

**X-Ray Fluorescence Analysis and Obsidian Hydration Rim
Measurement of Artifact Obsidian from 35-DS-193 and
35-DS-201, Surveyor Fire Rehabilitation Project,
Deschutes National Forest, Oregon**



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Introduction

Fifty-one obsidian artifacts from 35-DS-193 (N=32) and 35-DS-201 (N=19), Deschutes National Forest, Oregon, were submitted for X-ray fluorescence trace element provenience analysis. The artifacts were also processed for obsidian hydration measurements. All samples were prepared and analyzed at the Northwest Research Obsidian Studies Laboratory under the accession number BO-96-33.

All artifacts were recovered from burned archaeological sites located within the boundaries of the 1993 Surveyor Fire, Deschutes National Forest. Although little of the original pre-burn vegetation remains, the surrounding area is composed primarily of lodgepole pine (*Pinus contorta*), ponderosa pine (*Pinus ponderosa*), bitterbrush (*Purshia tridentia*), and scattered manzanita (*Arctostaphylos patula*) (Gregory 1994). The maximum temperature of the fire is estimated to have fallen within 800 and 1000° F. (426 - 537° C.) (personal communication to Lucy Hamilton, Deschutes National Forest, from Peter Sussman, Deschutes National Forest).

An additional objective of the research reported in this investigation was to examine the effects of a natural forest fire burn on the presence of obsidian hydration rims on recovered artifacts. Because of the *post hoc* nature of the research design employed here, no control samples were available from the two sites, i.e., no pre-burn obsidian hydration measurements were available for artifacts from either of the sites.

Analytical Methods

X-Ray Fluorescence Analysis and Characterization Studies

Introduction. Although a variety of physical, optical, petrographic, and chemical attributes are used to characterize volcanic glasses, the use of trace element abundances to "fingerprint" obsidian sources and artifacts has shown the greatest overall success. X-ray fluorescence analytical methods, with their ability to nondestructively and accurately measure trace element concentrations in obsidian, have been widely adopted for this purpose (Harbottle 1982; Rapp 1985).

Most geologic sources of obsidian are quite homogeneous in their trace element composition, yet demonstrate adequate intersource variability so that individual sources of glass can be distinguished. Because obsidian can be widely dispersed from its primary geologic source due to a variety of geologic and geomorphic processes, specimens of chemically identical glass are sometimes recovered from outcrops spread over large geographic areas (Hughes 1986a; Hughes and Smith 1993; Skinner 1983:52–56). These secondary source boundaries are often not as well documented as primary sources but must be carefully considered in obsidian procurement studies. Hughes (1986a) points out that these chemically identical obsidian outcrops must be considered as a single chemical group or chemical type and his terminology is followed here.

From small scale (household and site) to large scale (regional and interregional) levels of analysis, the spatial source patterning of characterized obsidian artifacts is influenced by many different environmental and cultural factors. Interpretation of these patterns can provide valuable information about the prehistoric behavioral and environmental procurement variables responsible for observed artifact distributions. At the site level of analysis, patterns of source use may suggest the presence of specific activity areas, of single tool manufacturing events, or, in special cases, may point to differential access of goods and the existence of non-egalitarian social structures. At the intersite or regional level of investigation, the geographic patterning of artifacts can provide information about seasonal procurement ranges, territorial and ethnic boundaries, the location of trails and travel routes, the curational value of particular sources or formal artifact types, cultural preferences regarding glass quality and colors, the presence of trade and exchange systems, the existence of intergroup interaction, and the exchange of prestige items between elites of different groups (Ericson 1981; Hughes 1978, 1990; Hughes and Bettinger 1984; Skinner 1983:87–91, 1995a:4.10). The effects of environmental influences such as the distance to source, the location of alternative or competing sources of lithic materials, the distribution of raw materials in secondary deposits, or the presence of potential barriers such as mountain ranges, must all be considered. Bias introduced during sampling by certain recovery methods, artifact size, and the use of small numbers of samples may also effect the reconstruction of the spatial patterning of analyzed artifacts.

Sample Preparation Methods. Obsidian samples selected for X-ray fluorescence analysis are typically restricted to clean artifacts (a wash with tap water and a brush will usually suffice) with a relatively flat surface at least 10 mm in diameter and at least 1.5 mm thick. Although it is possible to analyze slightly smaller samples (7-10 mm in diameter and 0.5-1.0 mm thick), these items will show some distortion in trace element values and may not be able to be reliably characterized. This is particularly true in areas with complex source use patterns. Source assignments of samples that do not meet the minimum reliable size criteria of 10 mm diameter and 1.5 mm thickness, and/or show distorted trace element values are indicated by an asterisk in the data tables that appear in the appendices.

Analytical Methods. Analyses of the samples were completed using a Spectrace 5000 energy dispersive X-ray fluorescence spectrometer. The system is equipped with a Si(Li) detector with a resolution of 155 eV FWHM for 5.9 keV X-rays (at 1000 counts per second) in an area 30mm². Signals from the spectrometer are amplified and filtered by a time variant pulse processor and sent to a 100 MHz Wilkinson type analog-to-digital converter. The X-ray tube employed is a Bremsstrahlung type, with a rhodium target, and 5 mil Be window. The tube is driven by a 50 kV 1 mA high voltage power supply, providing a voltage range of 4 to 50 kV. The principles of X-ray fluorescence analytical methods are reviewed in detail by Norrish and Chappel (1967), Potts and Webb (1992), and Williams (1987).

For analysis of the elements zinc (Zn), lead (Pb), thorium (Th), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), and niobium (Nb), the X-ray tube is operated at 30 kV, 0.45 mA (pulsed), with a 0.127 mm Pd filter. Analytical lines used are Zn (K-alpha), Pb (L-alpha), Th (L-alpha), Rb (K-alpha), Sr (K-alpha), Y (K-alpha), Zr (K-alpha) and Nb (K-alpha). Samples are scanned for 200 seconds live-time in an air path.

Peak intensities for the above elements are calculated as ratios to the Compton scatter peak of rhodium, and converted to parts-per-million (ppm) by weight using linear regressions derived from the analysis of

twenty rock standards from the U.S. Geological Survey, the Geologic Survey of Japan, and the National Bureau of Standards. The analyte to Compton scatter peak ratio is employed to correct for variation in sample size, surface irregularities, and variation in the sample matrix.

For analysis of the elements titanium (Ti), manganese (Mn), and iron (Fe_2O_3^T), the X-ray tube is operated at 12 kV, 0.27 mA with a 0.127 mm aluminum filter. Samples are scanned for 200 seconds live-time in a vacuum path. Analytical lines used are Ti (K-alpha), Mn (K-alpha), and Fe (K-alpha).

Concentration values (parts per million for titanium and manganese, weight percent for iron) are calculated using linear regressions derived from the analysis of thirteen standards from the U.S. Geological Survey, the Geologic Survey of Japan and the National Bureau of Standards. However, these values are *not* corrected against the Compton scatter peak or other scatter region, and we recommend against using them for anything other than approximate concentrations. Iron/titanium (Fe/Ti) and iron/manganese (Fe/Mn) peak ratios are supplied for use as corrected values.

A word of caution about titanium, manganese and iron concentration values (i.e. titanium ppm, manganese ppm, and iron weight percent)—as mentioned above, these values are not corrected against the Compton Scatter peak or other scatter region, resulting in lower than normal trace element values for small samples that fall below the minimum size requirement. The absence of a spectral reference also means that these values are subject to matrix effects errors. To compensate for these effects, iron-manganese and iron-titanium peak ratios are provided for use as corrected values. To ensure comparability among samples of different sizes, source assignments in all reports are based upon these ratios, and not on the absolute concentration values.

All samples are scanned as unmodified rock specimens. Reported errors represent counting and fitting error uncertainty only, and do not account for instrumental precision or effects related to the analysis of unmodified obsidian. When the latter effects are considered, relative analytical uncertainty is estimated to be between three and five percent.

In traditional X-ray fluorescence trace element studies, samples are powdered and pelletized before analysis (Norrish and Chappel 1967; Potts and Webb 1992). In theory, the irregular surfaces of most obsidian artifacts should induce measurement problems related to shifts in artifact-to-detector reflection geometry (Hughes 1986a:35). Early experiments with intact obsidian flakes by Robert N. Jack, and later by Richard Hughes, however, indicate that analytical results from lenticular or biconvex obsidian surfaces are comparable to those from flat surfaces and pressed powder pellets, paving the way for the nondestructive analysis characterization of glass artifacts (Hughes 1986a:35–37; Jack 1976). The minimum optimal sample size for analysis has been found to be approximately 10 mm in diameter and 1.5–2.0 mm thick. Later experimental studies conducted by Shackley and Hampel (1993) using samples with flat and slightly irregular surface geometries have corroborated Hughes' initial observations. In a similar experiment, Jackson and Hampel (1993) determined that for accurate results the minimum size of an artifact should be about 10 mm in diameter and 1.5 mm thick. Agreement between the U. S. Geological Survey standard RGM-1 (Glass Mountain obsidian) values and obsidian test samples was good at 1 mm thickness and improved markedly to a thickness of 3 mm.

