as a by-product of the pyrolysis and combustion of organic materials. Generally appears as fine carbon particles adhering to the surface of a specimen giving it blackened appearance.

building. An enclosed structure with walls and a roof, consciously created to serve some residential, industrial, commercial, agricultural, or other human use.

calcination. Loss of water of crystallization caused by heating resulting in reduction, oxidation or desiccation by strong heat.

canopy. (1) The more-or-less continuous cover of branches and foliage formed collectively by the crowns of adjacent trees in a stand or forest. (2) The stratum containing the crowns of the tallest vegetation present (living and dead).

charring. Carbonization of fuel or organic artifacts during heating or burning; to make or become black by burning, scorching.

color change. An observable color change of a specimen from original, pre-fire, color. Generally due to an alteration in the mineral composition of a specimen during exposure to heat.

combustion. The rapid oxidation of fuel in which heat and usually flame are produced. Combustion in wildland fuels can be divided into four phases. pre ignition, flaming, smoldering, and glowing.

community values. Beliefs held in common by a group of people.

compactness. Spacing between fuel particles, fuel bed density.

compliance. The process of fulfilling one’s legal responsibilities.

component. Culturally homogeneous stratigraphic unit within an archaeological site.

conduction. A heat-transfer mechanism through movement of gasses and liquids. Substances become heated and cooled through mixing or fluid motion.

context. The environment within which things (artifacts, archaeological sites and even cultures) are found or within which they operate. Includes variables of time, space, and human activities.

convection. A heating-mechanism through movement of gases and liquids. Substances become heated and cooled through mixing or fluid motion.

cover type. The designation of a vegetation complex described by dominant species, ages and form.

crazing. The presence of fine, non-linear or latticed cracks on the surface of a specimen.

creeping fire. Slow spreading surface fire with low flames; limited by fuel availability either because of limited biomass on the site or limiting high moisture conditions.

crown. The upper part of a tree carrying the main branch system and foliage.

crown fire. A fire that advances through the canopy of trees or shrubs independently of a surface fire, usually ignited by a surface fire, common in coniferous forests and chaparral shrublands.

CR. see **Cultural Resource**.

cultural landscape. Associated with a historic event, activity, or person or exhibiting other cultural or aesthetic values. A geographic area, including both cultural and natural resources and the wildlife or domestic animals therein. There are four general kinds of cultural landscape, not mutually exclusive. **historic site, historic designed landscape, historic vernacular landscape, and ethnographic landscape**.

cultural resource (often abbreviated **CR**). An aspect of a cultural system that is valued by or significantly representative of a culture or that contains significant information about a culture. A cultural resource may be a tangible entity or a cultural practice (see **tangible cultural resource**). Traditionally, this term refers to the physical evidence of past human occupations archaeologists use to reconstruct the past. This term has also come to signify objects, locations and landscapes that play a significant role in the cultural traditions of a group of people. **Artifacts**, for example, pottery sherds, are one type of cultural resource. Certain grasses used for traditional American Indian basketry are another. The remains that compose our nonrenewable heritage from the past, including both the archaeological and the historical records.

cultural resource management (**CRM**). Management and conservation of sites and artifacts preserving their value for further generations.

cultural resource management. The range of activities aimed at understanding, preserving, and providing for the enjoyment of cultural resources. It includes research related to cultural resources, planning for actions affecting them, and stewardship of them in the context of land and resource management. It also includes support for the appreciation and perpetuation of related cultural practices, as appropriate as well as the conservation and selective investigation of prehistoric and historic remains; specifically, the development of ways and means, including legislation, to safeguard the past.

