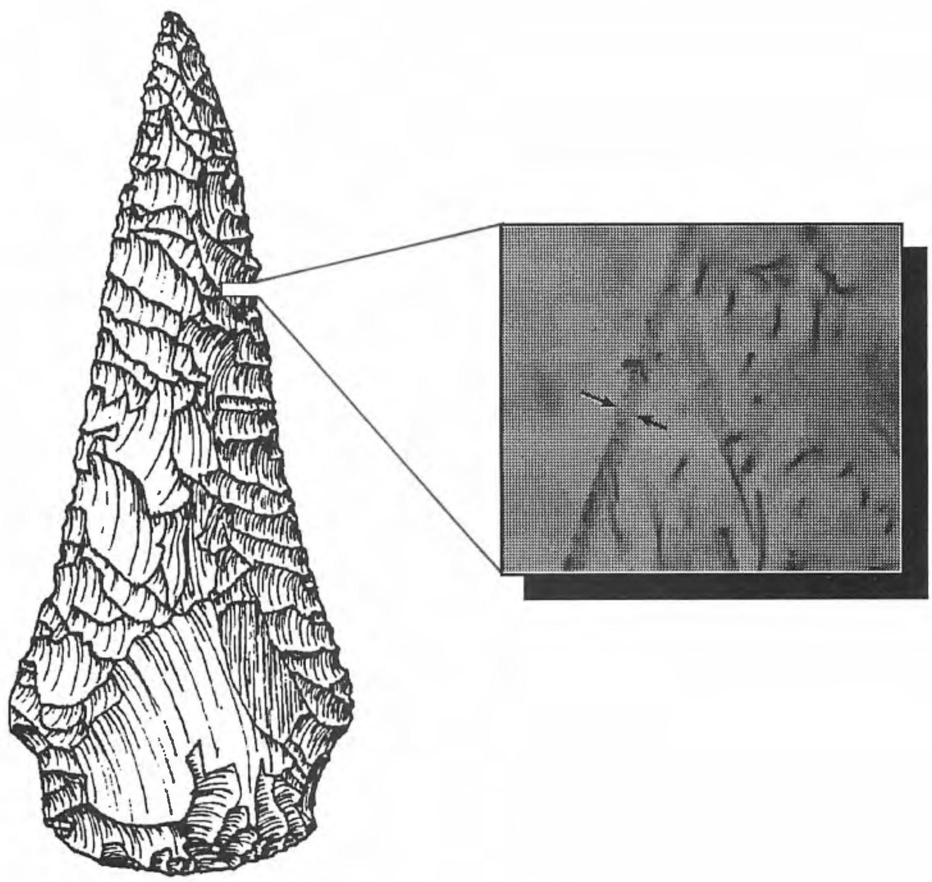
Obsidian Hydration Studies in Central Oregon: The Results of the First Cut



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Obsidian Hydration Studies in the Central Oregon Corridor: Results of the First Cut

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Abstract

Over 6,500 obsidian artifacts from 84 central Oregon archaeological sites were chemically characterized and examined for obsidian hydration rims during the PGT-PG&E Pipeline Expansion Project. Carbon for radiocarbon determinations is lacking in many central Oregon sites and obsidian hydration data often provide the only available chronometric avenue.

This initial examination primarily addresses four topics: 1) relative hydration rates of different sources (using Mazama tephra as a temporal control); 2) preliminary calculated rates for several sources; 3) anomalous hydration measurements associated with the 1,350-year old Big Obsidian Flow in Newberry Caldera, and; 4) diachronic rates of prehistoric obsidian production at major Oregon sources.

Although we caution against the overinterpretation of obsidian hydration data and the haphazard application of hydration rates - the variables that affect the intrasite patterning of hydration measurements are still not well understood - we remain optimistic in our initial assessment of the use of the method in central Oregon. When carefully used, especially in conjunction with other chronologic data, the use of obsidian hydration measurements for relative dating and the determination of approximate absolute ages will prove to be an important chronologic tool for the interpretation of central Oregon's past.

INTRODUCTION

In addition to extensive obsidian characterization studies, complementary obsidian hydration studies were also adopted as an important chronologic component of the Project research strategies. In Oregon and California, the Pipeline corridor passes through some of the most obsidian-rich areas of the world. The availability of obsidian hydration measurements with which to evaluate intersite and intrasite temporal relationships was considered an essential research element and an invaluable source of chronologic information for the evaluation of Project sites.

Table 1. PEP obsidian artifacts selected for obsidian hydration studies.

State	Number of Sites	Obsidian Debitage	Obsidian Tools	Non-Artifacts	Total
Idaho	1	2	0	0	2
Oregon	73	5,177	997	1	6,175
California	49	1,952	552	2	2,505
Total	123	7,129	1,549	2	8,682

