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The Effects of Fire and Heat on Obsidian

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Papers presented in Symposium 2

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EFFECTS OF PRESCRIBED FIRE ON OBSIDIAN AND IMPLICATIONS FOR RECONSTRUCTING PAST LANDSCAPE CONDITIONS

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Introduction

This study was designed to measure the effects of prescribed fire on obsidian hydration bands, and to explore the possibility of using obsidian hydration data as an aid in reconstructing fire histories, which could then be used in reconstructing past landscape conditions.

Obsidian hydration band studies provide researchers in Sierran forests a primary means of establishing prehistoric site chronologies and depositional integrity. 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. In addition, obsidian "hydrates," or absorbs moisture in ever thickening bands along freshly exposed surfaces, such as those created when stone tools are manufactured or refurbished, with obsidian from different sources hydrating at slightly different rates. The thickness of the band can indicate how long a surface has been exposed, allowing archaeologists to date obsidian that has been left at archaeological sites (although certain variables, such as soil moistures, soil pH, and temperatures can affect absorption).

In catastrophic wildfire situations, however, hydration bands become diffused and unreadable thus destroying a valuable analytical tool. The effects of prescribed fires are less well understood. Most researchers have assumed that less intense fires do not affect hydration bands; however, there has been little exacting data to support this assumption. Although there have been several experimental studies in the field with prescribed fire, and others which induced effects in the lab, previous experiments have generally measured maximum temperature or fire intensity, but not duration of heat, or only measured effects following a wildfire, without benefit of pre-fire data. Many of these studies have concluded that there are "temperature thresholds" above which artifacts are reportedly damaged -- temperatures which most researchers presume are not often reached in prescribed fires (Biswell 1989:213-220; Donaldson 1982:3). The current study measured temperature and duration of heat in the field in two prescribed burns (Figure 1) and assessed the effects on obsidian with previously measured hydration bands.

Studies by the Pacific Southwest (PSW) Forest Fire Laboratory have shown that prescribed fires in areas with heavy fuels often smolder for days. In these heavily fueled burns, all the organic material, regardless of duff moisture conditions, is usually consumed to mineral soil (Sackett and Haase n.d.). Soil temperatures in these conditions can easily range from 200 to over 780°F, with temperatures from 80 to more than 200°F at 12 inches below the surface (Sackett and Haase n.d.). In fact, elevated temperatures have been recorded nearly two feet below ground surface (Sackett and Haase 1993:2). Prior studies have shown that hydration bands on obsidian are initially affected at a threshold of about 260°C (500°F) (McIntyre n.d.:9), and seriously affected by around 427°C (800°F) (Trembour 1979). These temperatures are within the range often reached in prescribed burns.

Our study was conducted in cooperation with PSW experiments by Steve Sackett, Sally Haase, and Gloria Burke on prescribed fire and sugar pine mortality. Obsidian specimens were placed in two

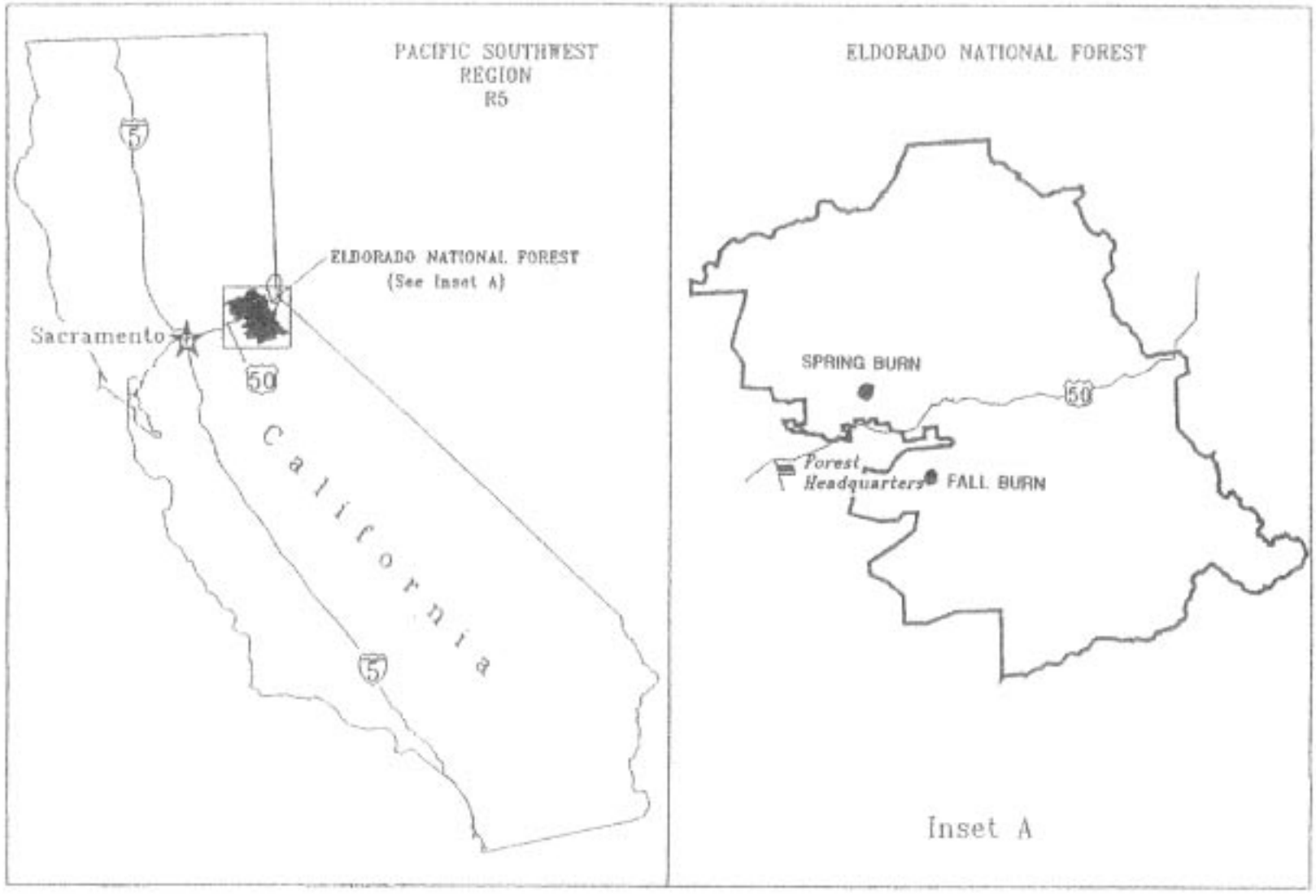


FIGURE 1. LOCATION OF SPRING AND FALL BURNS USED IN OBSIDIAN HYDRATION EXPERIMENT.

prescribed burns, situated in areas with different burn histories. Specimens with known hydration bands, obtained from 23 sites within the Pacific Ranger District of the Eldorado National Forest, were set at and below ground surface in a variety of fuel loading situations. Thermocouples were used to measure temperature and duration of heat. Obsidian samples were removed following the burns and resubmitted for hydration measurements. Preliminary results indicated that duration of exposure to heat, even at low temperatures, creates effects on obsidian hydration bands similar to effects of elevated temperature. These results have implications regarding the effects of prescribed burning in different fuel loads, as well as for potential landscape-level, reconstructive fire histories.