Cultural Resource Specialist. A person professionally trained in one of the cultural resource fields. Included are anthropologists (applied cultural anthropologists, archaeologists, ethnographers, and ethnohistorians), architectural historians, architectural conservators, archivists, curators, historians, historical architects, historical landscape architects, landscape historians, and object conservators.

culture history. See **cultural chronology**.

culture. A system of behaviors (including economic, religious, and social), beliefs (values, ideologies), and social arrangements; the socially transmitted patterns of learned behavior; a human means of adaptation.

data. Relevant observations made on objects, serving as the basis for study and discussion.

data potential. The ability of an artifact or resource class to provide data relevant to particular research objectives. Artifacts and other cultural resources might be affected by a process or activity with, or without, loss of potential data. For instance, fires may discolor or break artifacts without altering their data potential while other classes of materials may lose their data potential with these types of alterations (e.g., technology involved in manufacture of stone tools may still be present, even if the tools are broken or discolored; discoloration of pottery sherds, however, may lead to their misidentification and loss of data potential).

direct effects: Those effects caused by fire and its byproducts, such as smoke and ash. Direct effects result from the physical state of the fire environment (fuels, weather, and terrain) and the ignition pattern (heading-fire, flanking-fire, or backing-fire). Direct effects are the result of combustion and subject to all the laws of physics and chemistry, specifically heat transfer mechanisms and physical chemistry.

documentation. Drawings, photographs, writings, and other media that depict cultural and natural resources.

duff. The layer of partially and fully decomposed organic materials (leaves, pine needles, etc.) lying below the new forest litter and immediately above mineral soil. It includes the fermentation and humus layers of the forest floor (02 soil horizon or alternatively in some classifications $O_e + O_a$ horizons).

ecofact. Geological, biological, or botanical evidence used in deciphering the natural environment of an archaeological site. It may involve inorganic material (minerals, soils, etc.) or organic material (animal parts, such as bone, teeth, and antlers; plant parts, such as pollen, seeds, and leaves; and human remains, such as bone, teeth, coprolites, and quids).

ecosystem. The living organisms of an area, the physical environment in which they live, and the interactions between them; interrelated living entities, including humans, and their physical environment.

ecosystem management. The use of an ecological management approach that blends the needs of people and environmental values in such a way that the National Forests and Grasslands represent diverse, healthy, productive and sustainable ecosystems. Healthy ecosystems are those that maintain biological diversity, biotic integrity and ecological processes over time.

edge. (1) The area where plant communities meet or where seral stages or vegetative conditions within plant communities come together. (2) The boundary between two fairly distinct fuel types.

effects. Changes incurred to resources as a result of exposure to heat or from activities undertaken to prescribe burn, or to suppress fires and rehabilitate burned areas. Effects may be adverse, beneficial, significant, insignificant, actual, potential, short or long term, unavoidable or irreversible. In NEPA (United States) documents, effects are usually analyzed in three categories – direct effects **(First-Order)**, or those occurring at the same time and place as the triggering action; indirect effects, or those removed in time or distance from the triggering action; and cumulative effects, which includes an assessment of the past actions coupled with the proposed action and any reasonably foreseeable (i.e., planned) actions in the area in the future.

ethnic. A group or category of people who share or believe they share similar characteristics based on, for example, ancestry, language, and religion.

ethnographic group. Historically documented group or culture, usually meaning an American Indian group or other group sharing a common history.

ethnographic resource. A site, structure, object, landscape, or natural resource feature assigned traditional legendary, religious, subsistence, or other significance in the cultural system of a group traditionally associated with it.

excavation. The scientific examination of an archaeological site through layer-by-layer removal and study of the contents within prescribed surface units, e.g., square meters.

feature (archaeological). Nonportable object, located in an archaeological site, not recoverable from its matrix without destroying its integrity. Examples are rock paintings, hearths, post holes, floors, and walls.

feature (historic). (1) A prominent or distinctive aspect, quality, or characteristic or a historic property; (2) a historic property.

feeling. A property's expression of the aesthetic or historic sense of a particular period of time.

fire. Rapid oxidation of biomass accompanied by the evolution of energy in the form of sensible heat and light.

fire front. The moving region within which continuous flaming combustion occurs along the fire perimeter (see **flame depth**).

fire intensity. Used in this volume as equivalent to **fireline intensity**.