Correlation of Artifacts and Geologic Sources. Trace element values used to characterize the samples are compared directly to those for known obsidian sources such as those reported by Hamusek (1993, 1995), Hughes (1986a, 1986b, 1988, 1993, 1994), Hughes and Nelson (1987), Jack (1976), Jackson (1986, 1989), Nelson and Holmes (1979), Shackley (1991, 1992, 1995), Skinner (1983, 1986), and with unpublished trace element data collected by Northwest Research through analysis of geologic source samples. Artifacts are correlated to a parent obsidian source or chemical source group if diagnostic trace element values fall within about two standard deviations of the analytical uncertainty of the known upper and lower limits of chemical variability recorded for the source. Occasionally, visual attributes are used to corroborate the source assignments although sources are never assigned on the basis of only megascopic characteristics.

Diagnostic trace elements, as the term is used here, refer to trace element abundances that show low intrasource variation and uncertainty along with distinguishable intersource variability. In addition, this refers to elements measured by X-ray fluorescence analysis with high precision and low analytical uncertainty. In short, diagnostic elements are those that allow the clearest geochemical distinction between sources. Trace elements generally refer to those elements that occur in abundances of less than about 1000 ppm in a sample. For simplicity in this report, we use the term synonymously with major and minor elements such as iron, titanium, and manganese, which may be present in somewhat larger quantities.

Obsidian Hydration Analysis

Introduction. The obsidian hydration dating method was introduced to the archaeological community in 1960 by Irving Friedman and Robert Smith of the U. S. Geological Survey (Friedman and Smith 1960). The potential of the method in archaeological chronologic studies was quickly recognized and research concerning the effect of different variables on the rate of hydration has continued to the present day by Friedman and others.

When a new surface of obsidian is exposed to the atmosphere, such as during the manufacture of glass tools, water begins to slowly diffuse from the surface into the interior of the specimen. When this hydrated layer or rind reaches a thickness of about 0.5 Fm, it becomes recognizable as a birefringent rim when observed as a thin section under a microscope. Hydration rims formed on artifacts can vary in width from less than one micron for items from the early historic period to nearly 30 Fm for early sites in Africa (Michels et al. 1983a; Origer 1989).

Formation of the hydration rim is affected not only by time but also by several other variables. The most important of these are chemical composition and temperature, although water vapor pressure and soil alkalinity may also play a role in some contexts. The effects of these variables have often been summarized and will not be discussed further here (Freter 1993; Friedman and Obradovich 1981; Friedman et al. 1994; Michels and Tsong 1980; Stevenson et al., 1993; see Skinner and Tremaine 1993 for additional references).

Once a hydration layer has been measured, it can be used to determine the relative ages of items or, in some circumstances, can be converted into an *estimated* absolute age. In order to transform the

hydration rim value to a calendar age, the rate of the diffusion of water into the glass must be determined or estimated. The hydration rate is typically established empirically through the calibration of measured samples recovered in association with materials whose cultural age is known or whose age can be radiometrically determined, usually through radiocarbon dating methods (Meighan 1976). The hydration rate can also be determined experimentally, an approach that has shown increasing promise in recent years (Friedman and Trembour 1983; Michels et al. 1983a, 1983b; Tremaine 1989, 1993).

Sample Preparation Methods. An appropriate section of each artifact is selected for hydration slide preparation. The location of the section is determined by the morphology and the perceived potential of the location to yield information on the manufacture, use, and discard of the artifact. Two parallel cuts are made into the edge of the artifact using a lapidary saw equipped with 4-inch diameter diamond-impregnated .004" thick blades. These cuts produce a cross-section of the artifact approximately one millimeter thick which is removed from the artifact and mounted on a petrographic microscope slide with Lakeside thermoplastic cement. The mounted specimen slide is ground in a slurry of 600 grade optical-quality corundum abrasive on a plate glass lap. This initial grinding of the specimen reduces its thickness by approximately one half and removes any nicks from the edge of the specimen produced during cutting. The specimen is then inverted and ground to a final thickness of 30-50 microns, removing nicks from the other side of the specimen. The result is a thin cross-section of the surfaces of the artifact.

In the current investigation, the provenience of the top and bottom side of artifact was maintained so that any differences in hydration rim measurements could be monitored. Specimens were tagged on recovery in the field to preserve top and bottom orientation. During laboratory preparation, the top-bottom provenience was maintained throughout the preparation and measurement procedures. The hydration rim width of both the upper and lower surfaces of the artifact were then individually recorded during measurement of the artifacts.

The prepared slide is measured using an Olympus BHT petrographic microscope fitted with a filar screw micrometer eyepiece. A Panasonic color CCTV camera is mounted on the filar eyepiece and the image is directed to a Panasonic color video monitor. The filar eyepiece is used to measure the thickness of the hydration band projected onto the high resolution monitor. The specimen is first scanned under crossed polarizers and a first-order red (gypsum) plate in order to identify the birefringent hydration layer; the hydration layer is scanned under a magnification of 500X, 750X, or 1250X. The magnification is generally selected with regard to the opacity of the obsidian and the width of the hydration layer. When a clearly defined hydration layer is identified, the section is centered in the field of view to minimize parallax effects. Four rim measurements are typically recorded for each artifact or examined surface. Narrow rinds (under approximately two microns) are usually examined under a higher magnification. Hydration rinds smaller than one micron often cannot be resolved by optical microscopy.

Obsidian hydration data are presented in Table B-1 of the Appendix. Hydration thicknesses are reported to the nearest 0.1 μm and represent the mean value for all readings. Standard deviation values for each measured surface indicate the variability for hydration thickness measurements recorded for each specimen. It is important to note that these values reflect only the reading uncertainty of the rim values and do not take into account the resolution limitations of the microscope or other sources of uncertainty

that enter into the formation of hydration rims (Meighan 1981, 1983; Skinner 1995b:5.13–5.19). Any attempts to convert rind measurements to absolute dates should be approached with great care and considerable skepticism, particularly when rates are borrowed from existing literature sources. When considered through long periods, the variables affecting the development of hydration rims are complex, and there is no assurance that artifacts recovered from similar provenances or locales have shared thermal and cultural histories.

The Effects of Fire on Obsidian Artifacts

Introduction

Many different types of site formation and site disturbance processes act upon archaeological sites to transform them from their original state to the ones that are examined and interpreted by archaeologists (Schiffer 1978; Wildesen 1983; Wood and Johnson 1978). Forest fires and wildfires are but a single category of these human and environmental site formation processes that can impact or modify archaeological sites. Although site formation processes in general have been explicitly addressed in the literature, the role of fire on archaeological resources has only recently begun to gain attention.

In recent years, several major investigations about the effects of forest fires on archaeological projects have been completed or are currently in progress. Research programs carried out in conjunction with the La Mesa Fire (Bandelier National Monument, New Mexico; Traylor et al. 1979, 1990), the Henry Fire (Jemez Mountains, New Mexico; Lentz et al. 1996), and the Long Mesa Fire (Duncan 1990; Eininger 1990), have provided valuable information about the direct effects of heat upon artifacts and other site remains and about the impact of fire suppression activities on sites and artifacts.

Visual Appearance

Some obsidian artifacts exposed to fire undergo observable physical surface changes. In areas of intense heat in the 1977 Radio Fire (Coconino National Forest, Arizona), some obsidian artifacts were reported as partially melted (Lissoway and Propper 1988:5). At obsidian sources, thermal fracturing has reportedly obscured evidence of prehistoric quarrying activity (Pilles 1984:11). Trembour (1990) has reported that obsidian begins to melt and froth at a temperature of about 760° C. An obsidian artifact with a potlid removed is illustrated in Lentz (1996a:70), the result of exposure to a heavy fuel load fire.

At the Surveyor Fire, some lithic materials are reported as partially melted with degassing bubbles while others are reported to have taken on a “gun metal” luster on exposed surfaces (Gregory 1994).

Trace Element Composition

Given the homogeneous trace element composition of obsidian and the relatively low temperatures of most natural fires (in relation to the melting point of the glass), no changes in the trace element composition of burned artifacts would be expected. In the current investigation, for example, the results of X-ray fluorescence analysis of the fire-exposed obsidian artifacts were well within the usual trace element ranges for previously analyzed artifacts and geologic source samples. Studies currently

underway on effects of the Henry Fire, Jemez Mountain, New Mexico, on archaeological resources also confirm that artifact burning has no effect on the trace element composition of obsidian artifacts (Personal communication, Steve Lentz, Museum of New Mexico, 1996).

Obsidian Hydration Bands

Trembour Experimental Studies and the La Mesa Fire. The first experimental study of the effects of heat on hydrated obsidian was reported by Trembour (1979, 1990). He found that hydration rims on obsidian samples, when placed in an oven, became gradually indistinct and unmeasurable as oven temperatures increased (Table 1). Trembour also examined 110 severely burned artifacts collected from the surface after the 1977 La Mesa Forest Fire (Bandelier National Monument, New Mexico). He found that only 35% of the artifacts retained a measurable hydration rim; a control sample from an unburned site yielded a significantly higher success rate of 70 percent (N=138). He also analyzed a collection of subsurface artifacts, although their provenience and association with fires was not clearly described. Trembour did find, however, that 91 of the 111 analyzed subsurface artifacts (82%) produced measurable hydration rims. He concluded that the La Mesa Fire did not significantly affect the hydration rims of subsurface artifacts.

Table 1. Summary of the results of the effects of different oven temperatures on obsidian hydration rims. Summarized from Trembour (1990:175).