Prior Fire Effects Studies

The majority of prior studies of fire effects on archaeological resources have been conducted in the aftermath of wildfires (cf., Burgh 1960; Kelly and Mayberry 1979; Kelly 1984; Lentz et al. 1996; Lissoway and Propper 1988; NIFC 1995; Pilles 1982; Rogers and Francis 1988; Silvermoon 1987; Switzer 1974). Few of the studies on wildfire-affected obsidian have recorded the pre-burn hydration readings of the obsidian (for an exception, see Origer and Anderson 1994). Several prescribed fire experiments monitored pre-burn and post-burn effects to resources, although most of the effects noted were macroscopic (Linderman 1992; Picha et al. 1991; Pidanick 1982; Welch and Gonzales 1982). Laboratory experiments on the effects of fire on obsidian have primarily focused on the effect of varying temperatures on hydration bands, and most used freshly flaked obsidian for measuring effects (see Picha et al. 1991; Kelly and Mayberry 1979; Mazer et al. 1991; Stevenson et al. 1985; Trembour 1979). Although there have been a few exceptions, most wildfire, prescribed fire, and laboratory studies have focused on determining the temperatures at which archaeological resources are negatively affected, with negative effects generally defined macroscopically. These studies have resulted in statements such as those included in the National Interagency Fire Center course, "Introduction to Fire Effects RX340," which states that for prescribed burn temperatures in the range of 400 to 500°C (752 to 932°F), severe alterations to inorganic cultural material would not occur (NIFC 1995:4a.6).

Our Prescribed Fire Experiment

Sample Selection

The current study measured temperature and duration of heat in the field in two prescribed burns and assessed the effects on obsidian hydration band measurements. Obsidian which had been previously sourced and measured for hydration from sites on the Pacific Ranger District of the Eldorado National Forest, provided the samples used in this experiment. A total of 54 specimens from 23 sites within our study area was selected, with hydration bands ranging from 0.9 to 7.7 microns. Several criteria were used to select the samples. First, the specimens needed to be large enough to be recovered easily from the soil after the prescribed burn. Second, we wanted the total sample selected to reflect the same proportions of obsidian sources represented at sites on the Forest. Third, we wanted the samples to reflect the full temporal span represented on the Forest. Finally, in the hopes that obsidian might be useful for landscape level fire histories, we wanted the samples to be from geographically dispersed sites, stratified by elevation.

There are no known obsidian sources on the Eldorado National Forest; all the obsidian has traveled fair distances to get here, either through direct acquisition or trade. The majority of obsidian on the Pacific District is from Bodie Hills (77.6%), with lesser amounts from Mount Hicks (8.6%), Napa Valley (4.8%), Sutro Springs (4.0%), Mono Glass Mountain (1.7%), Pine Grove Hills (0.6%), with 0.3% each from the Truman-Queen, Grasshopper Flat/Lost Iron Wells, Fox Mountain, Coglan Buttes,

Borax Lake and Casa Diablo sources. Obsidian from unknown sources comprises 0.9% of the district's obsidian. These numbers are similar to those for the rest of the Forest. For our experiment, we selected 43 samples from Bodie Hills, 3 from Mount Hicks, 3 from Napa Valley, 2 from Sutro Springs, 1 from Mono Glass Mountain, 1 from Truman-Queen, and 1 from Pine Grove Hills. Table 1 shows the total number of specimens burnt by source and Table 2 shows site and obsidian sample data for the materials used in this experiment.

Table 1. Total number of burnt specimens by obsidian source.

Source	Number Burnt	% of Total
Bodie Hills	43	79.6
Mount Hicks	3	5.6
Napa Valley	3	5.6
Sutro Springs	2	3.8
Mono Glass Mtn.	1	1.8
Truman-Queen	1	1.8
Pine Grove Hills	1	1.8
Total	**54**	**100**

Using cross-dating and prior research with assumed hydration rates for Bodie Hills obsidian (see Tremaine and Jackson 1995), we divided our samples into Early, Middle and Late Periods based on thickness of the hydration bands. Samples with readings of 2.5 microns or less were chosen to represent the Late Sierran Period, roughly 200 to 1,000 years ago. For the Middle Sierran Period, roughly 1,000 to 2,500 years ago, readings of 2.6 to 4.0 microns were used, and for the Early Sierran Period, beginning roughly 2,500 years ago, readings of 4.1 microns and greater were used. Our objective was to have equal numbers of Early, Middle and Late Sierran obsidian samples; 17 of the specimens had early period bands, 18 had middle period bands, and 19 had late period bands.

Elevation was divided into three categories, with low elevation sites between 3,000 and 4,500 feet, mid-elevation sites between 4,501 and 6,500 feet, and high elevation sites above 6,501 feet. Our goal was to have equal representation of low, mid-, and high elevation sites. Seven of the sites represented were at high elevations, eight were from mid-elevations, and eight were situated at low elevations.

Experimental Context

Two prescribed burns, one in the fall of 1996 (see Photograph 1) and another in the spring of 1997, with very different fire and burn histories, were utilized for this study, resulting in differing burn conditions, particularly with respect to smoldering time. Three fuel situations ("light," "woody", and "log") were selected for specimen placement within each of the areas to be prescribed burned. Each fuel situation had three study spots: two at ground surface (under the duff layer and atop mineral soil), and one approximately 2 to 3 inches below ground surface. Obsidian was placed so that each of the three fuel locations received samples of early, middle and late period pieces of obsidian. Each bag also contained obsidian from either high, mid-, or low elevation contexts, such that obsidian from each time period and each elevation range was subjected to each of the three fuel situations. In order to facilitate specimen recovery and post-burn identification of any altered pieces, the contents of each sample bag were photocopied prior to placement in the ground.

Table 2. Site and sample data for Eldorado National Forest prescribed burn experiment.

Site 05-03-55-	Number of Specimens	Sources Represented	Time Period	Elevation
36	2	B-1, S-1	E-1 M-1	High
50	3	B-2, M-1	M-1 L-2	Low
78	3	B-1, M-1, Mg-1	M-1 L-2	High
90	7	B-6, N-1	E-5 M-2	Mid
144	1	B-1	L-1	Mid
167	6	B-6	E-3 M-2 L-1	Low
197	3	B-2, S-1	E-1 M-1 L-1	High
199	2	B-2	M-1 L-1	Mid
211	1	B-1	M-1	Low
228	1	N-1	L-1	Low
249	2	B-1, M-1	L-2	Mid
263	3	B-2, N-1	E-1 M-1 L-1	High
270	1	B-1	E-1	High
274	3	B-1, Q-1, P-1	M-1 L-1	High
279	1	B-1	M-1	Low
280	4	B-4	E-2 L-2	Low
319	1	B-1	L-1	Mid
333	3	B-3	E-1 M-1 L-1	High
347	1	B-1	E-1	Low
356	1	B-1	M-1	Low
368	1	B-1	M-1	Mid
415	3	B-3	M-2 L-1	Mid
421	1	B-1	E-1	Mid
Total = 23	**54**	**B-43, M-3, N-3, S-2, Mg-1, Q-1, P-1**	**Early – 17 Middle – 18 Late - 19**	**High - 7, Mid - 8, Low - 8**

Source Codes: B = Bodie Hills, M = Mount Hicks, N = Napa Valley, Mg = Mono Glass Mountain, SS = Sutro Springs, Q = Truman Meadows-Queen, P = Pine Grove Hills.

Burning conditions were monitored at each of the study spots by PSW scientists Steve Sackett, Sally Haase and Gloria Burke using grounded, stainless steel, chromed-alumel thermocouples to measure

soil temperatures. Thermocouples were placed into undisturbed soil, with subsurface cables running from the thermocouples to data loggers outside the fireline. Obsidian specimens were placed as close to the thermocouples as possible from the thermocouple/cable "cutbank" using forceps, rather than being inserted into the ground from above, in order to minimize fuels and ground disturbance which could affect fire behavior. Data logging for soil temperatures was conducted using seven channel, Campbell Scientific Model 21 microloggers, with data on soil moisture, temperature and duration stored on data-type cassette tapes (see Photograph 2).

The obsidian was retrieved following the burns and resubmitted for hydration readings. For consistency, the same individual who had completed the majority of the original hydration readings also read the hydration on the resubmitted samples, using identical equipment.