fire regime. Description of the patterns of fire including the frequency, occurrences, intensity, predictability size and seasonality of burns for a given location or ecosystem. Information from the historic record is used to schedule fuel reduction treatments and predict probably effects.

fire return interval (fire cycle or fire turnover time). The number of years between fires in a given location.

fire severity. A relative term used to describe the effect of the fire on a site's biophysical properties or cultural features; dependent on fireline intensity and residence time.

fireline. A constructed area around a fire that is dug to mineral soil to remove fuels and thereby, control the fire's spread. In general, for a fireline to be effective, it should be 1.5 times as wide as the height of the fuel that is burning. When fire lines are cut by crews using hand tools, they are often referred to as handlines; when cut by equipment such as a bulldozer, they are called dozerlines.

fireline intensity. The rate of heat energy released per unit length of the fire front, usually expressed as BTU/second/foot. Fire intensity or fireline intensity, is a meausre of the difficulty of suppressing a fire, and helps project a fire's potential for torching, spotting and crowning.

First-Order Fire Effects. Biophysical changes that occur directly as a result of the fire such as fuel consumption, smoke production, vegetation mortality, or soil heating; processes modeled in the First-Order Fire Effects Model (FOFEM) (Reinhardt et al. 2007). See **Second-Order and Third-Order Fire Effects**.

flame length. The length of flames in the propagating fire front measured along the slant of the flame from the midpoint of its base to its tip. Mathematically related to fireline intensity and the height of scorch in the tree crown, whereas flame height is not.

flaming combustion phase. Luminous oxidation of gases evolved from the rapid decomposition of fuel. This phase follows the pre-ignition phase and precedes the smoldering combustion phase, which has a much lower combustion rate. Water vapor, soot, and tar comprise the visible smoke. Relatively efficient combustion produces minimal soot and tar, resulting in white smoke; high moisture content also produces white smoke.

flank fire. Fire artificially created to achieve management objectives moving at right angles or obliquely to the direction taken by the **head fire**, usually. Lines of fire set into the wind that burn outward at right angles to the wind.

forb. Any non-grasslike plant having little or no woody material on it. A palatable, broad-leaved, flowering herb whose above ground stem does not become woody and persistent.

forest cover type. A classification of forest land referring to a group of timber stands of similar development and species composition.

fracturing. The fracturing of a specimen into multiple pieces and/or the presence of fractures or fissures that penetrate deeply into a specimen.

fuel bed. The entire biomass, live and dead, that is available to burn.

fuel continuity. A qualitative description of the distribution of fuels both horizontally and vertically. Continuous fuels readily support fire spread. The larger the fuel discontinuity, the greater the fire intensity required for fire spread.

fuel loading. The oven-dry weight of all existing fuels (may be available fuel or total fuel) in a given area. Loading is further analyzed by fuel size. Loading or mass per unit is usually expressed in tons per acre.

fuel treatment. The rearrangement or disposal of natural or activity fuels to reduce fire hazard or to accomplish other resource management objectives (e.g. lopping, chipping, piling, burning and crushing).

Fuels. (Wildland fire) Any living or dead vegetation that can be ignited and is capable of sustaining or carrying a wildland fire. (Other) Chemical compounds capable of releasing usable energy.

goal. In land planning, a goal is a concise statement that describes a desired condition to be achieved sometime in the future. It is normally expressed in broad, general terms that are timeless in that there is no specific date by which the goal is to be achieved.

ground fire. Fire that burns in the organic material below the litter layer, mostly by smoldering combustion. Fires in duff, peat, dead moss, lichens, and partly decomposed wood are typically ground fires.

habitat. The sum total of environmental conditions of a specific place occupied by an organism, population, or community of plants and animals.

head fire. The fire's most rapidly advancing edge; the forward movement of a flaming front.

heritage resources. A term adopted by the US Forest Service, more inclusive than the traditional term, "cultural resources." Heritage resources include objects, locations and landscapes that play a significant role in the cultural traditions of a group of people. Heritage resources also include physical materials, such as artifacts, that may provide information about people who lived in the past.