Oven Temperature	Comments
Untreated	10.7 μm hydration rim; sharp boundary between hydrated and unhydrated obsidian.
170, 220 and 350° C.	Progressive tinting of the hydration rind to grey or violet in plain light, lessening of rind brilliance in polarized light, blurring of hydration front, and inward movement of the lines to a deeper position. Attributed to diffusion and stress-relief with rising temperatures. At 350° C., the rim became unmeasurable.
430° C.	All traces of hydration rim are obliterated.
540° C.	First appearance of thermal crazing on obsidian surfaces; surface cracks are shallow.
760° C.	Beginning of melting and vesiculation of obsidian; sample becomes frothy because of escaping volatiles.

Stevenson Experimental Studies. Experimental studies of hydration rims and heating by Chris Stevenson produced similar results to those of Trembour. Hydration rims were found to initially increase slightly in width during heating and disappear entirely at temperatures between 300° C. and 400° C. (Figure 1; unpublished results provided by Chris Stevenson, Diffusion Laboratory).

Stevenson hypothesized that the bonded water within the hydration band is released as the temperature rises above 300° C. Subsequent analysis of heated samples by sputter-induced optical emission (SIMS)

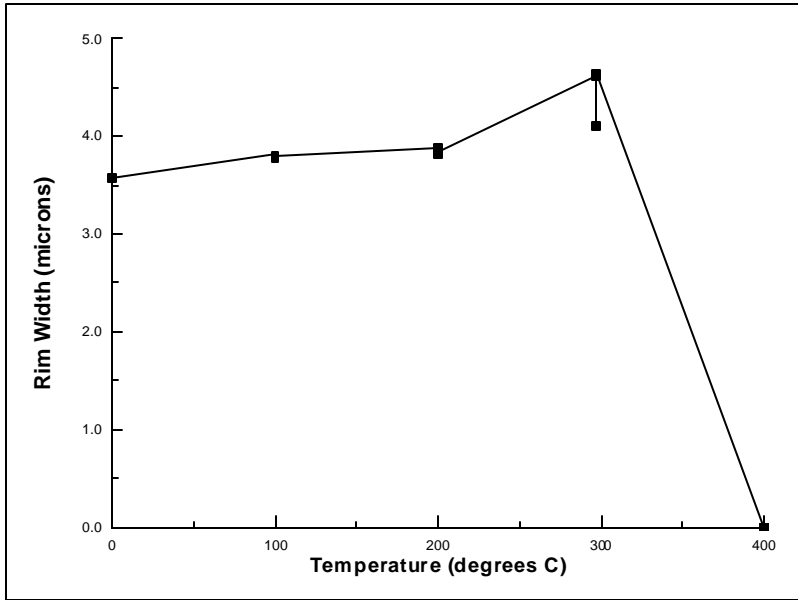


Figure 1. Relationship of obsidian hydration rim width and oven temperature. Three samples each were heated for 20 minutes at each temperature interval. Based on unpublished data provided by Chris Stevenson, Diffusion Laboratory.

methods showed very low concentrations of hydrogen at the surface of the glass, an indication that water has been driven out of the sample (Tsong et al. 1978).

Willamette National Forest Fire Studies. The results of two controlled burn studies carried out by the Willamette National Forest, Oregon, are described by Linderman (1991, 1992). One of the tenets of this investigation was that obsidian hydration rims would not be affected by temperatures below 932° F. (500° C.), a figure based on earlier studies reported by Kelly and Mayberry (1979).

In the first controlled burn using sparse to light fuel loads, 20 obsidian artifacts with measured hydration rims were placed on the ground surface prior to the fire along with temperature-sensitive plastic markers. After the burn, estimated to be less than 90° C. at the ground surface, the artifacts were collected and the rims were re-measured. Linderman reports that there were no appreciable effects on the hydration rims.

In a second investigation using moderate to heavy fuel loads, 60 artifacts with previously measured hydration rims were covered with heat-sensitive paints and placed in burn plots. After the burn was completed, 54 flakes were recovered. The heat-sensitive paint indicated that all had been exposed to temperatures up to 1400° F. (760° C.) for varying amounts of time. Six flakes were found to retain the same pre-burn hydration measurement while four showed diffuse hydration; the remaining 44 flakes yielded no visible hydration bands. Four of the six artifacts with unaffected rims had been placed below the surface prior to the burn.

Linderman concluded that the threshold temperature at which flakes were affected was approximately 800° F. (426° C.), a temperature somewhat higher than that suggested by the experimental investigations reported elsewhere. It was apparent, however, that hydration rims would survive fires with light fuel loads unaffected while moderate to heavy loads significantly affected hydration rim survival.

Henry Fire Study, New Mexico. Origer (1996) reports the results of obsidian hydration analysis of ten artifacts from the Henry Fire Study (Lentz et al. 1996). He found that five out of six artifacts exposed to light and moderate burn intensities retained measurable rims. Only one out of three artifacts exposed to heavy burn temperatures was found to retain a hydration rind. This study lacked a pre-burn comparative sample, however. Phase II investigations in which comparative samples of obsidian samples will be measured before and after prescribed burns are planned (Lentz 1996b:95).

Modoc National Forest. In this recent investigation by the Modoc National Forest, 90 obsidian tools and flakes were collected at a site that was to be burned for management purposes (Personal communication, Dee Green, Warner Mountain Ranger District, Madoc National Forest, 1996). The rims on all 90 artifacts were measured and returned to the site in three areas of low, medium, and heavy fuel loads. Temperature sensitive pellets were placed under each artifact. The fuel consisted primarily of sage and grasses with no heavy (timber) fuels.

After the burn, the artifacts were recollected and re-measured. In areas of medium and high fuels, hydration rims were absent; the temperature pellets indicated temperatures in excess of 400° F. (205° C.). Obsidian hydration rims were found to be intact in areas of low fuel load (temperatures up to about 400° F.).

Salt Point State Park (CA-SON-458), California. Origer and Anderson (1994) have recently described the results of an obsidian hydration investigation of obsidian artifacts recovered from CA-SON-458, Salt Point State Park. They compared analyzed artifacts collected from the site prior to and immediately after a 1993 wildfire that burned dozens of archaeological sites. They were able to find measurable hydration rims on all of the 23 pre-burn artifacts but found rims on only 15% (N=37) of the burned artifacts. All of the surviving post-burn hydration rims were associated with artifacts from subsurface contexts. They concluded that:

The 1993 Salt Point fire clearly affected hydration on surface specimens. A build up of substantial fuel loads as a result of modern fire suppression practices possibly contributed to high fire temperature. In contrast, there is evidence to suggest that prehistoric occupants of the land may have managed the land somewhat differently by periodically burning to improve resource availability. Prehistoric fires, then possibly burning with reduced fuel loads, may have had less affect on obsidian.

Experimental Studies of the Effects of Heat on Newberry Volcano Obsidian Artifacts

As part of the current investigation, we initiated a simple experiment to quantitatively ascertain the effects of heat on the survivability and width of obsidian hydration rims. Our objectives were to locate the temperature range in which a pre-existing hydration rim would be unable to be detected *and* to monitor any changes in rim width during the process.

Methods

A single large obsidian flake that had been previously geochemically correlated with the Newberry Volcano source group was selected for the heating experiment. The flake was cut into six pieces with a lapidary saw. For control purposes, the hydration rind thickness was then determined individually for each of the six debitage fragments (see Table 2). The reading uncertainty for each hydration rim measurement is approximately 0.2 microns.

Next, each obsidian flake fragment was placed in a porcelain crucible and heated for one hour in a pre-warmed muffle furnace at temperatures of 100°, 200°, 300°, 400°, 500°, and 600° C. After the heating cycle was completed, each sample was briefly left in the oven to cool before it was removed. After the completion of the oven trials, a second set of thin sections were made and analyzed. Obsidian hydration analysis. The results of the heating experiment are summarized in Table 2 and Figure 2.

Results

The hydration band shows no visible changes after being heated for one hour at 100° C. The band remains distinct and easy to identify and the diffusion front is sharp and clearly defined. Under plain light, the hydration band displays a bluish hue that is sharply delineated in the interior of the glass by the boundary of the diffusion front. After one hour at 200° C., the rim width has increased slightly but is still clearly visible and easily measurable; the diffusion front remains sharp and easy to distinguish. The appearance of the rim has begun to significantly alter after one hour at 300° C. The hydration rim is now difficult to measure because the diffusion front has become very diffuse and indistinct. Under polarized light, the main body of the hydration band still retains a distinct bluish hue that fades as the now indistinct edge of the diffusion front is reached. The hydration band becomes extremely diffuse after one hour at 400° C. and all traces of the diffusion front are now gone; the band has become impossible to measure and the only sign of a rim that remains is the very slight bluish hue that is visible under plain light. All signs of the hydration band have completely disappeared after the flake has been heated for an hour at 500° and at 600° C. (Figure 5).

Conclusions

In this experimental investigation of the effects of heat on hydration rims, the hydration rim front was observed to become increasingly indistinct up to a temperature of 300° C., finally becoming completely unmeasurable at a point between 300° C. and 400° C. The rim width was also found to significantly increase in size between 200° C. and 300° C. The results of this investigation generally agree with those of previous investigators.