Fall Burn in Unmanaged Fuels

In the fall of 1996, we placed obsidian samples in a prescribed burn conducted by PSW which was designed to continue studies on the effect of prescribed fire on sugar pine mortality (Sackett and Haase n.d.). The burn site on Baltic Ridge covered a fairly flat acre on a ridge top saddle, at an elevation of 4,760 feet. Vegetation consisted of plants common to the yellow pine / black oak community; no prior fuels management, and no wildfires, had occurred in the study area during at least the last 86 years. Dead and down woody fuels -- those responsible for carrying the flames -- at the burn site were estimated at about 40 tons per acre. Fuels on the forest floor, or those fuels that will smolder after the flaming front has passed, ranged from 18 to 60 tons per acre within the one acre burn site. At our obsidian study area, the forest floor inventory of "light" fuels measured 20 tons per acre of fuel, primarily in the form of deep duff; "woody" fuels measured 31 tons per acre of fuel in the form of duff and 1/4-inch to 1-inch diameter twigs and branches; and "log" fuels measured 16 tons per acre by an 8-inch diameter log (Sackett 1997).

Half (27) of the total obsidian specimens were placed in the fall burn area (see Photograph 3). The fall obsidian was stratified by elevation and age, and divided into nine sample bags, with each bag containing an early, middle and late piece of obsidian from either all low, all mid- or all high-elevation sites. These were then evenly distributed at each of three fuel conditions. In each of the three fuel locations, six samples were placed on the ground surface below the duff layer, with three more placed two to three inches below the ground surface.

The prescribed burn was ignited at the northeast corner of the unit at 12:15pm on October 7, 1996. Relative humidity ranged from 27-40%, and winds were generally calm at about one mph. Soil moistures were very high, averaging 26.2% at depths of 0-2 inches and 25.9% at 2-4 inches. Fuel moisture content of the ¼-1-inch diameter fuels ranged within a low 7-8%. Flame lengths of one to three feet were common, with scorch heights in the heaviest fuel loads at 10-15 feet.

The fire reached the obsidian study locale shortly after 4:00pm, with the flaming front crossing the study area in about 10 minutes. As the flames reached the study area, temperatures jumped at all three surface thermocouples. Flame lengths at the light fuels ranged from 4 to 10 inches, at the woody fuels from 12 to 24 inches, and at the log fuels to about 10 inches. After the flames passed over the study site, the temperatures continued to rise as the area was subjected to deep duff glowing combustion (Sackett and Haase 1996). Temperatures at the ground surface reached their maximum 2½ hours later as the fire smoldered through the duff and woody fuels, with the highest temperatures recorded at ground surface under the log (971°F). Surface woody fuels reached maximum temperatures of 590°F; light surface fuels reached 584°F. Temperatures dropped off gradually in the surface settings, with recorded temperatures as high as 200°F as late as 2:00am in the surface log fuels. Temperatures continued to be elevated 44 hours later, still approaching 100°F.

Subsurface temperatures took 6½ hours to reach their maximum temperatures after the flaming front passed, with log fuels topping out at a fairly low 163°F and light fuels at 153°F. The temperature at the subsurface woody fuels location was not recorded due to an equipment failure. Temperatures remained elevated and nearly constant at the subsurface sites (mostly over 100°F) for the next two days (see the graph on the following page). Average soil moistures dropped to 5.7% at 0-2 inches, and to 16.7% at 2-4 inches. (Interestingly, soil moistures rose at depths between 6 and 14 inches; below this, measurements were not taken.)

The obsidian samples were retrieved two days after the fire had passed over the obsidian study area. Smoldering in the duff was still present. Nearly all surface fuels had been consumed, and a deep ash layer covered the site (see Photograph 4).

A 10-inch diameter log, which had been suspended 18 inches above the ground over the woody fuels location, had fallen to the ground adjacent to the obsidian samples. This log was still burning with a slow, glowing combustion from underneath.

Fall Burn Results

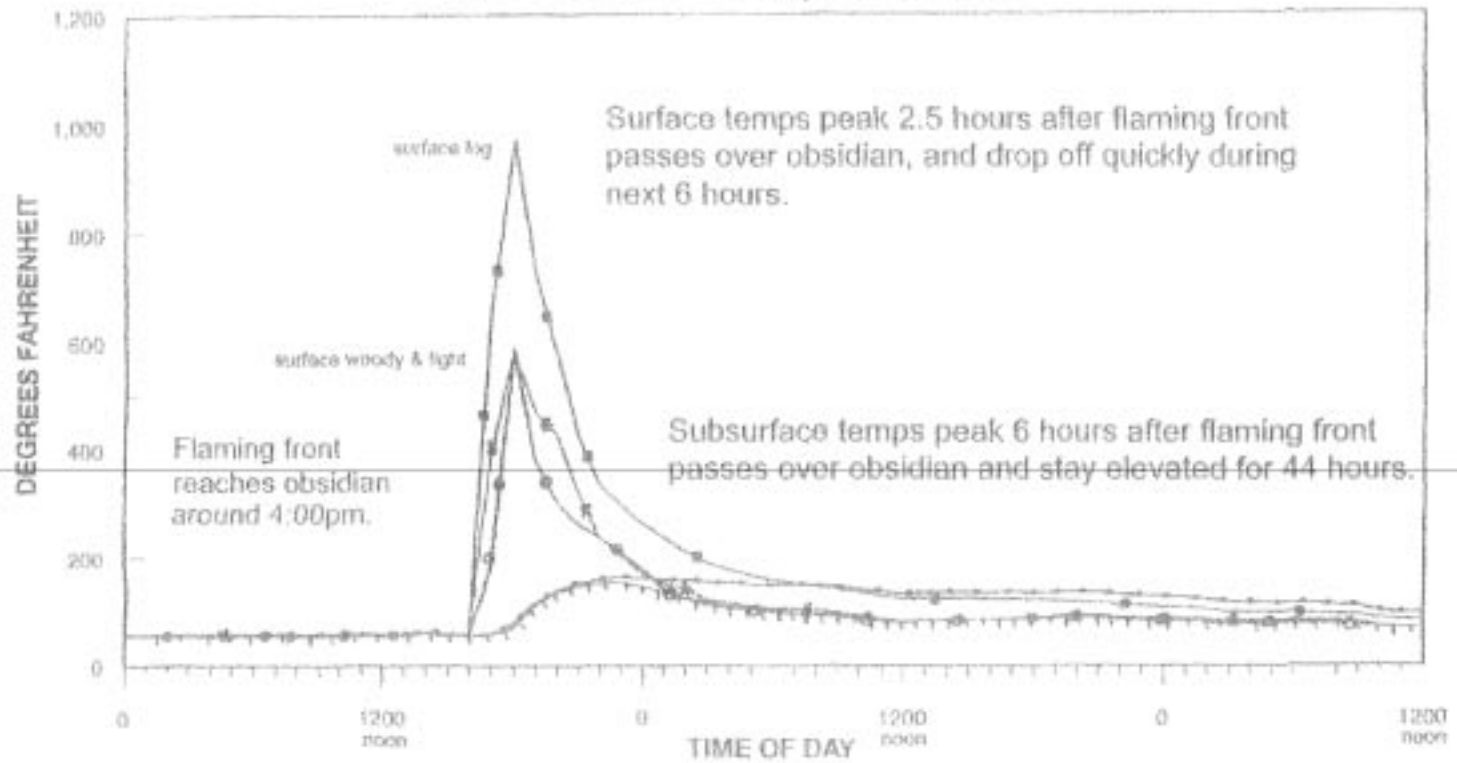
Table 3 shows the results of the fall burn on the obsidian samples. Hydration bands were radically altered on 67% (18 of 27) of the obsidian samples placed in the fall burn. These changes generally resulted in the hydration readings dropping to "zero" (i.e., there was no visible hydration band, or the band was too vague and diffused to read), no matter how thick the original bands were. In the light fuels, 5 of 9 samples were altered (56%). For woody fuels, 6 of 9 (67%) were changed and in the log fuels, 7 of 9 (78%) were affected. The woody fuel samples could have experienced additional effects from the suspended log dropping near the samples, which increased the time of glowing combustion at the site. However, it is not known when the log actually dropped to the ground.