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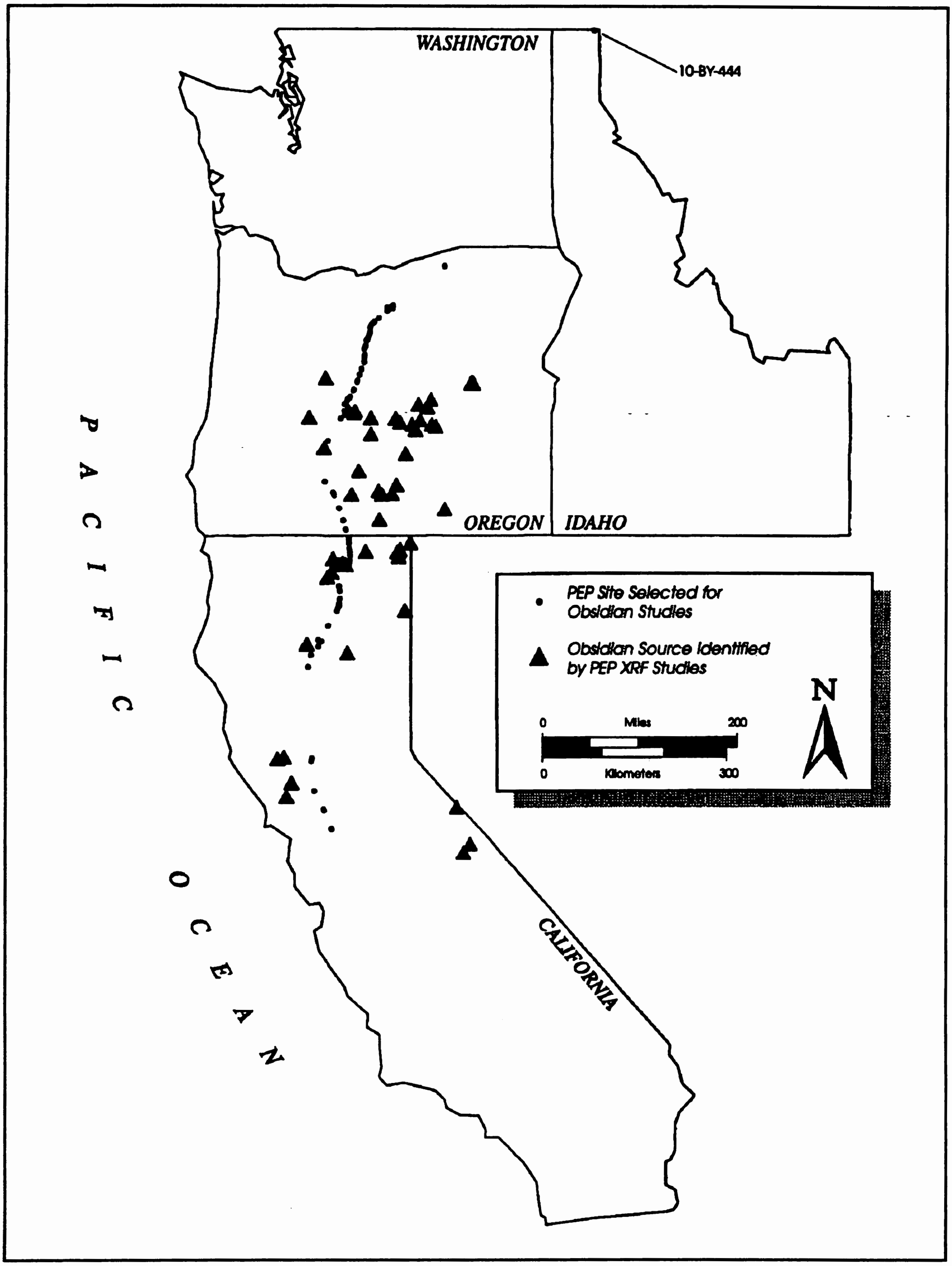


Figure 1. Distribution of Project sites selected for obsidian hydration studies.

A total of 8,682 obsidian samples from 123 Idaho, Oregon, and California archaeological sites were selected for obsidian hydration measurements as a part of the Pipeline Expansion Project testing and data recovery activities. Of the samples that were prepared for obsidian hydration analysis, 7,409 yielded measurable hydration rims. The geologic sources of all samples that were prepared for obsidian hydration measurements were determined through trace element characterization techniques and, for a limited number of samples, through visual characterization methods.

In this paper, we take an early look at the results of these extensive obsidian hydration studies in Oregon. These topics include anomalous hydration measurements associated with the 1,350-year old Big Obsidian Flow in Newberry Caldera, the relative hydration rates of different sources (using Mazama tephra as a temporal control), preliminary calculated rates of hydration for several sources, and obsidian production rates over time for major sources. We end by suggesting some future directions of obsidian hydration research in central Oregon.

Principles of Obsidian Hydration Dating Methods

First announced in the geological literature in 1958, 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 1958, 1960). The technique was initially developed in conjunction with geologic studies of the hydration of natural glass and the formation of perlite (Friedman et al. 1966). Its application to archaeological chronologic problems was quickly recognized, however, and research concerning the effect of different variables on the rate of hydration has continued to the present day by Friedman and others. Numerous descriptions of the obsidian hydration dating method and its application to archaeological problems have appeared since the inception of the method (Friedman 1977; Friedman and Long 1976; Friedman and Obradovich 1981; Friedman and Trembour, 1978, 1983; Michels and Tsong 1980; Trembour and Friedman 1984; see Skinner and Tremaine 1993 for others).

As soon as 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 micron, it becomes recognizable as a birefringent rim when observed as a thin section under a microscope. Hydration rims formed on artifacts vary in width from less than one micron for items from the historic period to nearly 30 μm for early sites in Africa (Michels et al. 1983a; Origer 1989).

Once a hydration layer has been measured, it can be used for determining 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 that are recovered in association with materials whose cultural age is known or whose age can be radiometrically determined, usually through radiocarbon dating methods (Meighan 1976). In special circumstances, the cultural age of the artifact can sometimes be directly determined through thermoluminescence or fission-track geochronologic methods (Fleischer et al. 1975; Huntley and Bailey 1978). 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. 1980; Michels et al. 1983b; Tremaine 1989, 1993).

Variables Affecting the Rate of Hydration

The formation of the hydration rim is affected not only by time but also by a number of different factors, most notably the past temperature of the artifact and its chemical composition (Figure 2).

Temperature. Friedman and Smith, in their 1960 article describing the obsidian hydration dating method recognized that temperature was an important variable affecting the rate of hydration. Obsidian artifacts from tropical environments were found to hydrate at a much greater rate than artifacts recovered from the Arctic. Later research by a number of investigators comparing obsidian that had been buried, recovered from the surface, or exposed to heat from natural thermal areas confirmed the early recognition of the significance of temperature on the hydration rate (Friedman et al. 1966; Layton 1973; Friedman 1976; Friedman and Long 1976; Ericson 1981:28-31; Friedman and Obradovich 1981). The considerable effect of temperature increase on the diffusion rate is estimated by Friedman and Trembour (1983) to be about 10 percent for each 1° C. It is clear from these data that the most effective use of obsidian hydration measurements are made among artifacts that have experienced very similar thermal histories.

It was originally anticipated that the study of temperature regimes at the specific sites in which artifacts for hydration studies were recovered would make it possible to determine effective hydration temperatures (EHT) that could be used to calculate the rate of hydration at these precise localities (Friedman and Long 1976; Friedman and Trembour 1983). The use of buried diffusion cells to record long-term temperature and humidity information has been used in a few studies but has yet to be adopted on a widespread basis or effectively integrated into routine obsidian hydration research plans (Friedman and Trembour 1983; Trembour et al. 1988).