It is clear from this simple experiment that the effects of heating upon both the survival and width of an obsidian hydration rim are very significant in their potential implications regarding the interpretation of the archaeological record. Exposure to heat and natural fires can not only erase or reset the obsidian hydration “clock” but is also capable of altering and increasing the hydration rim width in certain temperature ranges. In the instance of high temperature rim erasure, the obsidian hydration age of the artifact will appear too young; in cases where the rim width increases but is not erased, the hydration age will appear as too old.

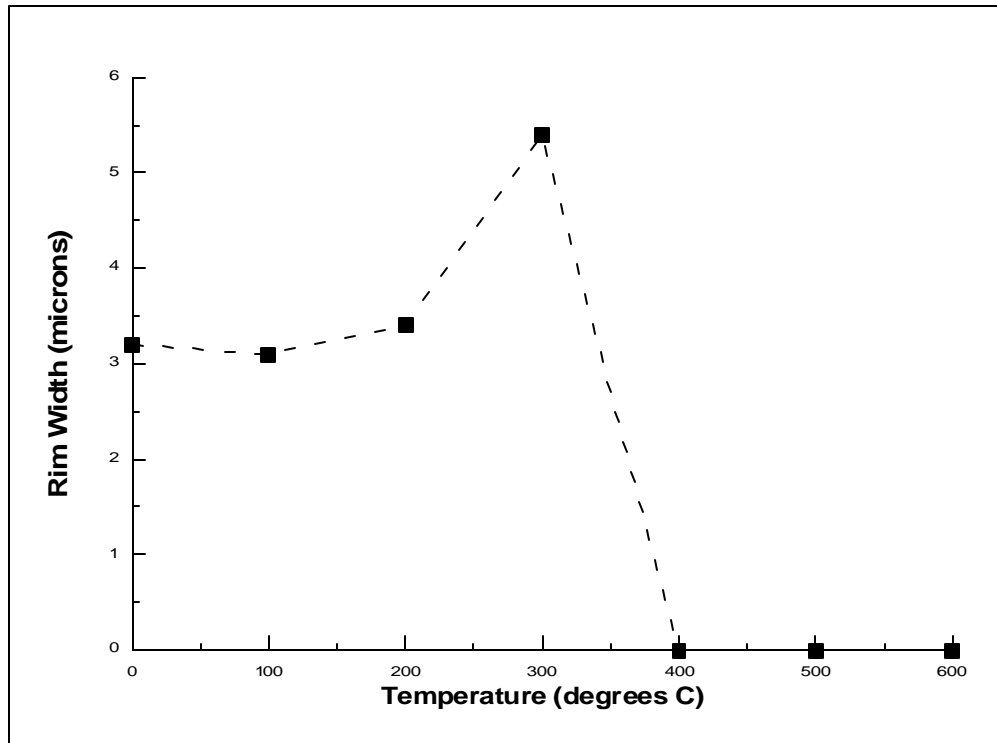


Figure 2. Relationship of obsidian hydration rim width and oven temperature. Six pieces of a single flake from the Newberry Volcano chemical source were heated for one hour at each temperature interval.

Table 2. Summary of the results of the effects of different oven temperatures on obsidian hydration rims. Each test sample was heated for 60 minutes.

Oven Temperature	Hydration Rim before heating	Hydration Rim after heating	Comments
100° C.	3.2 ± 0.1 μm	3.1 ± 0.1 μm	No change in the rim width or rim appearance.
200° C.	3.2 ± 0.1 μm	3.4 ± 0.1 μm	Slight increase in rim width; diffusion front remains clearly defined.
300° C.	3.2 ± 0.1 μm	5.4 ± 0.0 μm	Hydration rim becomes very diffuse; diffusion front becomes very indistinct and difficult to measure.
400° C.	3.2 ± 0.2 μm	None	Extremely diffuse rim is only marginally recognizable and could easily be missed; absolutely no sign of a diffusion front remains.
500° C.	3.2 ± 0.1 μm	None	No visible hydration rim.
600° C.	3.2 ± 0.1 μm	None	No visible hydration rim.

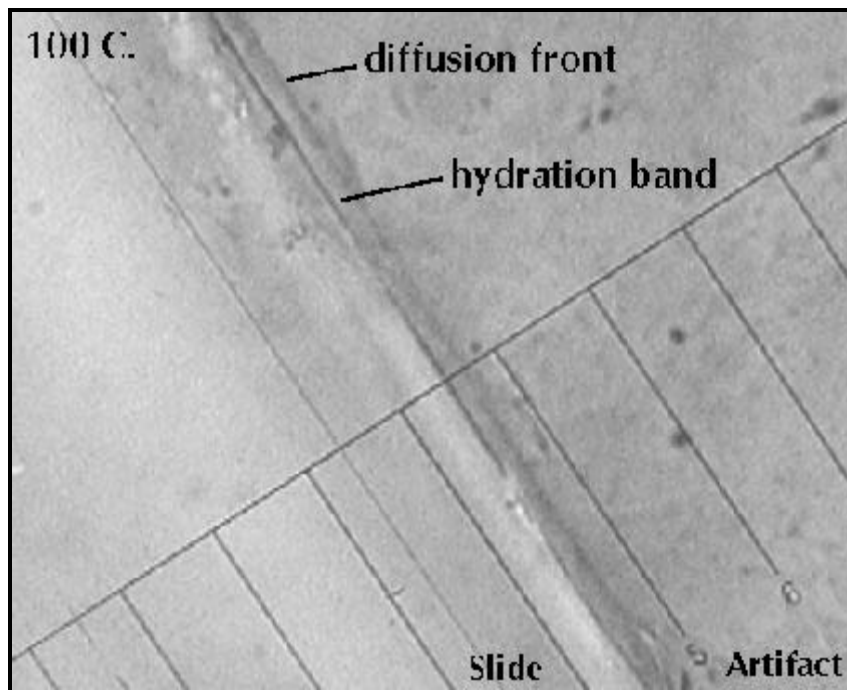


Figure 3. Magnified image of the obsidian test flake after 1 hour at 100° C. The hydration rim and diffusion front are clearly visible and there has been no change in the band width. X500; the micrometer tick marks are 18.1 μ m apart.

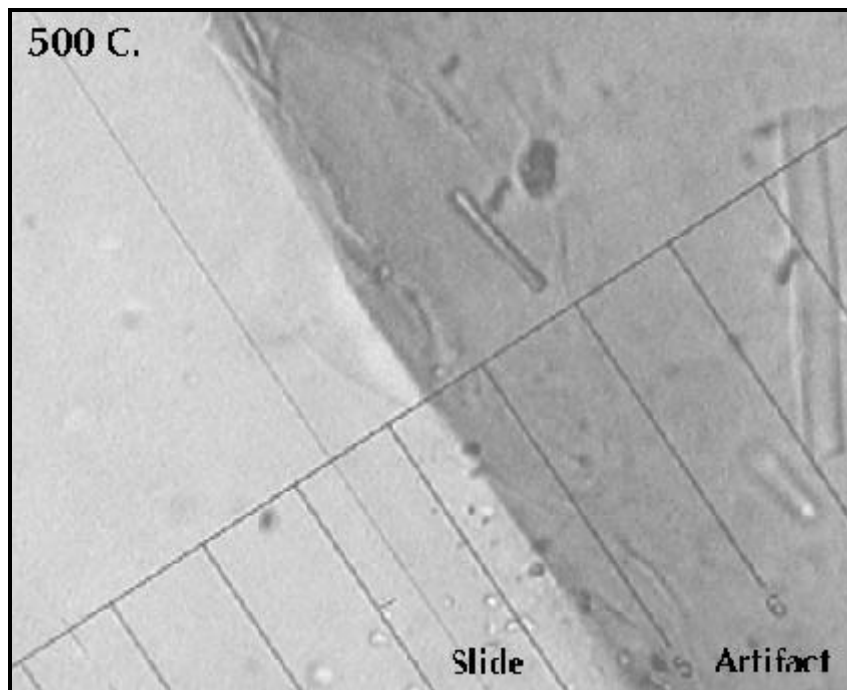


Figure 4. Magnified image of the edge of the obsidian test flake after one hour at 500° C. All traces of the hydration rim and diffusion front are gone. X500; the micrometer tick marks are 18.1 μ m apart.

It is also possible that the anomalously large hydration rims sometimes found on artifacts associated with recent obsidian sources may be due to the increase in rim width that is sometime associated with exposure to heat. Friedman (1977) reported hydration rims ranging from 0.8 - 1.2 μm from non-cultural obsidian collected at the 1,350 year-old Big Obsidian Flow in Newberry Caldera, Deschutes National Forest. Later hydration measurements of artifacts collected near the margins of the Big Obsidian Flow, however, yielded hydration rims ranging from 1.2 - 2.3 μm (Origer 1988 and 1993 – N=16; average value = $1.4 \pm 0.2 \mu\text{m}$; median = 1.3 μm). In a recent analysis of the Big Obsidian Flow quarry site (35-DS-212), Flenniken and Ozbun (1993:36) speculate that the large amounts of undiagnostic debitage found at the site may have resulted from the shattering of reduction debris by wildfires. They also noted that many of the artifacts had “crazed and crenated fractures indicative of burning”. The exposure of obsidian at the source to natural fires provides a potential explanation both to the existence of larger than anticipated hydration rims and to the presence of thermally modified reduction debris.