historic. The time period after appearance of written records. In North America, this period begins with Spanish contact, after A.D. 1500. The wide-ranging influence of inter-cultural contact during the historic period represents significant changes to the archaeological record.

historic landscape. A cultural landscape associated with events, persons, design styles, or ways of life that are significant in American history, landscape architecture, archaeology, engineering, and culture; a landscape listed in or eligible for the National Register of Historic Places.

historic property. A district, site, structure, or landscape significant in American history, architecture, engineering, archaeology, or culture; an umbrella term for all entries in the National Register of Historic Places.

historic site. A landscape significant for its association with a historic event, activity, or person. (Cultural Resource Management Guideline Glossary: 1997, p. 179 the site itself possesses historical, cultural, or archaeological value apart from the value of any existing structure or landscape); see **cultural landscape**.

historical archaeologist. Scientist with advanced training in historical archaeology and in the use of historical documents in the reconstruction of the past (see anthropology).

historical archaeology. Sub-discipline of archaeology concerned with the remains left by literate societies (in contrast to prehistoric archaeology, although the distinction is not always clear-cut). In the United States, historical archaeology generally deals with the evidences of Euro-American societies and of aboriginal societies after major cultural disruption or material change from Euro-American contact.

history. Study of the past through written records, oral history, and material culture. Evidence from these is compared, judged for veracity, placed in chronological or topical sequence, and interpreted in light of preceding, contemporary, and subsequent events.

identification. Process through which cultural resources are made known.

indirect effects: Those fire effects that are derived from or dependant on the fire's occurrence, but that are not caused by the biophysical process of combustion. If the fire had not occurred indirect effects could not occur. Indirect effects are of two types: biophysical processes acting on the fire-altered environment and human responses.

infiltration. The passage of water through the soil surface into the soil.

integrity. the authenticity of a property's historic identity, evidenced by the survival of physical characteristics that existed during its historic or prehistoric period; the extent to which a property retains its historic appearance.

intangible effects. The effects of natural disturbance, e.g., fire and epidemics, or active management, e.g., fuels treatment and restoration on humans' spiritual or emotional sense of well being (sense of place).

inventory. A list of cultural resources, usually of a given type and/or in a given area.

Location. The place where the historic property was constructed or the place where the historic event(s) occurred.

landscape. A region that includes a variety of plant and animal communities and environments.

litter. The top layer of the forest floor (01 soil horizon, alternatively the Oi horizon in some classifications); includes freshly fallen leaves, needles, fine twigs, bark flakes, fruits, matted dead grass, and a variety of miscellaneous vegetative parts that are unaltered by decomposition. Litter also accumulates beneath rangeland shrubs. Some surface feather moss and lichens are considered to be litter because their moisture response is similar to that of fine dead fuel.

management area (MA). A contiguous area of land used in planning to which one or more management prescriptions are applied. These areas have similar characteristics, similar capability and common management direction. Management areas do not vary between alternatives; however, the prescriptions applied to them may vary.

management practice. A specific activity, measure, course of action, or treatment.

Management Prescription. Management practices and levels of intensity selected and scheduled for application on a specific area to further forest **goals** and **objectives**.

mass transport (spotting). The dominating fire-propagating mechanism for high intensity fires where burning embers are moved through the air far ahead of the flaming front via surface winds.

material. The physical elements that were combined or deposited to form a property. Historic material or historic fabric is that from a historically significant period, as opposed to material used to maintain or restore a property following its historic period(s).

midden. Layers of soil mixed with prehistoric or historic trash including broken pottery, animal bones, discarded shell, charcoal, etc. ; an accumulation of debris, resulting from human disposal behavior, removed from areas of manufacturing and use; it may be the result of one-time refuse disposal or long-term disposal resulting in stratification.