Chemical Composition. The chemical composition of volcanic glass was recognized by Friedman and Smith in 1960 to be a variable that might affect the rate of diffusion of water into the surface of obsidian. Their suggestion, despite later supporting archaeological evidence (Aiello 1969; Clark 1961; Kimberlin 1971), was largely ignored until the mid-1970's when it finally became widely accepted that the chemical composition of the glass was often the most important variable influencing the rate of hydration. Until this time, it was assumed that meaningful regional rates of hydration, applicable over large geographic areas with similar temperature and environmental conditions, were possible. When the importance of composition was widely recognized, the concept of source-specific obsidian

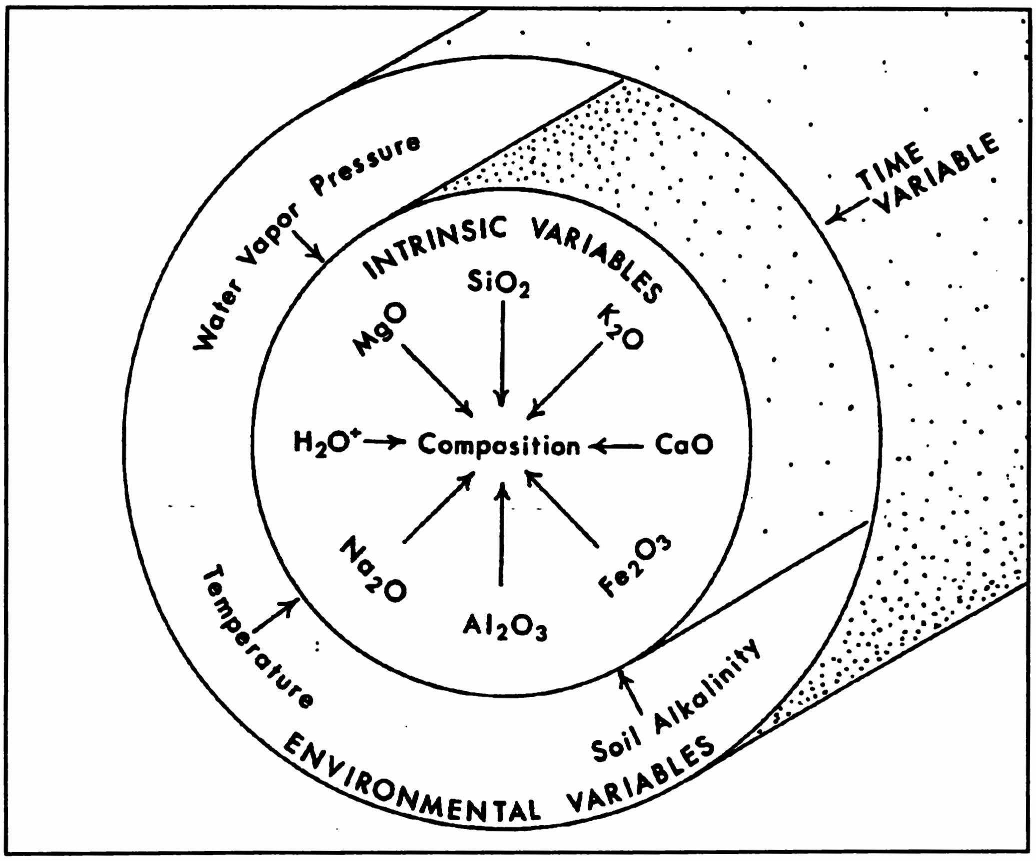


Figure 2. Major variables affecting the rate of hydration (from Skinner 1983:45)

characterization studies was adopted for most archaeological obsidian hydration studies (Ericson 1975). Using the source-specific approach, the geologic source (e.g., the chemical composition) is determined through characterization studies prior to analysis and interpretation of hydration data. Attempts by Friedman and Long (1976) to calculate hydration rates using a combination of EHT and major element or refractive index data were encouraging but were not actively pursued in later studies.

Intrinsic Water Content: A New Complication. Very recent research by Stevenson et al. (1993) indicates, however, that the source-specific concept may contain a serious flaw. In typical characterization studies, trace element abundances are used to identify the source of an artifact, and, in most sources, the trace (and major) element composition of the glass is found to be very consistent throughout the source. Using IR (infrared) spectroscopy, Stevenson and his associates examined the intrinsic water content of obsidians from several sources in the Coso Volcanic Field of California and found considerable intrasource variability at each location. Previous experimental studies examining hydration rim development at elevated temperatures (110° and 240° C.) have shown a strong positive correlation between intrinsic water content and hydration rate (Jambon 1979; Mazer et al. 1991, 1992). It is also well known that tektites, natural glasses with very low water content, do not develop hydration rims, an observation supporting the influence of water on hydration (Friedman 1958; LaMarche et al. 1984; Lee et al. 1984). If intrinsic water content is a significant factor influencing the rate of hydration **and** if intrinsic water content is not consistent throughout otherwise chemically homogeneous flows, the potential implications to obsidian hydration studies are considerable. Stevenson et al. (1993:380-381) summarize their results and the implications of their findings:

> The results provide important information for researchers using obsidian hydration dating for archaeological or geological studies. The most significant finding is that the intrinsic water content of obsidian samples is homogeneous within hand sample-sized volumes, but inhomogeneous on larger scales. This result indicates that obsidian samples from a quarry will hydrate at different rates. Previously, it was assumed that trace element chemistry could be used to identify samples from individual obsidian flows and that these obsidian samples hydrated at identical rates. While trace element chemistry ... is useful in sourcing obsidian samples, there is no apparent correlation between trace element chemistry and water contents in an obsidian flow.
>
> As a result, the assignment of prehistoric obsidian artifacts to geological locations using XRF analysis or other trace element characterization methods will not provide the required control over the variation in water contents.

The authors go on to conclude that multiple hydration rates would be possible for items from a single geologic source and propose that IR water determinations be made for individual artifacts prior to obsidian hydration dating.

At this point, the potential impact of this research on obsidian hydration studies has yet to be evaluated. Because of the importance of the implications of the work on previous and future obsidian hydration investigations, further studies of other obsidian sources and the role of intrinsic water and hydration within more normal, low-temperature environments are needed.

Relative Humidity. The humidity (i.e., water vapor pressure) is considered by most researchers to have little or no effect on the rate of hydration. Ambrose (1976), however, cites experimental studies in which the surface adsorption of water was clearly shown to be dependent on humidity. More recently, Friedman et al. (1990) write:

> We have determined that the hydration rate of obsidian under surficial conditions is a function of relative humidity (rH). Relative humidity measurements of soil at various sites, integrated over a one year time-span, show that the soil rH is approximately 100% at depth greater than about 10 cm. Obsidian samples that hydrated on the surface are exposed to a higher effective temperature than those that were buried. However the effect on the rate of hydration of the lower rH tends to compensate for the increased rate due to the higher temperature experienced by these samples. This explains why surface samples seldom show thicker hydration than those buried in the soil at the same site.