Recommendations

It is an absolute certainty that many prehistoric, historic, and modern natural and intentional fires have swept through large areas of the Deschutes National Forest and that these fires have affected archaeological resources within the Forest. Obsidian hydration dating will remain as one of the key chronologic methods for interpreting archaeological sites in the Deschutes National Forest and it is critical that the local effects of fire upon this analytical method be better understood. Given the fact that the heat of natural fires will affect obsidian hydration rim measurements, we recommend the implementation of further experimental and controlled studies specifically tailored to the Deschutes National Forest in order to address the following research questions:

1. What visual or petrographic (microscopic) indications of fire exposure are retained by obsidian artifacts or other artifacts or features found at archaeological sites?
2. What types of vegetation and fuel loads are necessary to reach temperatures capable of erasing *or* altering obsidian hydration rims?
3. What variables can significantly ameliorate the effects of fire, e.g., depth of burial of an artifact?
4. How much heat over what period of time is required to affect or erase hydration rims?
5. What effect does the chemical composition of the glass have upon rim survivability during heating, i.e., are temperature effects source-specific?

These research questions could be best answered with a straightforward two-stage research program:

1. *Initial experimental studies.* Controlled furnace studies (similar to the example reported here) monitoring the variables of temperature, exposure time, geologic source composition (major and trace element), and hydration band characteristics could provide valuable basic information about the effects of heat on hydration rims.
2. *Subsequent controlled burns.* Following the results of experimental oven studies of artifacts, the real-world effects of fires on obsidian hydration rims could best be monitored with controlled burns of simulated archaeological sites. During these controlled fires, the significant variables affecting the characteristics of the fire can be monitored, e.g., fuel load, vegetation type, length of burn, maximum temperature, and depth of burial. It would also be instructive to compare the fire effects of modern-day managed forests that are shaped by fire suppression methods versus those associated with pre-management forest plant communities.

Results of Analyses

X-Ray Fluorescence Analysis

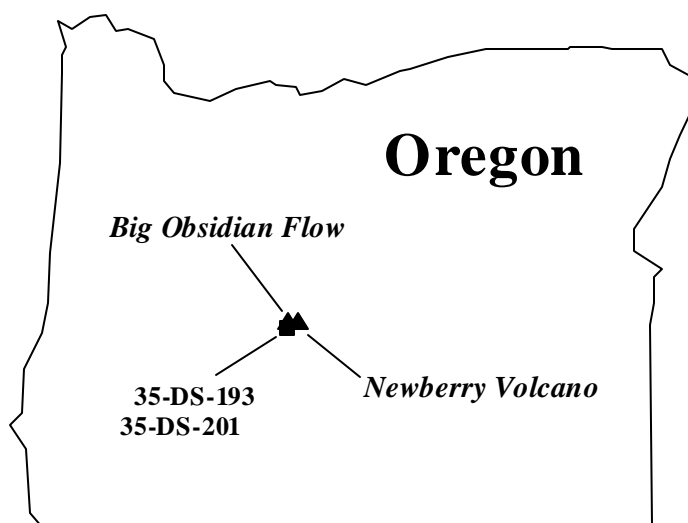
Two geochemical obsidian source groups, both of which were correlated with known geologic sources, were identified among the 51 artifacts characterized by X-ray fluorescence analysis. The locations of the sites and obsidian sources are shown in Figure 5. Analytical results are presented in Table A-1 in the Appendix and are summarized in Table 3 and Figure 7.

Table 3. Geologic sources of obsidian identified by trace element analysis. Totals include provisional source assignments.

Geologic Source	35-DS-193	35-DS-201	Total
Big Obsidian Flow	22	0	22
Newberry Volcano	10	19	29
Total XRF	32	19	51

Newberry Volcano. Twenty-nine samples were correlated with the Newberry Volcano source group, a composite source consisting of several geochemically indistinguishable Holocene obsidian flows (Central Pumice Cone, East Lake, Game Hut, and Interlake flows; see Figure 8) located within Newberry Caldera. The flows making up this geochemical group all erupted after the Mazama ashfall of about 6,850 ¹⁴C years ago (Friedman and Obradovich 1981; Macleod et al. 1995), providing a unique temporal window for the prehistoric use of the glass. The widespread prehistoric use of Newberry obsidian in the post-Mazama period is well documented in central and north-central Oregon (Skinner 1995a) in the period following the eruption of the flows and is occasionally encountered at sites in the Western Cascades and northwest Oregon (Skinner and Winkler 1991, 1994).

Figure 5. Location of archaeological sites and obsidian sources identified by trace element analyses.



Big Obsidian Flow. Twenty-two artifacts were assigned to the Big Obsidian Flow chemical group, Newberry Volcano (see figures 6 and 8). This chemical group consists of the 1,350 year-old Big Obsidian Flow and the early Holocene to late Pleistocene Buried Obsidian Flow, both located within the summit caldera of Newberry Caldera (Skinner 1983; Macleod and Sherrod 1988; Macleod et al. 1995). Trace element studies by Macleod and Sherrod (1988) and Linneman (1990:277) and unpublished analyses by Northwest Research indicate that both flows are chemically similar and comprise a single geochemical source.

There are striking differences in source use patterns between the two sites – none of the analyzed artifacts from 35-DS-201 were correlated with the Big Obsidian Flow while two-thirds of the samples from 35-DS-193 originated from that source. This difference in source use may be attributable to several factors, including:

1. The occupation of 35-DS-201 *may* predate that of 35-DS-193. Obsidian from the 1,350 year-old Big Obsidian Flow may simply not have been available when obsidian was left at 35-DS-201. Unfortunately, no measurable obsidian hydration rims that could provide evidence for recent site use were found on the artifacts from 35-DS-193. Additionally, the Big Obsidian Flow chemical group also includes the early Holocene to late Pleistocene Buried Obsidian Flow.
2. The occupation of the two sites may represent two distinct periods of use related to different site activities.



Figure 6. Big Obsidian Flow, Newberry Caldera. Photograph taken facing northeast from the summit of Paulina Peak.

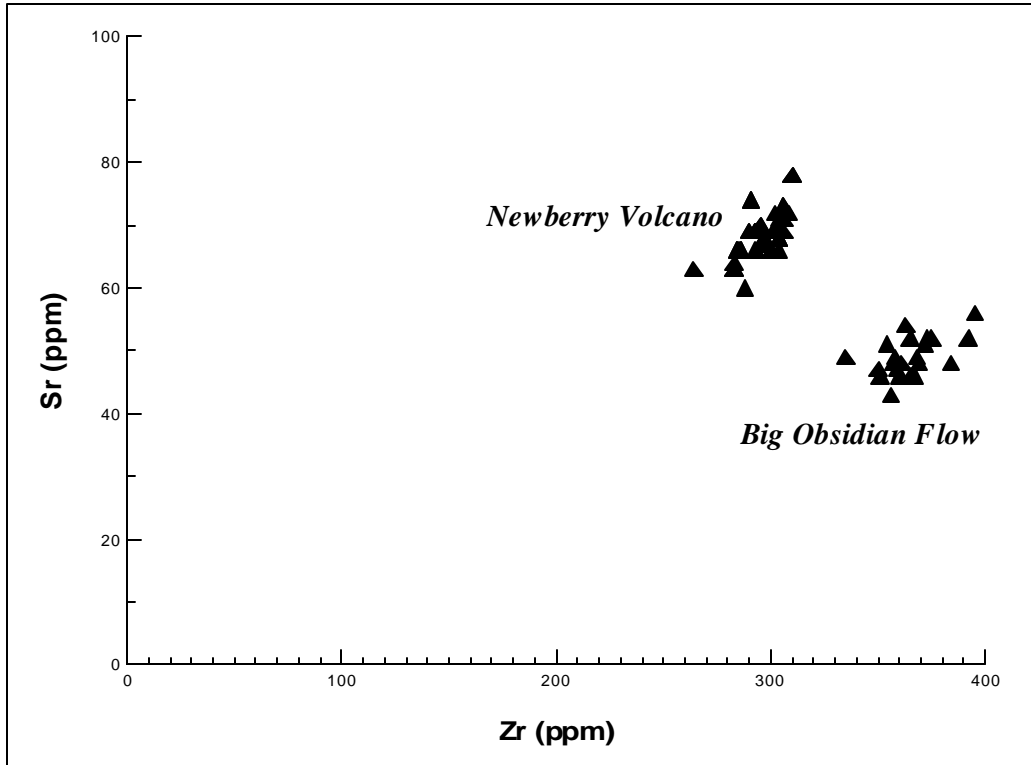


Figure 7. Scatterplot of zirconium (Zr) plotted versus strontium (Sr).