mitigation. Actions to avoid, minimize, compensate, reduce, eliminate, or rectify the adverse effects of a management practice. Mitigation measures can include efforts to educate governments, businesses and the general public on measures they can take to reduce loss and injury and are often informed by lessons learned from prior incidents.

mechanical fire suppression. The use of machinery such as bulldozers to control and extinguish fire following detection by removing available fuel and creating large lines of exposed mineral soil.

mineral soil. The soil layer directly below the litter and duff layers composed of sand, silt, clay and less than 20% organic matter. Its properties are predominantly determined by inorganic matter.

mitigation. Actions to avoid, minimize, compensate, reduce, eliminate, or rectify the adverse effects of a management practice.

moisture content. The amount of water contained by a fuel in relation to the weight of the particle. Fuel moisture is directly correlated with fire propagation and is essential for predicting expected fire behavior on a site.

monitoring. The formal evaluation, on a sample basis, of management practices to determine how well objectives have been met, as well as the effects of those management practices on the land and environment; a critical component of adaptive management.

mortality. Dead or dying vegetation resulting from forest fire, insects, diseases, climate or other factors.

museum object. A material thing possessing functional, aesthetic, cultural, symbolic, and/or scientific value, usually movable by nature or design. Museum objects include prehistoric and historic objects, artifacts, works of art, archival material, and natural history specimens that are part of a museum collection. Structural components may be designated museum objects when removed from their associated structures. Large or immovable properties, such as monumental statuary, trains, nautical vessels, cairns, and rock paintings, are defined as structures or features of sites.

Native American Graves Protection and Repatriation Act of 1990 (NAGPRA) (United States). The Act provides for the inventory and return of human remains, associated and unassociated objects from burial contexts, sacred objects, and items of patrimony to the descendents. Cultural affiliation is to be determined by the Federal government.

National Register of Historic Places (United States). The comprehensive list of districts, sites, buildings, structures, and objects of national, regional, state, and local significance in American history, architecture, archaeology, engineering, and culture kept by the NPS under authority of the National Historic Preservation Act of 1966.

Native American. Pertaining to American Indian tribes or groups, Eskimos and Aleuts, and native Hawaiians, Samoans, Chamorros, and Carolinians of the Pacific Islands. Groups recognized by the Federal and State governments and named groups with long-term social and political identities who are defined by themselves and others as Indian are included.

natural fuels. Fuels resulting from natural processes and not directly generated or altered by management activity. This includes fuels that have accumulated because of deliberate fire exclusion.

objective. In land planning, an objective is a concise, time-specific statement of measurable desired condition that responds to pre-established goals. An objective forms the basis for further planning to define the precise steps to be taken and resources used in achieving identified goals.

oxidation. The process in which an atom or ion combines with oxygen. Oxidation of iron may cause pottery to turn red in color and metal to rust. The oxidation of pigment (organic or mineral) on decorated ceramic specimens. Alterations can include a change in color from the original pigment black to red), or the combustion of the pigment entirely. Oxidation of carbon creates carbon dioxide gas.

patination. An alteration of rock surfaces by molecular or chemical change; cherts and flints develop weathered surface.

pitting. Formation of depressed scars.

potlidding. The process of flakes popping off leaving irregular, pitted scar; result of differential expansion of heated rock. It is similar to spalling, but specific to lithic artifacts manufactured from cryptocrystalline silicate rocks such as chert. The fracture is characterized by a circular pit on the surface of the specimen. The pit represents the area in which the original portion of the surface has been exfoliated due to differential heating and pressure release. The exfoliated section is generally circular, flat on the dorsal side, and convex on the ventral side (resembling the lid of a cooking pot).

potsherds. Broken pieces of ceramic vessels. Archaeologists collect data from potsherds to learn about the lifeways of past peoples.

prehistoric. The time period before the appearance of written records. In North America, the prehistoric period ends with Spanish contact.

prehistory. The course of events in the period before recorded history.

prescribed burn. Intentional use of fire under predetermined weather and fuel conditions to achieve specific objectives, e.g., disposal of slash, control of unwanted vegetation.