Soil Alkalinity. Some limited evidence exists to indicate that alkali-rich environments increase the rate of hydration in natural glass. Lofgren (1970) and Cormie (1981:47) both found that obsidian hydrated at a greatly accelerated rate when placed in strong alkaline solutions but added that environmental conditions as severe as these were not likely to be duplicated in nature. It appears that the effect of soil alkalinity can be ignored in all but a very few cases.

Rates of Hydration

The greatest promise of the obsidian hydration dating method is the empirical or experimental determination of hydration rates followed by the conversion of hydration rim measurements to calendar years. Initially, the use of hydration rim measurements to establish reliable absolute chronologies seemed like a simple and straightforward issue. In practice, however, this has proved much more difficult than expected – over the thirty years since the introduction of the method this goal has still proved elusive.

The calculation of an obsidian hydration age requires two different components, the hydration rate and a mathematical model for describing the diffusion of water into the glass. Although many different rate equations have been developed to represent the advance of the hydration front into obsidian glass, in this initial exploration of the PEP obsidian hydration results we rely on the nonlinear diffusion model introduced by Irving Friedman (Friedman and Smith 1960; Friedman and Trembour 1983):

$$x^2 = kt \qquad (1)$$

where x is the thickness of the hydration band in μm, t is time in thousands of years, and k is a constant at a given temperature (the hydration rate expressed as μm^2/1000 yrs). In Figure 3, different rates of hydration (t) are applied to this same diffusion equation.

Alternative hydration models based on linear, parabolic, square root, cubic, and other functions have also been advanced in the literature and may also be applicable to the problem of obsidian hydration age determinations in some areas (Meighan 1983). Meighan et al. (1968), for example, found that a linear model best described the distribution of hydration rims determined from Mexican artifacts associated with radiocarbon dates. In the end, however, the empirical approach described by Meighan (1976) for determining rates and rate equations based on observable archaeological chronologic information is likely to prove the most reliable one. When considered through long periods of time, the variables and processes affecting the development of hydration rims are complex and there is no assurance that artifacts recovered from similar proveniences have shared similar cultural and thermal histories.

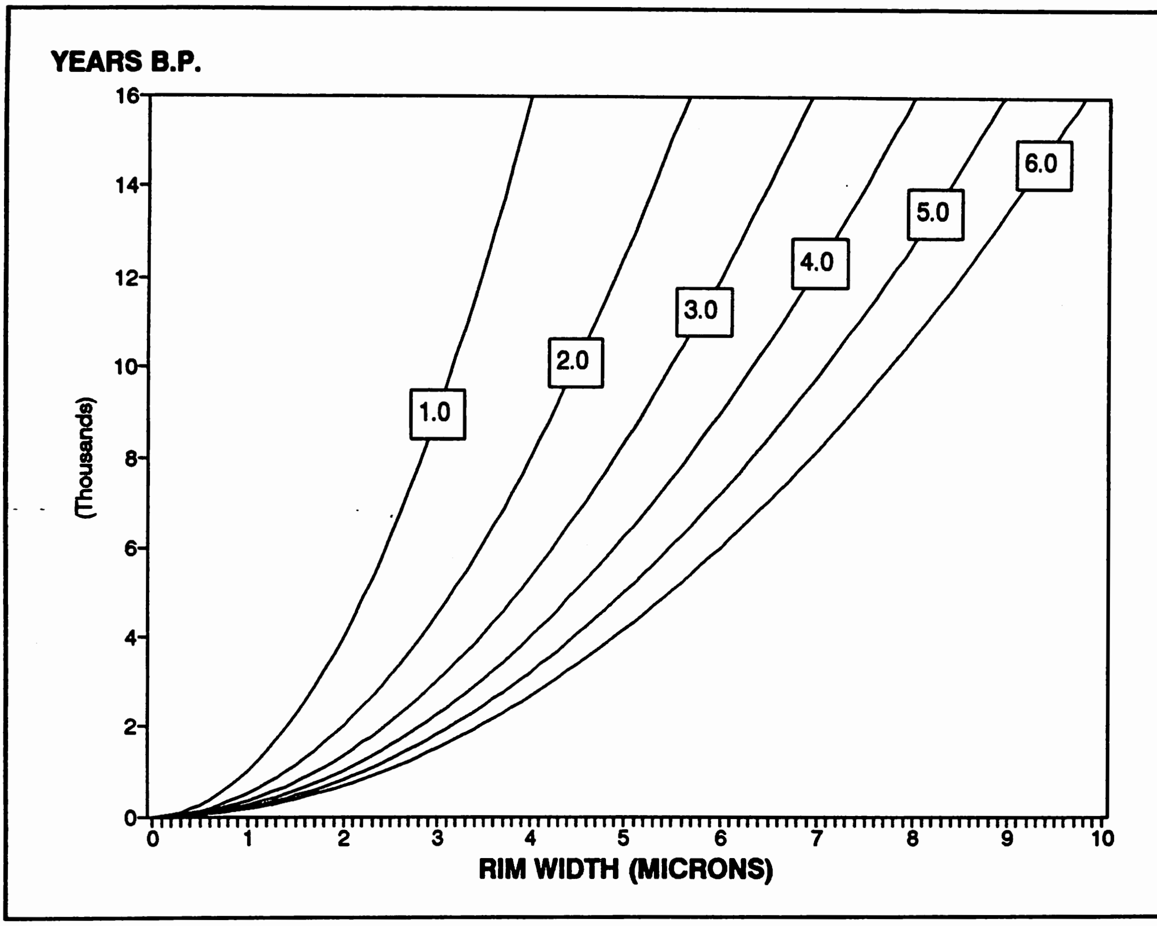


Figure 3. Examples of the results of different hydration rates applied to the diffusion model ($x^2=kt$) of hydration developed by Friedman and his associates. (1.0 = rate of 1 μm^2 /1000 years, and so on).

Factors Affecting the Range and Frequency Distribution of Obsidian Hydration Measurements

The characteristics of frequency distributions and the overall range of hydration rim measurements may be used to interpret source use patterns over time at both site and regional levels. In addition to those factors just described, however, the overall range and frequency distribution of hydration rim values are influenced by a variety of different cultural and non-cultural variables. In this paper, the characteristics of hydration rim distribution curves (presented as histograms) are used to examine diachronic issues, such as the temporal range of source use and changes in source utilization intensity over time. Because of the large regional and individual source sample sizes analyzed in the PEP obsidian studies, sample size effects are minimized so that these hydration data are readily analyzed.