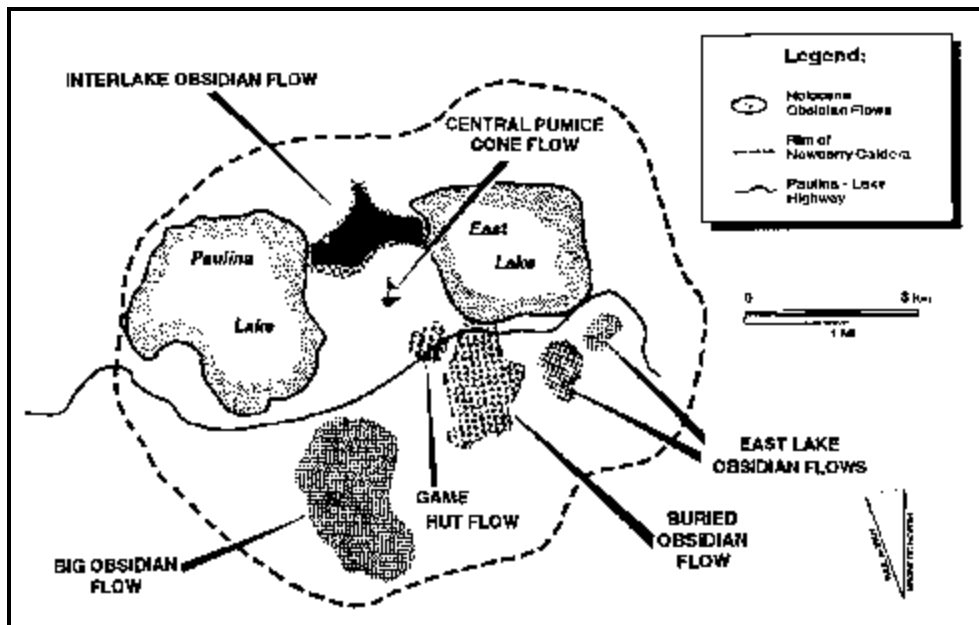


Figure 8. Obsidian sources located within Newberry Caldera, Newberry Volcano (map adapted from Skinner 1995a:4.32).

Many of the obsidian flakes from the two sites (and from many other sites in the Newberry Volcano region) are covered with a dark gray (N 4/0) to medium dark gray (N 3/0) patina that often makes trace element identification problematic. The patina is resistant to a 30 percent solution of HCl and is probably a silica-based encrustation. Silica is weakly soluble in water and the crust may have originated from the tephra-rich soils of the Newberry Volcano region. Opaline silica deposits are often found in the surface horizons of soils derived from volcanic ash (Jenny 1980:105; Rieger 1983:136–137). The presence of the patina presents problems for both the chemical characterization and obsidian hydration analysis of artifacts. The encrustation contains elevated levels of titanium (Ti), an element that is sometimes diagnostically important for sources in the Newberry Volcano region. The encrustation also makes the hydration rims more difficult to read, although well-established hydration rims remain easily identifiable when examined in thin section.

Obsidian Hydration Analysis

All 51 obsidian artifacts from the two Deschutes County sites were prepared for obsidian hydration analysis. The specimen slides are curated at the Northwest Research Obsidian Studies Laboratory under specimen accession number BO-96-33. The results of the analyses are summarized in Table 4 and are reported in Table B-1 in the Appendix.

Table 4. Summary of results of obsidian artifact hydration measurements. Totals include all measurable hydration rims.

Geologic Source	35-DS-193		35-DS-201		Total
	Total	Range (microns)	Total	Range (microns)	
Big Obsidian Flow	0	NA	0	NA	0
Newberry Volcano	3	1.9 - 2.6	2	1.6 - 3.2	5
Total	3	–	2	–	5

Only five measurable hydration rims were found on the 51 analyzed artifacts, the results of the high temperatures that the samples were exposed to during the Surveyor Fire. The estimated fire temperature of 800 to 1000° F. (426 - 537° C.) is completely consistent with the disappearance of the rims.

Of the remaining five hydration rims, there was no apparent relationship between the orientation of the obsidian sample during the fire or between the buried and surface artifacts. The heat of the fire was apparently adequate to erase hydration rims to a depth of at least six centimeters, the maximum depth from which any of the analyzed artifacts were recovered.

Although some of the obsidian artifacts burned in the Surveyor Fire were reported as melted and bubbly (Gregory 1994), we noted few visual differences between the burned flakes that were analyzed and an unburned set of control flakes that were also examined. All samples were covered, to various degrees, by

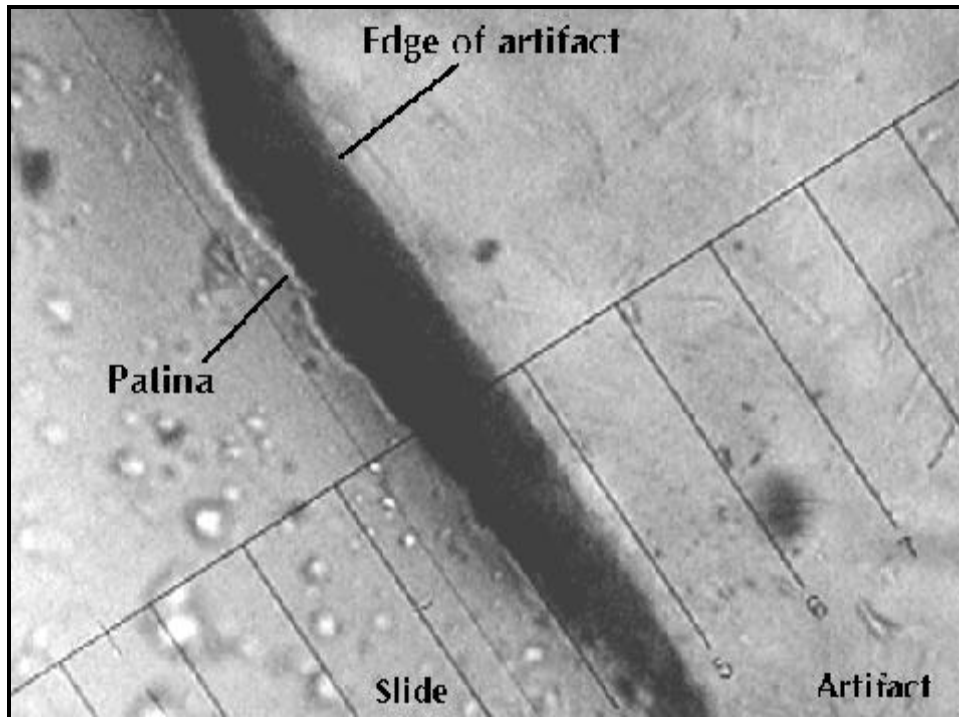


Figure 9. A cross-section of a typical burned obsidian flake (specimen no. 14). In this artifact, the hydration rim that would normally be visible along the edge of the artifact has been completely erased.

the gray encrustation that was previously described. In post-burn samples, the patina was very thin and it appeared that thicker deposits found on the control samples may have spalled off during the heating of the artifacts. After burning, the encrustation became much more difficult to physically remove from the sample than from the unburned control sample. It is likely that the “gun metal” luster report by Gregory (1994) for Surveyor Fire artifacts refers to the well-baked patina on the surface of the items.

Under the microscope, many of the artifacts lacking hydration rims still retained a faint blue hue under plain light that was suggestive of the former presence of a rim. All traces of diffusion fronts, however, were completely gone. The baked encrustation that covered many of the artifact surfaces also made the hydration rims more difficult to measure (Figure 9). The opaque patina sometimes made it difficult to accurately locate and measure the exterior surface of the hydration rim.

Although hydration rates have been posited for obsidian from the Big Obsidian Flow and the Newberry Volcano source groups (see Table 5), we caution against their application at 35-DS-196 and 35-DS-201. The results of the heating experiments described earlier in this report suggest that recorded rim measurements may be greater than those originally formed on the artifacts.

Table 5. Different hydration rates reported in the literature for obsidian sources identified in the current investigation.

Source	Hydration Rate	Comments	Reference
Big Obsidian Flow	0.7 μ^2 / 1000 yrs ^A 0.8 μ^2 / 1000 yrs ^B	Hydration rate slower than other Newberry Caldera sources ^{A B} ; slower rate also supported by archaeological evidence ^C .	^A Friedman 1977 ^B Friedman and Obradovich 1981 ^C Skinner 1995b
Newberry Volcano	2.9 μ^2 / 1000 yrs ^A 3.0 μ^2 / 1000 yrs ^B 2.8 μ^2 / 1000 yrs ^C	All flows post-Mazama in age; maximum hydration rim measurements artifacts correlated with the Newberry Volcano source group are approximately 5.2 - 5.3 μm ^D .	^A Friedman 1977 ^B Friedman and Obradovich 1981 ^C Connolly and Byram 1992 ^D Skinner 1995b

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Appendix

**Results of X-Ray Fluorescence
and Obsidian Hydration Analysis**

Northwest Research Obsidian Studies Laboratory

Table A-1. Results of XRF Studies: 35-DS-193 and 35-DS-201, Surveyor Fire Rehabilitation Project, Deschutes County, Oregon