preservation. The act or process of applying measures to sustain the existing form, integrity, and material of a historic structure, landscape or object.

protection. Action to safeguard a historic property by defending or guarding it from further deterioration, loss, or attack or shielding it from danger or injury. In the case of structures and landscapes such action is generally of a temporary nature and anticipates future preservation treatment; in the case of archaeological sites, the protective measure may be temporary or permanent. Protection in its broadest sense also includes long-term efforts to deter or prevent vandalism, theft, arson, and other criminal acts against cultural resources.

provenience. The location of an artifact or structure described in terms of horizontal location, distance and direction from a known point on a topographic or plan map and vertical locations, e.g., surface or subsurface.

radiation. A heat transfer mechanism that relies on energy transmission through waves or a stream of particles where though the energy is traveling through space, only the object is heated and not the surrounding space.

Radiocarbon Dating (^{14}C dating). An "absolute" or chronometric dating technique for organic material applied by comparing its amount of ^{14}C, a radioactive carbon isotope, to that present in living material.

records. refers to all information fixed in a tangible form. Used by the National Archives and Records Administration to refer to official records (q.v.).

rehabilitation. The act or process of making possible an efficient compatible use for a historic structure or landscape through repair, alterations, and additions while preserving those portions or features that convey its historical, cultural, and architectural values.

relative humidity. The ratio of the actual water vapor pressure at a given time to the vapor pressure saturated air at the same ambient temperature is capable of carrying when saturated; expressed as a percentage. The air's ability to hold moisture increases with air temperature increasing.

repair. Action to correct deteriorated, damaged, or faulty materials or features of a structure or landscape.

restoration. Interventive treatment action taken to return an object to its original or former appearance by removing accretions and later additions and/or by replacing missing elements: (1) The act or process of accurately depicting the form, features, and character of a historic structure, landscape, or object as it appeared at a particular period of time by means of the removal of features from other periods in its history and reconstruction of missing features from the restoration period; (2) the resulting structure, landscape, or object.

residence time (duration of fire). The length of time that combustion occurs at a given point. Relates closely to downward heating and fire effects below the fuel surface, as well as heating of tree boles above the surface. Also known as residence time.

return interval. The mean time between disturbances on any given piece of ground (sometimes known as a "cycle" or the "turnover time"). Fire return interval is the length of time between fires.

risk. potential danger as measured by the probability of damages or losses and the magnitude of the consequences.

Second-Order fire effects. Fire effects that result from the combined effects of post-fire influences, e.g., drought, erosion, insect and disease attack acting upon the fire-altered biophysical system.

Section 106 (United States): The section of the National Historic Preservation Act, as amended in 1992, that requires consultation between an agency and the **SHPO** or **THPO** when ground disturbance may occur on a Federal project or on any project that uses Federal funding. Also requires Native American consultation. Term is often applied to the documentation that must be submitted. Section 106 requires Federal agencies to take into account the effects of their proposed undertakings on properties included or eligible for inclusion in the National Register of Historic Places and give the Advisory Council on Historic Preservation a reasonable opportunity to comment on the proposed undertakings.

setting. The physical environment of a historic property; the character of the place in which the property played its historical role.

site preparation. Preparing an area of land for reforestation; may include removing unwanted vegetation and debris from a site.

size class. A standard size classification system used for fuel inventory or timber management planning inventories.

State Historic Preservation Office or Officers for each state (SHPO). An official within each State appointed by the governor to administer the state historic preservation program and carry out certain responsibilities relating to Federal undertakings within the State.

sintering. In ceramics, the process by which clay particles adhere to one another when heated close to but below their melting points. Sintering causes fired pottery to become hard and dense.

slash. The residue left on the ground after timber cutting, or after storms, fire, etc. It includes unutilized logs, uprooted stumps, broken stems, branches, twigs, leaves, bark, and chips.

smoldering. A slow spreading fire burning without flame.