The range of hydration measurements is typically directly related to the span of time over which the site or source was used, although it can also reflect the eruption of new sources of glass, scavenging and reuse, curation behavior, or the biases introduced by the method in which the artifacts were recovered. Variations in amplitude can be related to changes in population, changes in territoriality and seasonal procurement ranges, climatic influences, changes in access to sources, and the influence of exchange systems. A similar approach in California obsidian hydration studies has been employed by Ericson (1981), who used the term *obsidian production rate curve* to describe the overall distribution of obsidian from a specific source.

A population of artifacts generated during an occupational event or period should exhibit a symmetrical distribution of hydration bands that is approximately normal (Raymond 1984:54, 1984-1985). The characteristics of the distribution curve resulting from observed artifact rim values can then be examined for characteristics such as amplitude, kurtosis, range, and modality. A normal unimodal distribution of hydration rim readings suggests increasing use of material from a source followed by a decrease in frequency that is often interpreted as resulting from depopulation of aboriginal groups in the protohistoric and historic period. Multiple peaks in the distribution of rim values can suggest multiple periods of occupational intensity or, when the chemical source is controlled, the presence of glass from sources with different rates of hydration. Skewed distributions may provide clues about rapid or dramatic changes in source use. The kurtosis of the distribution curve contributes information about the length of occupation; a narrow distribution suggests relatively short term use and occupation while a flattened peak indicates source use over long periods. Descriptive measures of location and central tendency of the distribution of hydration bands such as range, mode, median, mean, or standard deviation provide quantitative confirmation of trends that are often quite apparent when graphical methods of analysis are used.

Sampling biases can also shape the nature of recovered materials. The relative sample sizes of components of different ages, the overall sample size, the size bias towards larger items introduced by trace element characterization methods, and the uncertainties introduced during the slide preparation and rim measurement process must all be considered. Site elevation, amount of annual snow cover, soil types, vegetation cover and burning history, and other environmental factors may also significantly influence the frequency distribution of recovered artifacts. Linderman (1991), for example, in an experimental study of slash burns over sites, points out that a hot enough fire can erase existing hydration rims, effectively resetting the obsidian hydration clock. Site modification processes such as animal disturbance, freeze-thaw cycles, and other erosional processes may profoundly alter the provenience relationship between artifact deposition and archaeological recovery (Schiffer 1987).

In short, the formation of obsidian hydration bands and their resultant provenience in an archaeological context is the result of a complex interaction of natural and cultural agents. By using the large sample sizes and descriptive methods outlined here, though, we can explore the prehistoric use of glass from Oregon PEP sites and begin to fill in the very broad and incomplete outline of site chronologies, procurement patterns, and source use that currently exists throughout much of the Project area.

Research Objectives

PEP obsidian hydration measurements were used primarily to provide relative intersite and intrasite chronological information about the recovered artifacts and their contexts. Materials suitable for radiocarbon dating are frequently not encountered at archaeological sites in the study area and obsidian hydration dating methods provided an important source of chronological information. Obsidian artifacts found in association with or below volcanic tephra from the well-dated 6845 ± 50 B.P. eruption of Mount Mazama (Bacon 1983) can also be used to provide temporal information that can be generalized to other regional sites in which characterized obsidian artifacts with measured hydration rims are available. Tephra from the Mazama eruptions is widely distributed in eastern Oregon and provides an important regional chronostratigraphic marker. No attempt was made here to use previously published hydration rates such as those offered published by Friedman (1977) to convert rim measurements to calendar ages.

X-ray fluorescence (XRF) trace element studies were used to identify the geologic sources of most obsidian artifacts subjected to hydration studies. The identification of chemically homogeneous groups was used to control for the effects of chemical composition on the hydration rate of the glasses. Although very recent investigations of the effect of intrinsic water content on hydration rates, discussed previously, suggest that water determinations may be an important consideration in hydration studies, no attempt was made to measure the intrinsic water content of the PEP samples. These intriguing and potentially significant findings concerning water content were reported in the literature after almost all Project hydration studies were completed, and still require further investigation and verification.

METHODS

Sample Selection

With the exception of 401 visually characterized artifacts from several California sites (N=352) and Oregon Site 35-JE-49 (N=49), sources for all samples selected for obsidian hydration measurements were determined through trace element studies.

Slide Preparation and Measurement

Hydration rim measurements for most of the obsidian specimens were carried out by Thomas M. Origer at the Sonoma State University Obsidian Hydration Laboratory (Anthropological Studies Center, Department of Anthropology). Hydration rim measurements for most California artifacts recovered during 1990 testing activities were made by Brian Wickstrom (BioSystems Analysis) and Dr. Chrisopher Stevenson (Diffusion Labs).

Each specimen was prepared generally following the procedures outlined by Michels and Tsong (1980). Two small parallel cuts were made along the selected edge of the sample with a 4-in. lapidary trimsaw; the resultant isolated section of the artifact was removed and mounted with Lakeside Cement onto a petrographic slide. The thickness of the sample was reduced by manual grinding with a slurry of #500 silicon carbide abrasive on a glass plate. The sample was first ground until any damage created by the saw blade during cutting was eliminated. The specimen then was inverted on the slide and ground until the sample was thin enough for a cover glass to be placed on it.

Hydration rims were measured on a Nikon petrographic microscope equipped with a strainfree 40-power objective and a Bausch and Lomb 12.5 filar micrometer eyepiece. Six measurements were taken at different locations along the edge of the thin section; the average of these six values is recorded in Appendix C.2 as the hydration rim width. The hydration measurements also have an uncertainty of about ± 0.2 μm due to normal limitations of the equipment.

All completed thin sections are curated either at the Sonoma State University Obsidian Hydration Laboratory, Rohnert Park, California, or at BioSystems Analysis, Santa Cruz, California.

Problems

The largest problem encountered during hydration studies of PEP artifacts is reflected by the relatively low success rate for items from many of the Deschutes County sites in Oregon. Approximately one-fourth of all selected Deschutes County artifacts failed to yield readable hydration bands. The presence of a patina-like encrustation on the surface of many of these artifacts made it difficult to locate and measure hydration rims. In addition, only about 50 percent of the artifacts assigned to the McKay Butte source yielded measurable hydration rims, perhaps due to the microcrystalline texture of much of the glass from this location. In many other areas of the project, the success rate for measurable rims was often greater than 90 percent.