Site	Spec. No.	Catalog No.	Trace Element Concentrations											Ratios		Artifact Source/Chemical Type
			Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	Fe ₂ O ₃ ^T	Fe:Mn	Fe:Ti	
35-DS-201	1	35DS201-1	70	18	145	69	45	290	18	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 8	4	3	9	3	8	2	NM	NM	NM	NM			
35-DS-201	2	35DS201-2	55	22	143	66	44	300	18	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 7	4	3	9	3	8	2	NM	NM	NM	NM			
35-DS-201	3	35DS201-3	63	26	154	73	47	306	15	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 8	4	4	9	3	8	2	NM	NM	NM	NM			
35-DS-201	4	35DS201-4	58	22	149	68	44	297	18	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 7	4	3	9	3	8	2	NM	NM	NM	NM			
35-DS-201	5	35DS201-5	62	15	144	70	42	295	18	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 7	4	3	9	3	8	2	NM	NM	NM	NM			
35-DS-201	6	35DS201-6	57	19	139	66	46	286	18	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 7	4	3	9	3	8	2	NM	NM	NM	NM			
35-DS-201	7	35DS201-7	69	21	152	68	47	304	17	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 7	4	3	9	3	8	2	NM	NM	NM	NM			
35-DS-201	8	35DS201-8	61	20	155	69	45	304	16	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 7	4	3	9	3	8	2	NM	NM	NM	NM			
35-DS-201	9	35DS201-9	54	16	134	66	44	284	15	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 7	4	3	9	3	8	2	NM	NM	NM	NM			
35-DS-201	10	35DS201-10	63	19	145	69	45	302	20	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 7	4	3	9	3	8	2	NM	NM	NM	NM			
35-DS-201	11	35DS201-11	64	21	143	67	43	296	22	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 7	4	3	9	3	8	2	NM	NM	NM	NM			
35-DS-201	12	35DS201-12	83	23	165	78	45	310	23	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 8	4	4	9	3	8	2	NM	NM	NM	NM			
35-DS-201	13	35DS201-13	53	22	142	69	41	293	18	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 7	4	3	9	3	8	2	NM	NM	NM	NM			
35-DS-201	14	35DS201-14	73	19	146	74	42	291	17	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 8	5	4	9	3	8	2	NM	NM	NM	NM			
35-DS-201	15	35DS201-15	76	17	139	63	42	283	18	NM	NM	NM	NM	NM	NM	Newberry Volcano
			± 7	4	3	9	3	8	2	NM	NM	NM	NM			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.

NA = Not available; NM = Not measured.; * = Small sample.

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Table A-1. Results of XRF Studies: 35-DS-193 and 35-DS-201, Surveyor Fire Rehabilitation Project, Deschutes County, Oregon

Site	Spec. No.	Catalog No.	Trace Element Concentrations											Ratios		Artifact Source/Chemical Type
			Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	Fe ₂ O ₃ ^T	Fe:Mn	Fe:Ti	
35-DS-201	16	35DS201-16	59 ± 7	20 4	152 3	66 9	43 3	293 8	14 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano
35-DS-201	17	35DS201-17	45 ± 8	18 4	141 3	66 9	46 3	285 8	17 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano
35-DS-201	18	35DS201-18	60 ± 8	21 4	153 3	72 9	47 3	308 8	20 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano
35-DS-201	19	35DS201-19	53 ± 7	19 4	152 3	69 9	47 3	306 8	20 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano
35-DS-193	20	35DS193-1	65 ± 7	22 4	119 3	51 9	58 3	372 8	18 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Big Obsidian Flow
35-DS-193	21	35DS193-2	65 ± 7	21 4	148 3	66 9	48 3	304 8	20 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano
35-DS-193	22	35DS193-3	48 ± 7	19 4	133 3	60 9	44 3	288 8	19 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano
35-DS-193	23	35DS193-4	68 ± 8	19 4	152 4	71 9	49 3	306 8	16 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano
35-DS-193	24	35DS193-5	69 ± 7	17 4	148 3	68 9	47 3	304 8	20 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano
35-DS-193	25	35DS193-6	84 ± 8	25 5	142 4	56 9	67 3	395 9	18 2	1192 97	373 47	NM NM	1.72 0.11	45.4	46.3	Big Obsidian Flow
35-DS-193	26	35DS193-7	65 ± 7	22 4	149 3	69 9	45 3	301 8	22 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano
35-DS-193	27	35DS193-8	61 ± 8	20 4	146 4	69 9	48 3	293 8	15 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano
35-DS-193	28	35DS193-9	59 ± 7	17 4	133 3	64 9	43 3	283 8	15 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano
35-DS-193	29	35DS193-10	69 ± 7	23 4	159 3	71 9	47 3	304 8	19 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano
35-DS-193	30	35DS193-11	71 ± 10	17 5	133 4	63 10	41 3	264 9	12 3	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano *

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide. NA = Not available; NM = Not measured.; * = Small sample.

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Table A-1. Results of XRF Studies: 35-DS-193 and 35-DS-201, Surveyor Fire Rehabilitation Project, Deschutes County, Oregon

Site	Spec. No.	Catalog No.	Trace Element Concentrations											Ratios		Artifact Source/Chemical Type
			Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	Fe ₂ O ₃ ^T	Fe:Mn	Fe:Ti	
35-DS-193	31	35DS193-12	61 ± 8	26 4	171 4	72 9	45 3	302 8	20 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Newberry Volcano
35-DS-193	32	35DS193-13	75 ± 7	21 4	119 3	46 9	57 3	367 8	19 2	1182 97	376 47	NM NM	1.81 0.11	47.2	48.9	Big Obsidian Flow
35-DS-193	33	35DS193-14	77 ± 7	27 4	124 3	52 9	60 3	375 8	19 2	1345 97	413 48	NM NM	2.07 0.11	48.4	49.1	Big Obsidian Flow
35-DS-193	34	35DS193-15	67 ± 7	20 4	120 3	48 9	58 3	369 8	20 2	1313 97	426 48	NM NM	1.97 0.11	44.6	48.0	Big Obsidian Flow
35-DS-193	35	35DS193-16	72 ± 8	22 4	121 3	46 9	58 3	365 8	21 2	1285 97	378 47	NM NM	1.81 0.11	47.1	45.2	Big Obsidian Flow
35-DS-193	36	35DS193-17	75 ± 7	18 4	120 3	49 9	53 3	358 8	19 2	NM NM	NM NM	NM NM	NM	NM	Big Obsidian Flow	
35-DS-193	37	35DS193-18	58 ± 7	17 4	118 3	48 9	55 3	361 8	18 2	NM NM	NM NM	NM NM	NM	NM	Big Obsidian Flow	
35-DS-193	38	35DS193-19	83 ± 8	25 4	137 3	52 9	56 3	392 8	19 2	964 96	313 47	NM NM	1.52 0.11	49.3	50.7	Big Obsidian Flow
35-DS-193	39	35DS193-20	80 ± 7	16 4	124 3	49 9	56 3	368 8	19 2	NM NM	NM NM	NM NM	NM	NM	Big Obsidian Flow	
35-DS-193	40	35DS193-21	63 ± 7	13 4	114 3	46 9	55 3	351 8	18 2	1323 97	397 48	NM NM	2.05 0.11	50.0	49.3	Big Obsidian Flow
35-DS-193	41	35DS193-22	74 ± 7	19 4	119 3	54 9	55 3	363 8	19 2	NM NM	NM NM	NM NM	NM	NM	Big Obsidian Flow	
35-DS-193	42	35DS193-23	68 ± 8	21 4	120 3	43 9	55 3	356 8	16 2	729 96	232 47	NM NM	0.89 0.11	43.0	40.5	Big Obsidian Flow
35-DS-193	43	35DS193-24	79 ± 7	24 4	134 3	48 9	62 3	384 8	18 2	1274 97	381 48	NM NM	1.90 0.11	48.8	47.7	Big Obsidian Flow
35-DS-193	44	35DS193-25	80 ± 7	15 4	121 3	47 9	55 3	359 8	20 2	820 96	308 47	NM NM	1.32 0.11	44.0	52.0	Big Obsidian Flow
35-DS-193	45	35DS193-26	67 ± 7	18 4	116 3	51 9	56 3	354 8	19 2	NM NM	NM NM	NM NM	NM	NM	Big Obsidian Flow	

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide. NA = Not available; NM = Not measured.; * = Small sample.

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Table A-1. Results of XRF Studies: 35-DS-193 and 35-DS-201, Surveyor Fire Rehabilitation Project, Deschutes County, Oregon

Site	Spec. No.	Catalog No.	Trace Element Concentrations											Ratios		Artifact Source/Chemical Type
			Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	Fe ₂ O ₃ ^T	Fe:Mn	Fe:Ti	
35-DS-193	46	35DS193-27	65 ± 8	18 4	129 3	52 9	56 3	373 8	18 2	NM NM	NM NM	NM NM	NM NM	NM	NM	Big Obsidian Flow
35-DS-193	47	35DS193-28	78 ± 7	23 4	123 3	52 9	59 3	365 8	20 2	1568 97	455 48	NM NM	2.19 0.11	45.8	44.6	Big Obsidian Flow
35-DS-193	48	35DS193-29	65 ± 7	20 4	118 3	46 9	57 3	360 8	21 2	1249 97	379 47	NM NM	1.82 0.11	47.1	46.7	Big Obsidian Flow
35-DS-193	49	35DS193-30	62 ± 8	16 4	105 3	49 9	50 3	335 8	20 2	848 96	296 47	NM NM	1.15 0.11	40.7	44.4	Big Obsidian Flow
35-DS-193	50	35DS193-31	62 ± 7	18 4	120 3	48 9	55 3	357 8	20 2	1492 97	439 48	NM NM	2.08 0.11	45.4	44.5	Big Obsidian Flow
35-DS-193	51	35DS193-32	66 ± 7	18 4	117 3	47 9	51 3	350 8	22 1	1538 97	416 48	NM NM	2.13 0.11	49.3	44.2	Big Obsidian Flow
NA	RGM-1	RGM-1	38 ± 7	21 4	150 3	104 9	27 3	224 8	14 1	1788 97	286 48	NM NM	2.00 0.11	71.3	35.8	RGM-1 Reference Standard

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
 NA = Not available; NM = Not measured.; * = Small sample.