Surface samples suffered the greatest effects, with 14 of 18 (78%) altered. The surface effects might also be inflated by the log drop on woody fuels (all six surface samples in woody fuels dropped to zero hydration band widths); if the surface woody fuels samples had not been affected, the surface percentage affected drops to 44%. For the subsurface obsidian, 4 of 9 samples (44%) were affected. None of the subsurface woody fuels samples were altered, suggesting that the log dropped onto the ground perhaps as long as 12 hours after the flaming front had passed over the obsidian site.

Comments on the Fall Burn

These results were somewhat surprising. We expected to see minimal to no effects on the obsidian, since from a firefighter's perspective, this was a low intensity fire with flame lengths of only one to three feet -- a fire easily contained by a handline around the burn. If California Indians were frequently burning large portions of the landscape, presumably with low intensity fires, how is it that the greater proportion of collected surface obsidian samples produce good hydration readings? Perhaps their frequent, periodic fires substantially reduced ground fuels, and although those fires might behave essentially the same as our fall burn, they would probably have been f shorter duration and much less severe at the ground surface, at least in terms of the glowing and smoldering phase of the fire.

FALL BURN
Time and Temperature



	A (Light Fuels) 2 inch soil depth	A (Light Fuels) Soil/Duff	B (Under Log) Soil/Duff	B (Under Log) 3 inch soil depth	C (1/4"-1" fuels) Soil/Duff	C (1/4"-1" fuels) 2 inch soil depth
MAX TEMP (F)	153	584	971	163	590	data missing
OBSIDIAN SAMPLE BAG	C	A & H	G & R	M	J & O	B

Table 3. Fall burn results.

Fuel & Burn Situation			Early Period		Middle Period		Late Period	
Fuels probe # – depth maximum temp.	**Bag**	**Elev.**	site # *pre-burn reading*	spec #/ source *post-burn reading*	site # *pre-burn reading*	spec #/ source *post-burn reading*	site # *pre-burn reading*	spec #/ source *post-burn reading*
Light 2 – surface 584°F	A	high	none**		333 ***2.8***	175/B ***0***	263 ***2.3*** 78** ***1.9***	433-n/B ***0*** 300-o/M ***0***
Light 2 – surface 584°F	H	mid	90 ***5.7***	74-aa/N ***0***	415 ***4.0***	610-c/B ***3.9***	199 ***1.0***	303-e/B ***1.1***
Light 1 – 2 inches 153°F	C	low	280 ***4.7***	477-e/B ***0***	50 ***3.4***	34-d/B ***3.4***	167 ***1.0***	268-k/B ***1.2***
Woody 6 – surface 590°F	J	high	36 ***5.1***	589-bb/B ***0***	197 ***3.5***	301-q/B ***0***	274 ***2.0***	406-l/Q ***0***
Woody 6 – surface 590°F	O	low	167 ***4.1***	268-a/B ***0***	211 ***2.6***	307-a/B ***0***	280 ***2.4***	477-b/B ***0***
Woody 5 – 2 inches data missing	B	mid	90 ***4.5***	74-gg/B ***4.4***	368 ***3.2***	571-h/B ***2.8***	319 ***1.4***	590-c/B ***1.5***
Log 3 – surface 971°F	R	low	347 ***4.2***	562-m/B ***4.1***	167 ***3.4***	268-l/B ***0***	228 ***1.1***	584-a/N ***0***
Log 3 – surface 971°F	Q	mid	421 ***4.7***	613-c/B ***0***	90 ***2.8***	74-xx/B ***0***	249 ***1.4***	383-c/B ***1.5***
Log 4 – 2 inches 163°F	M	high	270 ***4.6***	405-a/B ***0***	36 ***3.5***	589-aa/S ***0***	333 ***0.9***	174/B ***0***

Source codes: B = Bodie Hills; M = Mount Hicks; N = Napa Valley; Q = Queen; S = Sutro Springs

Source total: Bodie (22/82%); Hicks (1/4%); Napa (2/8%); Queen (1/4%); Sutro (1/4%)

Fuel situations: 2 bags of samples at ground surface and one bag at 2-3 inches; each fuel situation also had samples from a high, mid-, and low elevation site.

Pre- and post-burn hydration band measurements in microns. Shaded entries mark radical changes.

** *No Early Period sample; two late sites are represented in Bag A*

Spring Burn in Managed Fuels

In order to mimic burn intensities and ground fuel conditions that might have occurred in a forest periodically burnt by Native Americans, the spring burn site was placed in an area that had been prescribe burned several times (in 1978, 1979 and 1985). This area was located at an elevation of 3,670 feet on a gentle slope with a southern aspect in the yellow pine / black oak belt. Dead and down fuels were estimated at four tons per acre (see Photograph 5). Average fuel loading of the forest floor was 21 tons per acre, with fuels at the burn site consisting of less than a half inch of pine needles mixed with a few pine cones, twigs and a few small logs. A well-developed duff layer was not present.

As in the fall burn, a total of 27 pieces of obsidian was placed in the spring burn site, again with nine total sample bags, each with an early, middle and late piece of obsidian from either high, mid- or low elevation sites. These were placed in similar fuels situations -- light fuels (less than one-half inch of pine needle cast), woody fuels (pine needles with ¼ to one-inch diameter twigs and branches) and log fuels (a 4-inch diameter deadfall log). Each fuel situation had a total of nine samples, with six placed on the ground surface and three placed below the surface at depths of 2-3 inches. Some live fuels (bearclover, 6-inch tall oak, bracken fern) were present in the burn plot. At the woody fuels site, pre-burn soil moistures varied from 18% to as high as 30% at 0-2 inches. The log fuels site had pre-burn soil moistures of nearly 20%, while the light fuels site had soil moistures varying from 14% to nearly 18% (Sackett and Haase 1999).

The 16 x 13 foot spring burn plot was ignited at 11:20am on May 17, 1997. Winds were calm, air temperature was 22°C (72°F), and the relative humidity was 52%. The fire burned at a rate of six inches per minute, passing over the obsidian samples roughly 20 minutes after ignition, with the last of the flaming front reaching the bottom of the burn plot in 36 minutes. Flame lengths of 3 to 12 inches were reached. The pine needles, cones and ¼ to one-inch fuels were completely consumed by the fire, and overall fuel loads reduced by half. Post-burn soil moistures dropped to between 12% and 20% in the woody fuels location, to 14% in the log fuels location, and between 11% and 16% in the light fuels.

Maximum surface temperatures were reached quickly, with the log fuels peaking at 885 degrees, the woody fuels at 137°C (279°F), and the light fuels at 79°C (175°F). Field notes on the burn day indicated that by 12:15pm, the surface temperatures were already dropping, but the subsurface temperatures were starting to rise. By 2:30pm, the three surface sites had temperatures of 27°C (81°F) in light fuels, 34°C (94°F) in woody fuels, and 35°C (95°F) in log fuels. Subsurface temperatures were noted at 23°C (73°F) in light fuels, 30°C (86°F) in woody fuels, and 36°C (96°F) in the log fuel site. Near ambient temperatures were reached one hour later, with sample retrieval initiated at 3:30pm. These smoldering, glowing combustion burn times differed radically from the fall burn, with its 80+ years of fuel buildup (see Photograph 6).

Spring Burn Results

The effects on the obsidian burnt in the spring are shown in Table 4. One-third of the spring samples (33% or 9 of 27) had hydration bands that were radically altered, resulting in band readings of zero (not visible), compared to the two-thirds affected in the fall burn. In the light fuels, a surprising 4 of 9 (44%) were changed, possibly due to volatile oils at the burn plot from nearby bearclover or from the relatively new pine needle cast. For woody fuels, only 1of 9 (11%) were substantially altered. In log fuels, 4 of 9 (44%) obsidian readings dropped to zero. Half of the spring surface samples (9 of 18) were altered by the burn. None of the subsurface samples were affected, compared to 44% in the fall burn. All of these figures are lower than those noted in the fall burn in unmanaged fuels.