RESULTS OF OREGON OBSIDIAN HYDRATION STUDIES

John Day River Drainage

The success rate of hydration studies for artifacts from the eight sites in the John Day River drainage of Gilliam, Sherman, and Umatilla counties was very high. Out of 193 prepared slides, measurable rims were found on 190 artifacts. The high source diversity in this regions, however, leaves the hydration results difficult to interpret. Obsidian found in sources in this region must be imported from other areas and glass from many different sources located to the southwest, south, and southeast is found. In addition, many sources remain unidentified. Only at 35-GM-25, where 64 artifacts were firmly or provisionally assigned to the Whitewater Ridge source, do source-specific sample sizes approach robust numbers. Rims range in width from 1.1 to 7.4 μm, suggesting a relatively long span of occupation in this region.

Lower Deschutes River Drainage

Artifacts from 29 PEP sites in Wasco, Sherman, and Jefferson counties along the Lower Deschutes River drainage also showed a high rate of success in measurements. Of 2,284 analyzed artifacts, hydration rinds on 2,125 items were successfully recorded. Source diversity, while still high in this region, is lower than for sites located in the John Day River drainage. Glass from post-Mazama Newberry Volcano sources is found at most sites with significant quantities of obsidian also originating from Glass Buttes, Obsidian Cliffs, and Quartz Mountain. At some sites, the Big Obsidian Flow chemical type, McKay Butte, and Whitewater Ridge sources also produced significant numbers of readable bands. The presence of a limited number of heavily used sources, combined with the large sample size, produced large numbers of source-specific rim readings for many of the sites. Limited quantities of artifacts from pre-Mazama components at several sites also were successfully examined for hydration bands, providing important regional information on the relationship of rim width and the emplacement of the Mazama ash horizon.

Upper Deschutes River Drainage

Out of 2,709 obsidian samples selected from 19 Crook and Deschutes County sites, 2,026 obsidian hydration rims were successfully measured. The success rate of hydration measurements from this region, for reasons discussed previously, was the lowest of all those along the Pipeline corridor. The dominant use of only a few sources, however – Newberry Volcano, McKay Butte, and Unknown X – guaranteed that large numbers of source specific samples were available for the chronologic interpretation of many of the investigated sites. Artifacts from Obsidian Cliffs, Quartz Mountain, and the Big Obsidian Flow chemical groups are also available in significant numbers. Sampling activities at the Deschutes and Crook County sites were concentrated at 35-DS-33 (N=964), 35-DS-263 (N=408), and 35-DS-557 (N=652). The latter two sites contained significant pre- and post-Mazama components associated with obsidian artifacts. The chronological use of this tephra horizon was considered to be an important key for examining the hydration characteristics of several Newberry Caldera area sources. The results of initial investigations of hydration rates are discussed later in this paper.

The occupational span represented by the range of hydration measurements found in the Upper Deschutes River drainage sites is considerable. Bands of less than one micron from 35-DS-33 suggest very late prehistoric or early historic use of that site while artifacts with rims exceeding eight microns from the McKay Butte source suggest early Holocene to late Pleistocene occupation of sites near that source. The large samples, when combined with the presence of glass from the temporally-limited Newberry Volcano source and the striking diachronic shifts in use of the McKay Butte and Unknown X sources, create an archaeological scenario in the Upper Deschutes River drainage area that is unique in the Project corridor.

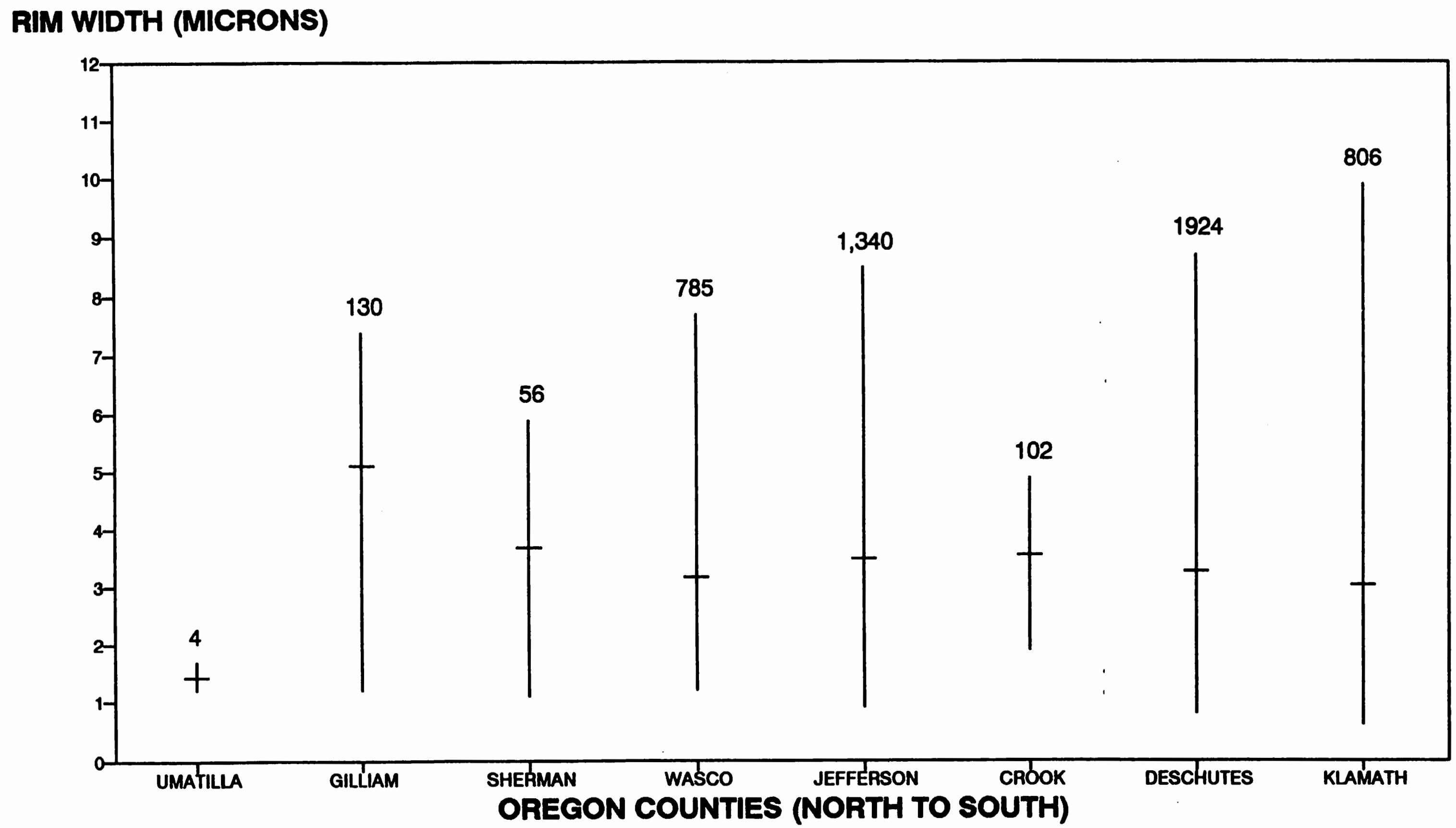


Figure 4. Ranges of obsidian hydration measurements for artifacts from PEP sites located in different Oregon counties. (The vertical bar spans the maximum to minimum hydration values; the horizontal tic is placed at the mean value. The number above each bar marks the size of the data set. When the values of outliers (empty circles) fall outside the range of the y-axis, the rim measurements are indicated).