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Table B-1. Obsidian Hydration Results and/or Sample Provenience: 35-DS-193 and 35-DS-201, Deschutes County, Oregon

Site	Spec. No.	Catalog No.	Sample Provenience	Artifact Type ^A	Artifact Source	Hydration Rims			Comments ^B		
						Rim 1	Rim 2	Rim 3			
35-DS-201	1	35DS201-1	36m @ 257 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	REC	PAT
35-DS-201	2	35DS201-2	36m @ 257 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	REC	PAT
35-DS-201	3	35DS201-3	36m @ 257 degrees	Surface	DEB	Newberry Volcano	3.2 ± 0.1	NM ± NM	NM ± NM	REC	DFV
35-DS-201	4	35DS201-4	36m @ 257 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	REC	PAT
35-DS-201	5	35DS201-5	36m @ 257 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-201	6	35DS201-6	36m @ 257 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	UNR
35-DS-201	7	35DS201-7	36m @ 257 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	UNR
35-DS-201	8	35DS201-8	36m @ 257 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	REC	PAT
35-DS-201	9	35DS201-9	36m @ 257 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	UNR
35-DS-201	10	35DS201-10	36m @ 257 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	UNR
35-DS-201	11	35DS201-11	36m @ 257 degrees	0-3 cm	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	REC	PAT
35-DS-201	12	35DS201-12	36m @ 257 degrees	3-6 cm	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	UNR
35-DS-201	13	35DS201-13	36m @ 257 degrees	3-6 cm	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	REC	PAT
35-DS-201	14	35DS201-14	36m @ 257 degrees	3-6 cm	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-201	15	35DS201-15	36m @ 257 degrees	3-6 cm	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	REC	PAT
35-DS-201	16	35DS201-16	36m @ 257 degrees	6-9 cm	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-201	17	35DS201-17	36m @ 257 degrees	6-9 cm	DEB	Newberry Volcano	1.6 ± 0.1	NM ± NM	NM ± NM	DFV	--
35-DS-201	18	35DS201-18	36m @ 257 degrees	6-9 cm	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	UNR
35-DS-201	19	35DS201-19	36m @ 257 degrees	6-9 cm	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	REC	PAT
35-DS-193	20	35DS193-1	132m @ 12 degrees	Surface	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	UNR
35-DS-193	21	35DS193-2	132m @ 12 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	22	35DS193-3	132m @ 12 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	UNR
35-DS-193	23	35DS193-4	132m @ 12 degrees	Surface	DEB	Newberry Volcano	2.0 ± 0.1	NM ± NM	NM ± NM	PAT	DFV

^A BIF = Biface; COR = Core; DEB = Debitage; PPT = Projectile Point; UTF = Utilized Flake

^B See text for explanation of comment abbreviations

NA = Not Available; NM = Not Measured; * = Small sample

Northwest Research Obsidian Studies Laboratory

Table B-1. Obsidian Hydration Results and/or Sample Provenience: 35-DS-193 and 35-DS-201, Deschutes County, Oregon

Site	Spec. No.	Catalog No.	Sample Provenience	Artifact Type ^A	Artifact Source	Hydration Rims			Comments ^B		
						Rim 1	Rim 2	Rim 3			
35-DS-193	24	35DS193-5	132m @ 12 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	25	35DS193-6	132m @ 12 degrees	Surface	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	26	35DS193-7	132m @ 12 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	27	35DS193-8	132m @ 12 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	28	35DS193-9	132m @ 12 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	29	35DS193-10	132m @ 12 degrees	Surface	DEB	Newberry Volcano	NM ± NM	NM ± NM	NM ± NM	PAT	UNR
35-DS-193	30	35DS193-11	132m @ 12 degrees	0-3 cm	DEB	Newberry Volcano *	2.6 ± 0.1	NM ± NM	NM ± NM	DFV	PAT
35-DS-193	31	35DS193-12	132m @ 12 degrees	3-6 cm	DEB	Newberry Volcano	1.9 ± 0.0	NM ± NM	NM ± NM	DFV	PAT
35-DS-193	32	35DS193-13	58m @ 72 degrees	Surface	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	33	35DS193-14	58m @ 72 degrees	Surface	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	34	35DS193-15	58m @ 72 degrees	Surface	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	35	35DS193-16	58m @ 72 degrees	Surface	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	36	35DS193-17	58m @ 72 degrees	Surface	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	37	35DS193-18	58m @ 72 degrees	Surface	UTF	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	38	35DS193-19	58m @ 72 degrees	Surface	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	39	35DS193-20	58m @ 72 degrees	Surface	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	40	35DS193-21	58m @ 72 degrees	Surface	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	41	35DS193-22	58m @ 72 degrees	Surface	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	42	35DS193-23	58m @ 72 degrees	0-3 cm	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	43	35DS193-24	58m @ 72 degrees	0-3 cm	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	44	35DS193-25	58m @ 72 degrees	0-3 cm	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	UNR
35-DS-193	45	35DS193-26	58m @ 72 degrees	0-3 cm	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	46	35DS193-27	58m @ 72 degrees	0-3 cm	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH

^A BIF = Biface; COR = Core; DEB = Debitage; PPT = Projectile Point; UTF = Utilized Flake

^B See text for explanation of comment abbreviations

NA = Not Available; NM = Not Measured; * = Small sample

Northwest Research Obsidian Studies Laboratory

Table B-1. Obsidian Hydration Results and/or Sample Provenience: 35-DS-193 and 35-DS-201, Deschutes County, Oregon

Site	Spec. No.	Catalog No.	Sample Provenience	Artifact Type ^A	Artifact Source	Hydration Rims			Comments ^B		
						Rim 1	Rim 2	Rim 3			
35-DS-193	47	35DS193-28	58m @ 72 degrees	3-6 cm	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	48	35DS193-29	58m @ 72 degrees	3-6 cm	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	49	35DS193-30	58m @ 72 degrees	6-9 cm	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	50	35DS193-31	58m @ 72 degrees	6-9 cm	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH
35-DS-193	51	35DS193-32	58m @ 72 degrees	6-9 cm	DEB	Big Obsidian Flow	NM ± NM	NM ± NM	NM ± NM	PAT	NVH

^A BIF = Biface; COR = Core; DEB = Debitage; PPT = Projectile Point; UTF = Utilized Flake

^B See text for explanation of comment abbreviations

NA = Not Available; NM = Not Measured; * = Small sample

Abbreviations and Definitions Used in the Comments Column

A, B, C - 1st, 2nd, and 3rd cuts, respectively.

BEV - (Beveled). Artifact morphology or cut configuration resulted in a beveled thin section edge.

BRE - (BREak). The thin section cut was made across a broken edge of the artifact. Resulting hydration measurements may reveal when the artifact was broken, relative to its time of manufacture.

DES - (DEStroyed). The artifact or flake was destroyed in the process of thin section preparation. This sometimes occurs during the preparation of extremely small items, such as pressure flakes.

DFV - (Diffusion Front Vague). The diffusion front, or the visual boundary between hydrated and unhydrated portions of the specimen, are poorly defined. This can result in less precise measurements than can be obtained from sharply demarcated diffusion fronts. The technician must often estimate the hydration boundary because a vague diffusion front often appears as a relatively thick, dark line or a gradation in color or brightness between hydrated and unhydrated layers.

DIS - (DIScontinuous). A discontinuous or interrupted hydration rind was observed on the thin section.

HV - (Highly Variable). The hydration rind exhibits variable thickness along continuous surfaces. This variability can occur with very well- defined bands as well as those with irregular or vague diffusion fronts.

IRR - (IRRegular). The surfaces of the thin section (the outer surfaces of the artifact) are uneven and measurement is difficult.

ISO - (1 Surface Only). Hydration was observed on only one surface or side of the thin section.

NOT - (NOT obsidian). Petrographic characteristics of the artifact or obsidian specimen indicate that the specimen is not obsidian.

NVH - (No Visible Hydration). No hydration rind was observed on one or more surfaces of the specimen. This does not mean that hydration is absent, only that hydration was not observed. Hydration rinds smaller than one micron often are not birefringent and thus cannot be seen by optical microscopy. "NVH" may be reported for the manufacture surface of a tool while a hydration measurement is reported for another surface, e.g. a remnant ventral flake surface.

OPA - (OPAque). The specimen is too opaque for measurement and cannot be further reduced in thickness.

PAT - (PATinated). This description is usually noted when there is a problem in measuring the thickness of the hydration rind, and refers to the unmagnified surface characteristics of the artifact, possibly indicating the source of the measurement problem. Only extreme patination is normally noted.

REC - (RECut). More than one thin section was prepared from an archaeological specimen. Multiple thin sections are made if preparation quality on the initial specimen is suspect or obviously poor. Additional thin sections may also be prepared if it is perceived that more information concerning an artifact's manufacture or use can be obtained.

UNR - (UNReadable). The optical quality of the hydration rind is so poor that accurate measurement is not possible. Poor thin section preparation is not a cause.

WEA - (WEAthered). The artifact surface appears to be damaged by wind erosion or other mechanical action.