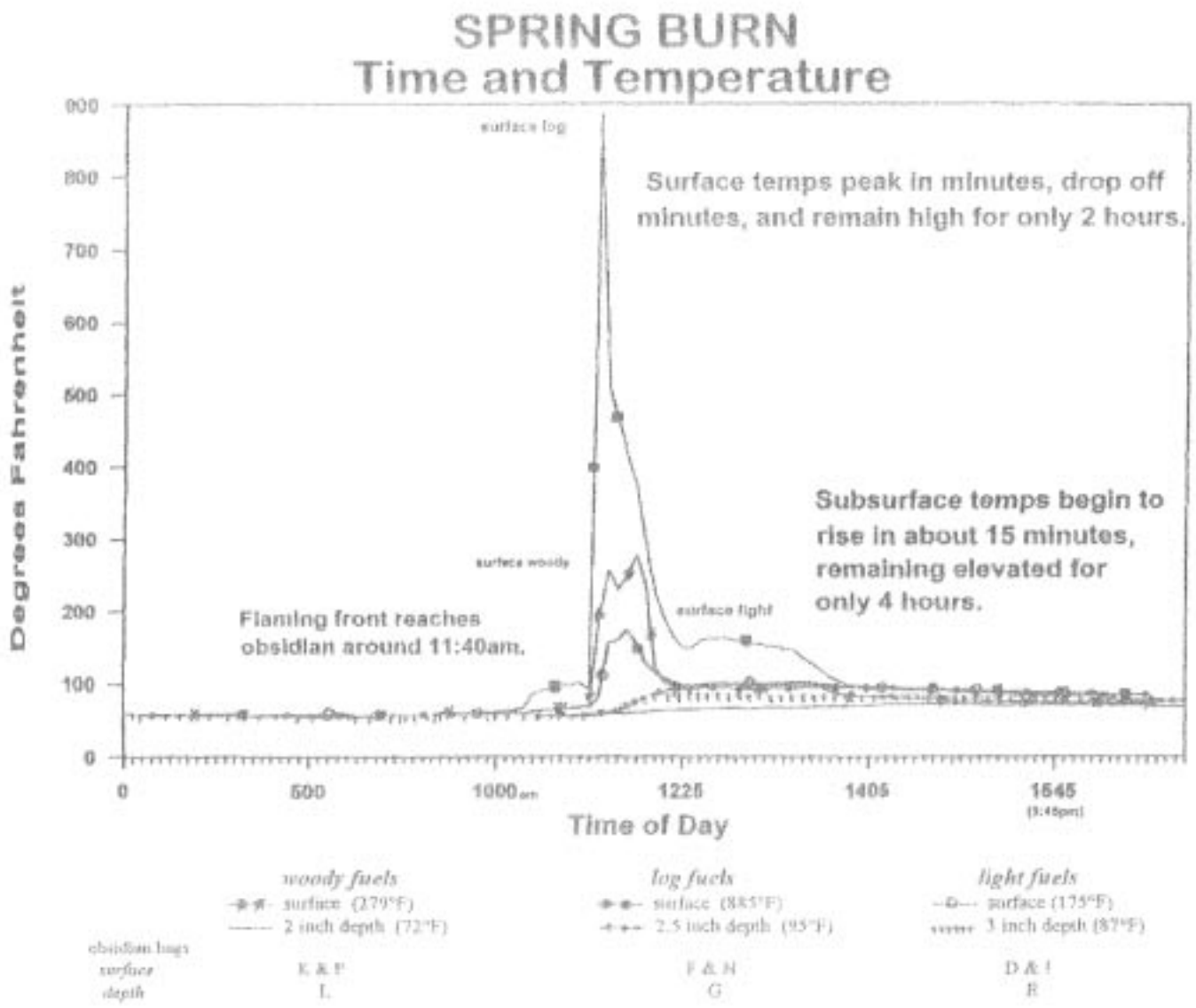

SPRING BURN
Time and Temperature
Degrees Fahrenheit
900
800
700
600
500
400
300
200
100
0
surface log
surface woody
surface light
Surface temps peak in minutes, drop off minutes, and remain high for only 2 hours.
Subsurface temps begin to rise in about 15 minutes, remaining elevated for only 4 hours.
Flaming front reaches obsidian around 11:40am.
0
500
1000am
1225
1405
1545
(3:45pm)
Time of Day
woody fuels
surface (279°F)
2 inch depth (72°F)
log fuels
surface (885°F)
2.5 inch depth (95°F)
light fuels
surface (175°F)
3 inch depth (87°F)
obsidian bags
surface
depth
K & P
L
F & N
G
D & I
R

Table 4. Spring burn results.

Fuel & Burn Situation			Early Period		Middle Period		Late Period	
Fuels			site #	spec.#/ source	site #	spec.#/ source	site #	spec.#/ source
Probe # – depth Maximum temp.	**Bag**	**Elev.**	*pre-burn reading*	*post-burn reading*	*pre-burn reading*	*post-burn reading*	*pre-burn reading*	*post-burn reading*
Light 1 – surface 175°F	D	high	333 ***4.1***	176/B ***4.1***	263 ***2.8***	433-e/N ***0***	78 ***1.8***	300-i/B ***0***
Light 1 – surface 175°F	I	low	167 ***4.4***	268-h/B ***4.4***	167 ***2.7***	268-d/B ***0***	50 ***2.5***	34-h/M ***0***
Light 2 – 2 inches 87°F	E	mid	90 ***5.9***	74-a/B ***5.8***	199 ***4.0***	303-b/B ***4.0***	144 ***1.9***	376-a/B ***1.8***
Woody 5 – surface 279°F	K	mid	90 ***4.1***	74-b/B ***4.1***	415 ***4.0***	610-f/B ***0***	249 ***1.3***	383-h/M ***1.3***
Woody 5 – surface 279°F	P	high	197 ***5.4***	301-b/B ***5.3***	274 ***3.8***	406-i/P ***3.8***	197 ***2.5***	301-o/S ***2.4***
Woody 6 – 2 inches 72°F	L	low	167 ***4.6***	268-j/B ***4.6***	356 ***3.2***	548-1/B ***3.2***	280 ***2.0***	477-f/B ***2.2***
Log 3 – surface 885°F	F	low	280 ***4.9***	477-d/B ***0***	279 ***2.8***	476-a/B ***0***	50 ***1.9***	34-c/B ***0***
Log 3 – surface 885°F	N	mid	90 ***4.5***	74-u/B ***4.6***	90 ***2.7***	74-ff/B ***2.7***	415 ***1.9***	610-a/B ***0***
Log 4 – 2 inches 95°F	G	high	263 ***7.7***	433-d/B ***7.5***	78 ***2.6***	300-d/Mg ***2.6***	274 ***2.4***	406-k/B ***2.4***

Source Codes: B = Bodie Hills; M = Mount Hicks; N = Napa Valley; Q = Queen; S = Sutro Springs; Mg = Mono Glass Mountain; P = Pine Grove Hills

Source Total: Bodie (21/78%); Hicks (2/7%); Napa (1/4%); Sutro (1/4%); Mono (1/4%); Pine Grove (1/4%)

Pre- and Post-burn hydration band measurements in microns. Shaded entries mark radical changes.

Comments on the Spring Burn

The effects of the spring burn were less in all fuel load situations, both in surface and subsurface contexts, than they were in the fall burn. Temperatures of 22°C to 474°C (72°F to 885°F) were within the range of those present in the fall. In both the fall and spring burns, the flaming front crossed the obsidian study areas in approximately 10 minutes. The major difference between the spring and fall burns was in the length of time each area remained in a smoldering, glowing phase of combustion. Where the fall burn site smoldered at elevated temperatures for several days, the spring burn site maintained elevated temperatures in the range of four to five hours. This difference in the length of time the obsidian was exposed to heat most likely accounts for the difference in effects between the two burns.