Big Obsidian Flow Chemical Group Hydration Rim Anomalies

Prior to the Pipeline Project, relatively few Oregon artifacts had been correlated with the 1350 year-old Big Obsidian Flow located in Newberry Caldera. Glass from this obsidian flow, the youngest in the summit caldera, was thought to be available only within a relatively recent and restricted period of time.

The existence of another older member of the Big Obsidian Flow chemical group was initially suspected in 1991 when two artifacts from 35-DS-866 were found to have rim values of 5.0 and 5.1 μm, considerably thicker rims than those that were expected from the Big Obsidian Flow. Friedman (1977) had measured hydration rims at the source and found them to range from about 0.8 to 1.2 microns. Hydration studies of five artifacts from 35-DS-212, a site bordering the Big Obsidian Flow, showed rims ranging from 1.3 to 1.5 microns (Flenniken and Ozbun 1988:133-135). Up until this point, only one other anomalous hydration rim value (3.3 μm) had been recorded for an artifact from this chemical group, recovered from the Apple Site (35-DO-265) in the Umpqua River drainage of the Western Cascades

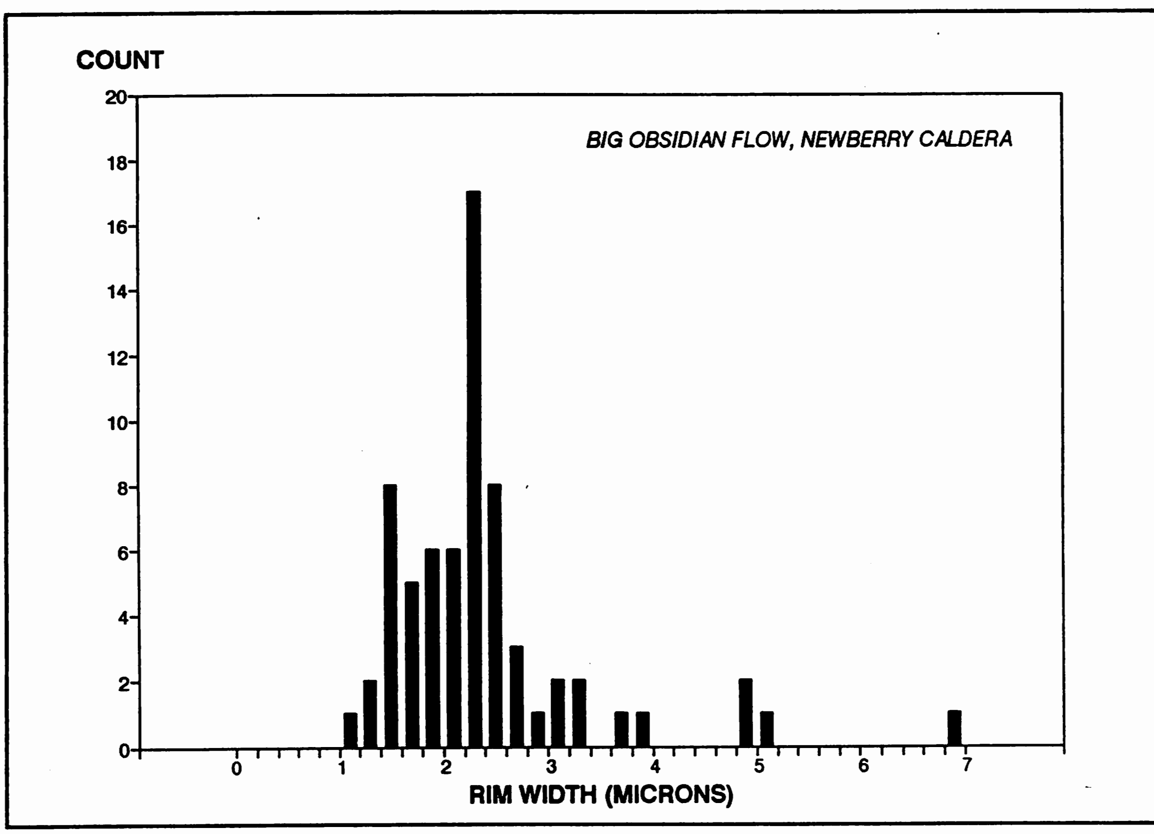


Figure 5. Frequency distribution of hydration rims associated with Big Obsidian Flow chemical group artifacts.

(Berryman 1987). As hydration studies of PEP artifacts progressed, it became increasingly clear that a substantial number of Big Obsidian Flow items were yielding rims thicker than were anticipated (Figure 5). These data led to a successful search for an older source of glass that was found to be geochemically similar to the recent Big Obsidian Flow, the Buried Obsidian Flow. This early Holocene to late Pleistocene flow, located about one kilometer east of the Big Obsidian Flow, is largely covered by later tephra deposits. Ongoing geochemical studies carried out in conjunction with Tom Connolly (Oregon State Museum of Anthropology) and Richard Hughes (Geochemical Research) will reveal whether it will prove possible to eventually separate the two flows into chemically distinguishable types.