smoldering combustion. Combined process of dehydration, paralysis, solid oxidation, and scattered flaming combustion and glowing combustion, which occur after the flaming combustion phase of a fire; often characterized by large amounts of smoke consisting mainly of tars.

snag. A standing dead tree from which the leaves and some of the branches have fallen. For wildlife purposes, one that is at least 15 inches DBH and 20 feet tall.

sooting. The carbon-based solid residue created by incomplete combustion of carbon-based fuels, resulting in smudging and blackening of the surface.

spalling. the exfoliation of a portion of the original surface of a specimen resulting from internal pressures associated with differential expansion or contraction upon heating or cooling. Differential expansion or contraction results from internal variation in the mineralogy or moisture content. For example, an artifact may exhibit spalling when its surface heats or cools more rapidly than its interior.

stabilization. Interventive treatment action taken to increase the stability or durability of an object when preventive conservation measures fail to decrease its rate of deterioration to an acceptable level or when it has deteriorated so far that its existence is jeopardized; actions taken to render an unsafe, damaged, or deteriorated property stable while retaining its present form.

stand. A community of trees or other vegetation sufficiently uniform in composition, constitution, age, spatial arrangement, or condition to be distinguishable from adjacent communities and to thus form a management entity; the basic unit for silvicultural prescriptions.

stratigraphy. The layered geological and/or cultural sediments in a site, whose arrangement allows interpretations of the site's cultural chronology.

structure. A constructed work, usually immovable by nature or design, consciously created to serve some human activity. Examples are buildings of various kinds, monuments, damns, roads, railroad tracks, canals, millraces, bridges, tunnels, locomotives, nautical vessels, stockades, forts and associated earthworks, Indian mounds, ruins, fences, and outdoor sculpture. In the National Register program "structure" is limited to functional constructions other than buildings.

subsistence. The traditional use of natural plants and wild animals for personal or family consumption, for the making and selling of handicraft articles out of the non-edible byproducts of fish and wildlife resources taken for personal or family use or consumption, and for customary trade. In Alaskan and Pacific parks, subsistence is the significant economic and cultural dependence on the harvest of wild natural resources by local rural residents through traditional hunting, fishing, and gathering activities. The legislation for some parks defines what constitutes subsistence there.

succession. the gradual supplanting of one plant community by a higher ecologically ordered one as a site changes over time, until a climax community is reached.

suppression. Actions taken to exclude, extinguish or confine a fire.

surface fire. A fire that burns in litter, dead branches, leaves and low vegetation at or near the surface of the ground, mostly by flaming combustion but not reaching the crowns of trees.

tangible cultural resources. Resources that are categorized as districts, sites, buildings, structures, and objects for the National Register of Historic Places and as archaeological resources, cultural landscapes, structures, museum objects, and ethnographic resources for management purposes.

tangible effects. The purposeful, intentional, observable, measurable human responses to the perceived risks or opportunities presented by fire or resource management. These include suppression, rehabilitation, mitigation, and exploitation.

temper. An archaeological term referring to non-plastic materials such as sand or crushed potsherds that traditional potters may add to improve the properties of raw clay. Modern ceramists use the term differently, referring to liquid additive; added to clay prior to pottery manufacture to reduce shrinkage and breakage during drying and firing.

temperature. The degree of hotness or coldness of an object or environment. Temperature can be measured using Fahrenheit (°F), Celsius (°C)or Kelvin (°K) scales.

thermoluminescence (TL). An absolute dating method for objects that were heated during manufacture or use. Measures the light energy released from an object when heated to 500 °C under laboratory conditions; the amount of energy released depends on the time passed since the object was last heated.

Third-Order effects. The impacts of fire on the human environment .Third-Order effects may be tangible or intangible.