Comments on Both Burns

Every fire has a number of microenvironments within the burn which will affect fire behavior, including differences from one portion of the fire to another in the condition of the fuels (size and shape, moisture content, temperature, compactness and arrangement, continuity, chemistry), wind speed and direction, eddies in wind current, slope, and aspect. A change in any one of these might create different effects to particular obsidian samples from one study spot to another (i.e., woody fuels versus light fuels locations). Potential variations were minimized, however, by placing the specimens in a geographically restricted area (generally all within six feet of each other), and by the fact that the flames burnt over the study plots in roughly 10 minutes, limiting the time in which environmental conditions such as moistures and wind speeds could change. Variables present in both the fall and spring burns -- soil chemistry, roots, volatile oils, rocks (which might block or radiate heat) -- were not controlled for, and may have affected the results.

At least one aspect of the design of our experiment -- the equal distribution of samples to each of the three fuels situations -- would probably not occur in fires on sites in a natural setting. In general, in natural conditions, an area with less ground fuels would have reduced opportunities for artifacts to be situated under downed logs and woody debris. Likewise, in an area where fuels are heavy, fewer opportunities would exist for obsidian to be located under light fuels. Distributing the obsidian samples equally among all three fuels types (light, woody, and log) may therefore skew the interpretive potential of our results.

Although this experiment was only designed to quantify alterations in hydration readings, several macroscopic changes were noted on 74% of our samples. These included the presence of a light sheen or luster, often on only one face of the specimen; a light "pitting" of the surface of some of the obsidian; and the presence of adhesions on the samples. These changes were noted on specimens placed in all three fuel contexts (light, woody and log fuels), on obsidian subjected to temperatures ranging from 31°C to 522°C (87°F to 971°F) for varying lengths of time, and on specimens placed on the soil surface and to depths of three inches.

Implications for Interpreting Fire Histories and Determining Past Fuel Loads

This study was conducted with a limited number of samples in only two prescribed burns. Although our results are similar to other studies where effects increased as temperature and length of exposure increased (see Deal 1999), additional studies are needed to better understand the parameters of those effects, particularly for prescribed fire. For instance, there are likely to be other components of the fire environment, such as wood ash, soil chemistries or soil moistures, that are mitigating or contributing to observed effects. Even so, these results bring forward some interesting questions

which have implications for ecosystem management: Can surface obsidian data suggest past fuel conditions? Can this data be used to reconstruct fire histories? Is this data consistent with the ethnographic record concerning Native American burning practices and historical landscape conditions?

Native American Burning and Historic Landscape Conditions

Native Americans shaped the landscape on a large scale, particularly through the use of fire (MacCleery 1994; Martinez 1993; Pyne 1982), which MacCleery (1994) points out as a fact contrary to popular images of the past:

> There is no question that enormous areas of the forests and grasslands we inherited (or invaded and stole, if you wish) were very much cultural landscapes, shaped profoundly by human action.... Indian use of fire as a management tool changed in profound ways the entire ecology of the forest and the plant and animal communities associated with it.... In fire-prone ecosystems in the West, Indian burning created an element of ecosystem stability that would not have existed without it (MacCleery 1994).

The degree to which Native Americans manipulated the local ecosystem of the Pacific District area is not known, but is expected to have been fairly extensive. Indians throughout California frequently set fire to areas to maintain montane meadows and increase forage, particularly for deer, whose numbers can increase by 400% in areas that have been burned (Taber and Dasmann 1957, cited in Mellars 1976:22). Other objectives of burning included clearing areas around habitations to watch for strangers and dangerous animals; facilitating travel and hunting; driving game; improving wild seed crops and maintaining populations of edible bulbs and tubers; improving certain characteristics of plants used in basketry; maintaining or enhancing the distribution of oaks; killing insects and pests; and maintaining springs and surface waters (Anderson 1992a, 1992b, 1993; Anderson and Moratto 1996; Biswell 1967; Kroeber 1925; Lewis 1973; MacCleery 1994; Matson 1972; McCarthy 1993; Mellars 1976; Wickstrom 1987; Shipek 1993; Sterling 1904; Williams 1993). However, when queried today on why their ancestors burned areas of the forest, the reason mentioned most often by California Indian elders in a recent study was the prevention of large, devastating fires (Anderson 1993b:25). Estimates for the number of acres burned annually in the state from both lightning and Native American ignitions range from 5.6 to 13.2 million (Smith et al. 1994:9), with the vast majority of acreage burned attributable to Native American burning practices. (During the last 80 years, far less than a million acres per year have burned in prescribed or wildland fires in California [Arno 1996:3]).

This deliberate setting of fires would have created an open landscape with less underbrush and an even spacing between trees. Small patches of vegetation in varying successional stages would be scattered throughout the forest (see Kilgore 1981:59). Shade intolerant species would have been favored over those that are shade tolerant, with pine (which is fire tolerant) increasing at the expense of incense cedar and fir, which are not fire tolerant (Johnston n.d.; McKelvey et al. 1996:1033; Pilles 1982:2; Warner 1980:91). Black oak stands would have been more extensive, as would some populations of grasses and annuals used as staple plant foods (Matson 1970:147). Meadows would have been expanded or maintained by fires, which prevented conifers from encroaching into them.

Fires continued to be set by the ranchers who moved into the Sierras in the mid- to late 1800s. Sheepmen set fires to facilitate the movement of flocks and the growth of browse (Sterling 1904); dairy ranchers to increase forage in pastures. Setting of fires by sheepherders was so prevalent, in

fact, that travel in the late 1800s was often hampered in autumn by dense smoke (Johnston n.d.). The incidence of destructive stand-replacing forest fires in the late 1890s brought the first attempts to suppress fires, to protect both watersheds and valuable timberlands.

Several fire histories derived from trees located on the Pacific Ranger District in the yellow pine / black oak belt and in the red fir zone (Ferrell 1994; Gethen 1993, 1994, 1994b and Rice 1983) strongly support the presence of wide-scale, deliberate burning in the past. The oldest fire scar found in these studies dates to 1676, or just over 300 years ago. Average fire return intervals in the yellow pine / black oak belt were found to be from 6 to 7 years; in the red fir zone, average fire return intervals were 12.8 years. These studies indicated that the prehistoric frequency of lightning fires alone could not account for fire occurrence in the areas studied, with lightning ignitions only matching the number of fires expected in the area once fire suppression policies were enacted. Additionally, since low intensity fires can burn without injuring new wood in trees, fire frequencies based on fire scars may be too conservative (Biswell 1989:55), hinting that fires might have been present in the environment even more frequently than indicated by these studies (cf., Lewis 1980).

Low fuel loads, and the removal of ladder fuels by the frequent setting of fires, would make it unlikely that many large-scale stand-replacing fires occurred during the management of the land by Native Americans (McKelvey et al. 1996:1035; Anderson and Moratto 1996:196-202; Skinner and Chang 1996:1042). This may be further supported by the fact that numerous pieces of surface obsidian have been collected from the forest with measurable hydration bands.

Using Obsidian to Determine Past Fuel Loads

We know from fire-scarred trees across the Pacific District that fires were occurring in the past at frequent intervals, thus providing numerous opportunities for obsidian to have been altered by fire. Yet, when tallied from sites and isolated finds across the District, more surface and near-surface obsidian returns readable hydration bands than unreadable (91% vs. 9%). This implies that few if any hot, catastrophic fires, or long, smoldering fires occurred in those areas where the obsidian was found, possibly due to reduced fuel loads in and around the locations where the obsidian was deposited. Since fuels build up naturally in forested environments, we can assume that fuels were being reduced by periodic prescribed fires deliberately ignited by Indians or left to (safely) burn after lightning strikes. Assuming for the moment that this is true, can obsidian data be used to assess how long this sort of managed fuels reduction was occurring on a landscape scale?

In order to explore this possibility, we looked for the oldest surface hydration date (i.e., the thickest hydration band as measured in microns), for individual locations (in this case, archaeological sites and isolate locations) where surface obsidian hydration data was available on the Pacific District. We then assigned a *tentative* chronological date to the micron readings (see Table 5), with each one-tenth micron reading assigned a numeric value representing years before present (which might be thought of as relative dates, rather than absolute ones). Next we plotted the dates back to their location on the Pacific District (Table 6 and Figure 2). The dates indicated in Figure 2 could possibly indicate the amount of time that has transpired since an intense stand-replacing, high temperature fire, or a long duration smoldering fire, has occurred at each location. In fact, hydration might still be present on obsidian from these sites precisely *because* they were located in areas subject to frequent, periodic fires with very restricted fire residence times, resulting in low fuel loads.

Our experiment showed an increased tendency for obsidian hydration to be altered with increased smoldering times common with heavier fuel loads, particularly when obsidian was on the ground surface. Given that frequent fires were known to be occurring over the District, that any piece of surface obsidian could be altered in any one of those fires, and that much of the data in Figure 2 spans several thousand years, the proposition that these lands were managed by deliberate burning for an

extended period of time is strengthened. One alternative scenario might be that hydration is present on obsidian at the locations in Figure 2 because people did not deliberately burn the places where they lived or worked. If this were so, over time, after specific areas were no longer used and fuels increased at the sites, it would be expected that fires from the surrounding terrain would easily spread into them and alter the obsidian hydration. Securing additional hydration readings from isolates, many of which were presumed to be lost or discarded away from habitation areas, might offer further insights regarding this possibility.

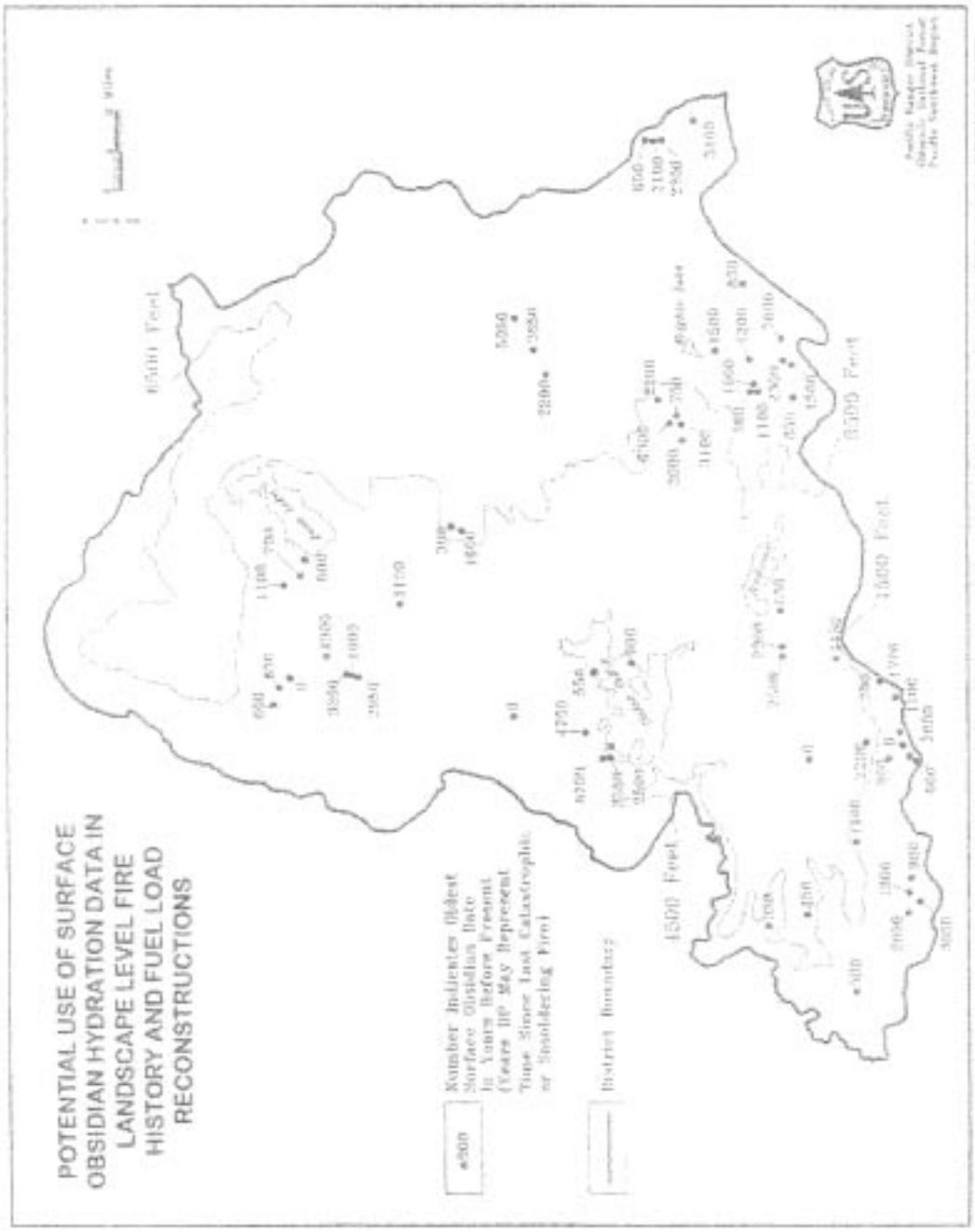


FIGURE 2. CONJECTURED YEARS BEFORE PRESENT SINCE A HIGH INTENSITY FIRE OR A SEVERE SMOLDERING FIRE HAS OCCURRED AT SPECIFIC LOCATIONS ACROSS THE PACIFIC DISTRICT.

Table 5 Tentative hydration band time conversions.

Late Sierran (200 –1000 BP)		Middle Sierran (1000 to 2500 BP)		Early Sierran (2500+ BP)			
micron reading	**years before present**	**micron reading**	**years before present**	**micron reading**	**years before present**	**micron reading**	**years before present**
0.9	200	2.6	1100	4.1	2650	6.5	6500
1.0	250	2.7	1200	4.2	2800	6.6	6600
1.1	300	2.8	1300	4.3	2950	6.7	6700
1.2	350	2.9	1400	4.4	3100	6.8	6800
1.3	400	3.0	1500	4.5	3250	6.9	6900
1.4	450	3.1	1600	4.6	3400	7.0	7000
1.5	500	3.2	1700	4.7	3500	7.1	7100
1.6	550	3.3	1800	4.8	3700	7.2	7200
1.7	600	3.4	1900	4.9	3850	7.3	7300
1.8	650	3.5	2000	5.0	4000	7.4	7400
1.9	700	3.6	2100	5.1	4150	7.5	7500
2.0	750	3.7	2200	5.2	4300	7.6	7600
2.1	800	3.8	2300	5.3	4450	7.7	7700
2.2	850	3.9	2400	5.4	4600	7.8	7800
2.3	900	4.0	2500	5.5	4750	7.9	7900
2.4	950			5.6	4900	8.0	8000
2.5	1000			5.7	5050	8.1	8100
				5.8	5200	8.2	8200
				5.9	5350	8.3	8300
				6.0	5500	8.4	8400
				6.1	6100	8.5	8500
				6.2	6200	8.6	8600
				6.3	6300	8.7	8700
				6.4	6400		

Note: These "time" conversions are only tentatively assigned an absolute value herein as an example of how hydration data might be used to aid in landscape reconstructions. The "time" before present, as plotted on Figure 2, might best be thought of as "micron years", or as years BP relative to each other. In either case, the data spans many thousands of years.

Several other things might affect the interpretation made here; for instance, any given piece of obsidian could have been underground, protected from the effects of fire, and brought to the surface more recently by burrowing rodents, or tree throw, or some other agent. The more samples with readable hydration bands from surface contexts at a particular location, the greater the confidence that the site was not subjected to smoldering or hot, stand-replacing fires. Although not quantified here, some of the sites shown in Table 6 did produce numerous obsidian hydration dates, thus increasing the confidence level for these particular areas. In any case, Figure 2 is provocative: the plotted dates, taken together, support the notion that fuels were being managed across the landscape for thousands of years. This conclusion is consistent with findings in ethnobotanical research regarding the length of time burning has been used for managing vegetation used as basketry materials (see Anderson 1999).