THPO. Tribal Historic Preservation Office or Officer.

threshold. The point or level of activity beyond which an undesirable set of responses begins to take place within a given resource system.

torching. A surface fire that intermittently moves vertically, consuming individual tree crowns, shrubs or small groups of trees as it advances through a forest stand; also termed passive crown fire.

traditional. Pertains to recognizable but not necessarily identical cultural patterns transmitted by a group across at least two successive generations. Also applies to sites, structures, objects, landscapes, and natural resources associated with those patterns. Popular synonyms include ancestral and customary.

traditional knowledge. The total understanding by indigenous people of their relationship to the earth and the universe, and the knowledge inherent within that relationship. This knowledge includes the spiritual, physical, emotional, and mental aspects of a person and related components of the earth and universe to these aspects

traditional ecological knowledge (TEK). TEK refers to the ability of Aboriginal peoples to comprehend local-ecosystem interrelationships and to achieve sustainable levels of resource use with no or minimum disruptions to ecosystem functions. It is the evolving knowledge acquired by indigenous and local peoples over hundreds or thousands of years through direct contact with the environment. This knowledge is specific to a location and includes the relationships between plants, animals, natural phenomena, landscapes and timing of events that are used for lifeways. It is an accumulating body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (human and non-human) with one another and with the environment. It encompasses the world view of indigenous people, which includes ecology, spirituality, human and animal relationships, and more.

traditional cultural property (TCP). A property associated with cultural practices or beliefs of a living community that are rooted in that community's history or are important in maintaining its cultural identity. Traditional cultural properties are ethnographic resources eligible for listing in the National Register. A location significant for its value to a community, based on traditional practices, beliefs, or customs, as long as the value extends into the past for at least 50 years. TCPs may be unaltered landscapes or historic properties.

tree tip-up. A tree that falls, exposing the root structure and leaving a void in the soil.

understory. Low-lying vegetation (herbaceous, brush or reproduction) growing under a stand of trees, i.e., the portion of trees in a forest stand below the overstory.

undertaking (United States). As referred to in Section 106 of the National Historic Preservation Act, any Federal, Federally assisted, Federally licensed, or Federally sanctioned project, activity, or program that can result in changes in the character or use of historic properties. Undertakings include new and continuing projects, programs, and activities that are (1) directly undertaken by Federal agencies; (2) supported in whole or in part, directly or indirectly, by Federal agencies; (3) carried out pursuant to a Federal lease, permit, license, approval, or other form of permission; or (4) proposed by a Federal agency for congressional authorization or appropriation. Undertakings may or may not be site-specific (see 36 CFS 800.2 [o] and Section 301[7] of the National Historic Preservation Act).

vegetation management. The practice of manipulating the species mix, age, fuel load, and distribution of wildland plant communities within a management area. It includes prescribed burning, grazing, chemical applications, biomass harvesting, and any other economically feasible method of enhancing, retarding, or removing the above ground parts of plants.

vesiculation. The formation of abundant and interconnected bubbles throughout the interior and at the surface of the glass object as a result of heating that, in turn, causes deformation and increase in object volume size or size.

vitrification. 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.

water bar. A shallow channel or raised barrier used as an erosion control structure with a cross drain to divert water to prevent gullying.

watershed. The total area above a given point on a stream contributing water to the flow at that point.

wet line. A line of water, or water and chemical retardant, sprayed along the ground that serves as a temporary control line from which to ignite or stop a low-intensity fire.

wildfire. An unplanned ignition of a wildland fire (such as a fire caused by lightning, volcanoes, unauthorized and accidental or human-caused fires) and prescribed fires that have exceeded prescription parameters or otherwise meets the criteria for conversion to wildfires (Guidance for Implementation of Federal Wildland Fire Management Policy. February, 2009).

wind direction. Compass direction from which wind is blowing, measured in 45° angles, generally referencing the cardinal directions.

wind speed. Ratio of the distance covered by the air to the time taken to cover that distance. Wind, in MPH, is measured at 20 feet above open, level ground or as adjusted to meet this standard to compensate.

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Rocky
Mountain
Research Station

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of the forests and rangelands. Research is designed to meet the needs of the National Forest managers, Federal and State agencies, public and private organizations, academic institutions, industry, and individuals. Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications may be found worldwide.

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