This hydration/mapping exercise serves as one example of how hydration data might be used on a landscape-level to aid in reconstructing fire histories and past fuel load conditions. And, if it holds that hydration data can be used as an indicator of the absence of heavy fuel loads or large fires in the past, then this sort of data is extremely valuable in providing information that goes well beyond the temporal limit of several centuries inherent in dating fires from tree cores.

Using Obsidian to Date Past Fire Events

Elevated temperatures apparently force resident moisture on exposed surfaces "into" obsidian, creating a wide, diffused band with unreadable or blurred margins (Jackson, personal communication, 1997; Trembour 1990). Whether obsidian can rehydrate following exposures to high temperatures, and the rate at which the obsidian rehydrates, if it does at all, is currently under investigation by the Eldorado National Forest as a follow-up to this study, and by Tom Origer and his colleagues at Sonoma State University. At least one researcher has suggested that past fire events are recorded on obsidian in the form of re-established hydration bands, stating that the:

> ". . . diffusion effects of a high heat experience in obsidian are eventually 'recovered' from by a lengthy period at normal conditions where a semblance of [a] 'normal' rind is re-established in time" (Trembour 1990:177-178).

Should Trembour's statement be found to be true under natural field conditions, that is, the original hydration band would become re-established over time, then using obsidian hydration to reconstruct fuel loads or fire histories as discussed in the last section could prove less useful, unless other markers of fires are present on the obsidian.

Some obsidian previously collected from archaeological contexts has returned wide, unreadable, diffused bands, with a second distinct, readable band retained on the surface of the object (Jackson, personal communication; Origer, personal communication, 1997), suggesting the possibility that this obsidian has rehydrated after an event such as a fire, which led the initial hydration band to become unreadable and diffused. In the case of diffused bands, labs usually note their presence, but provide a micron reading on the distinct, thinner, secondary hydration band, if one is present. This micron reading is then generally taken to indicate the age of manufacture of the artifact (which, because of the thinner band, would return a younger date than the original date of manufacture). For instance, one site on the Pacific District produced 16 surface samples with diffused bands, each with a second readable band - this second band provided the micron reading returned from the lab. However, if it can be shown that obsidian *does* rehydrate after a fire, then the thickness of the second, readable band would likely mark a past high intensity fire event, rather than a past cultural (manufacturing) event. Additional research is needed to more precisely identify what the markers of fire are on obsidian.

Table 6. Pacific District sites and isolates with hydration data.

Site/Isolate Number	Maximum Reading	Tentative years BP	Site/Isolate Number	Maximum Reading	Tentative years BP
36	3.7	2200	263	7.8	7800
50	3.5	2000	270	4.6	3400
78	2.6	1100	274	3.8	2300
85	--	--	275	3.6	2100
87	5.5	4750	276	1.8	650
90	8.7	8700	279	2.8	1300
96	--	--	280	4.9	3850
113	4.3	2950	283	1.5	500
127	2.7	1200	284	1.7	600
136	2.4	950	289	5.2	4300
143	1.7	600	290	5.3	4450
144	1.9	700	292	2.6	1100
146	4.5	3250	296	1.5	500
153	2.3	900	302	5.7	5050
165	1.8	650	309	2.2	850
167	4.1	2650	319	1.6	550
169	1.7	600	333	4.1	2650
172	2.6	1100	334	4.0	2500
174	3.1	1600	340	3.8	2300
178	2.3	900	347	1.9	700
197	5.4	4600	356	3.2	1700
198	1.1	300	368	3.7	2200
199	5.1	4150	369	--	--
210	3.0	1500	378	1.8	650
211	2.6	1100	415	4.0	2500
228	1.1	300*	421	4.7	3550
240	3.5	2000	427	2.5	1000
248	4.4	3100	Isosate-181	1.8	650
249	2.0	750	Isolate-231	--	--
255	6.3	6300	Isolate-232	1.4	450
259	3.8	2300	Isolate-233	1.2	350
261	3.0	1500	Isolate-238	3.7	2200

Note: *The micron readings are from surface finds only, and represent the thickest (i.e., oldest) micron readings from each surface context, converted to a tentative date in years before present (BP). For surface obsidian with two cuts, the thinner (youngest) reading was reported, based on the assumption that the material might have been scavenged from an older site prior to its deposition where it was found.*

Management Implications

It has been estimated that in the last 85 years, between 8.5 and 17 fire cycles have been missed in Sierran ponderosa pine stands due to fire suppression, from 4.3 to 10.6 fire cycles in mixed-conifer stands, and 1.3 to 5.7 fire cycles in Sierran red fir (United States Department of Agriculture 1995:3-73). These lost fire cycles represent a tremendous fuel buildup in Sierran forests, with a resultant increase in fire intensity and severity (United States Department of Agriculture 1995:3-73-99). Locations outside of managed fuels areas are now at great risk of increased resource damage when wildland fires occur. Since fire suppression activities result in the greatest disturbance to sites, and consequently the greatest loss of data, it is imperative that we work toward removing fuels to reduce these effects. Minimally, fuels should be reduced on sites themselves, to reduce data loss through burning or suppression activities.

Our experiment shows that prescribed burning will result in some predictable data loss to obsidian bearing readable hydration bands, particularly when located on or near the surface. If prescribed burns are planned in areas that have not had prior fuels management projects, these losses can be anticipated to be the greatest. However, if fuels can be reduced on sites prior to burning, either through hand removal of downed fuels or thinning via hand or mechanical means when appropriate (see Jackson 1993; Jackson et al. 1994), then this data loss is reduced. Often, however, fuels are so dense that the nature or even presence of surface artifactual materials is unknown. Collecting surface samples prior to burning (if even possible in dense fuel situations) would secure the data that could be affected by the prescribed burn.

Conclusion

This experiment helps to meet an expedited compliance process agreed upon between the California State Historic Preservation Office and Region 5 of the USFS, which called for continued research into the effects of prescribed burning. The experiment not only generated data regarding the effects of burning on obsidian, but also applied that data toward ecosystems management issues such as past fuel loads and fire histories. Given that increased ground fuels equate to increased smoldering time and increased data loss, the results of this experiment point to the merits of removal of fuels from sites, prior to the occurrence of a smoldering fire, a high-intensity fire, or large-scale suppression activities.

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Photograph 1. Fall burn fuels condition. Twenty-seven obsidian samples were placed in the fall burn study site in an area where no recorded wildland fires or prescribed burns had occurred. The woody fuels samples were placed under the suspended log on the right, the log fuels samples were placed under the small fallen log in the center, and the light fuels samples were placed under the duff on the left side of the frame. Forceps were used to place the obsidian in order to minimize disturbance to fuels.

Photograph 2. Thermocouples were placed into the soil by the obsidian samples to monitor soil temperatures. A cable led from the thermocouples to a datalogger, located outside the fireline. The datalogger was set to record temperatures at the obsidian samples at designated time intervals.

Photograph 3. Fall burn sample locations, all in flames. Light fuel samples are to the left underneath the duff, log fuel samples are in the center under the small fallen log to the right of the stump, woody fuel samples are beneath twigs and branches underneath the suspended log on the right.

Photograph 4. Fall burn, 40 hours after flames burned across the obsidian study site. Obsidian samples placed in light fuels were near the pin flag on the left, obsidian in log fuels were near the pin flag at the center, and woody fuels samples were underneath log to right. The log at the log fuels sample location was completely consumed, and the suspended log overhanging the samples at the woody fuels site had dropped to the ground, where it continued to smolder from underneath. The ground was still hot two days after ignition when the obsidian samples were retrieved. The obsidian was then resubmitted to the lab for hydration measurements.

Photograph 5. The spring burn study site was located in an area where the fuels had been previously reduced (in 1978, 1979 and 1985) using prescribed fire. Twenty-seven obsidian samples were placed in the spring burn study site, using the same procedures as in the fall burn.

Photograph 6. Fire burning over spring burn samples (located near pin flags). Light fuels obsidian samples are in the center background, woody fuels samples are near the center of the photo, and log fuels samples are situated under the small logs in the right foreground. Obsidian samples were retrieved later in the day.