Pre-Mazama Newberry Volcano Chemical Group Obsidian: A Case of Mistaken Identity

The several Newberry Caldera obsidian flows that make up the Newberry Volcano chemical group are known to have erupted after the Mazama ashfall of about 6,850 ^{14}C years ago. We were then puzzled when 57 artifacts correlated with the Newberry Volcano sources were recovered from almost certain pre-Mazama contexts at 35-DS-263 and 35-DS-557 (Figure 6). Hydration rim values of Newberry Volcano artifacts from 35-DS-263, the site in which we were most confident of the pre-Mazama context, showed a range of only 2.6 to 4.0 microns. Up until this point, archaeological and geologic evidence indicated that pre-Mazama Newberry Volcano glass should not exist and that the Mazama ashfall occurred at hydration measurements of about five microns for Newberry glass. The clear pre-Mazama provenience of many of the items and the large number of samples was too great to invoke a site disturbance explanation for these artifacts. Could other pre-Mazama Newberry Volcano group obsidian sources have been covered by later eruptive products within the caldera? In an earlier study by Flenniken and Ozbun (1988:130-132), a single flake with a 1.4 μm thick rim from a pre-Mazama component located within the caldera had been identified as originating from Newberry Volcano. The hydration rim readings of a chemically identical group from a pre-Mazama setting, though, would be expected to exceed five microns in thickness.

When the frequency distributions of the pre-Mazama Newberry Volcano and the pre-Mazama Unknown X source artifacts are compared, however, a simpler explanation presents itself (Figure 8). We suggest that the pre-Mazama Newberry Volcano items identified in this investigation are actually members of the geochemically similar Unknown X chemical type, an apparent local source of obsidian that was heavily used in the pre-Mazama period. Not only was this source intensively utilized locally prior to the Mazama ashfall, it also apparently hydrated at a much slower rate than either glass from the Newberry Volcano group or the nearby McKay Butte source. The distribution curve and range of hydration values is very similar to Unknown X artifacts and we hypothesize that the presence of pre-Mazama Newberry Volcano glass is a simple case of mistaken identity. The geochemical range of variability for the Unknown X source will remain incompletely known until the source itself is located and sampled.

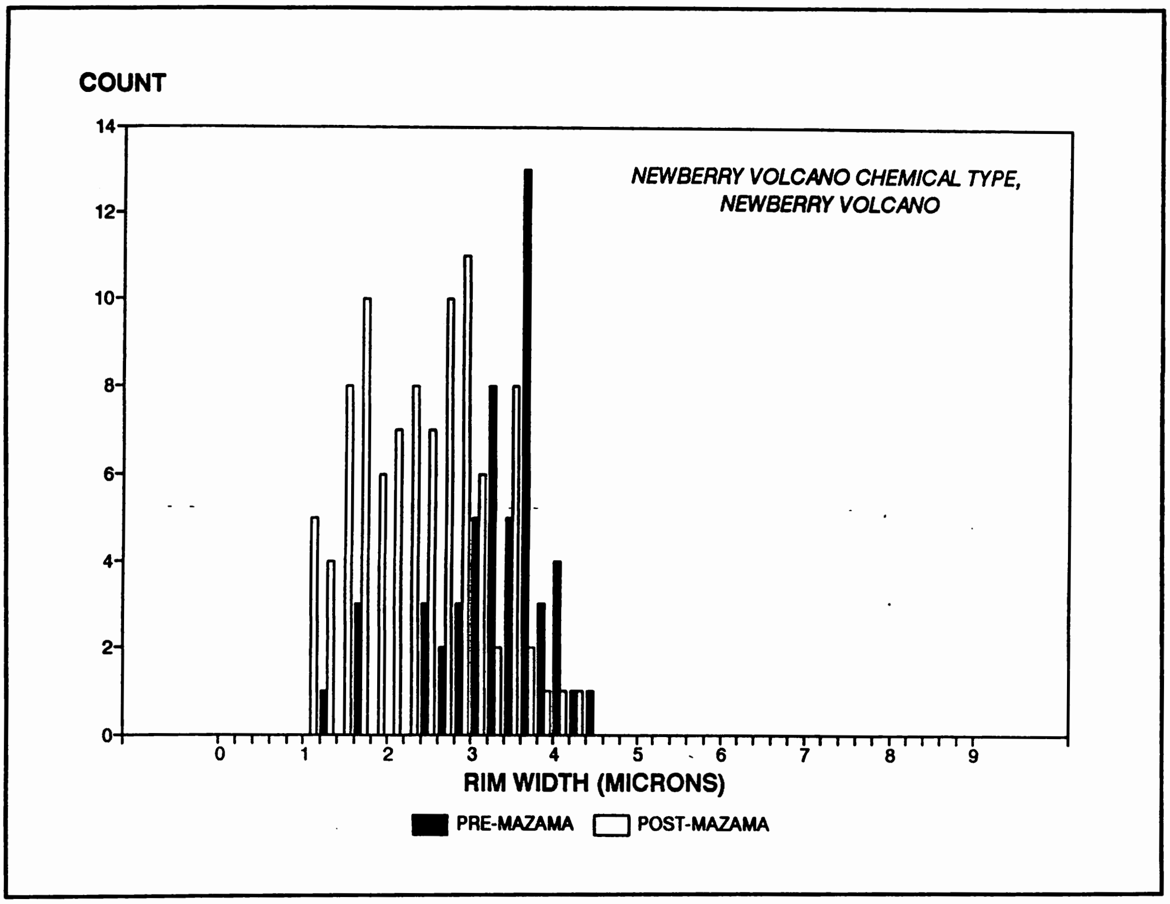


Figure 6. Frequency distribution of hydration rim Values for post- and pre-Mazama artifacts from sites 35-DS-263 and 35-DS-557 that were correlated with the Newberry Volcano chemical group.

The hydration rim value and setting for the pre-Mazama artifact cited in Flenniken and Ozbun (1988) suggests that this item may also belong to the Unknown X geochemical group. Connolly and Byram (1992) also report a possible source among uncharacterized pre-Mazama artifacts from Newberry Caldera that hydrates at a much slower rate than the Newberry Volcano source.

Klamath Lake Basin

Obsidian hydration measurements from artifacts recovered in 14 Oregon Klamath Basin sites ranged from the smallest of the entire project at 0.6 μm to the largest Oregon band at 9.9 μm. Measurable rims were found on over eighty percent (N=797) of the 989 artifacts prepared as thin sections. Over 92 percent of the characterized Klamath Basin artifacts were found to originate from the Spodue Mountain or Silver Lake/Sycan Marsh sources. The low source diversity and good success rate produced a high yield of source-specific obsidian hydration rim measurements for most of the Klamath Basin sites.

RATES OF HYDRATION FOR SELECTED OREGON SOURCES

Some of the best temporal and hydration data for establishing relative obsidian hydration rates come from the Deschutes County sites of 35-DS-263 and 35-DS-557. The combination of pre- and post-Mazama components, relatively recent post-Mazama obsidian sources, and large sample sizes at these sites make it possible here, more than any other Project area, to confidently assess relative rates of hydration among sources. In this examination, we assess only the relative rates of hydration and do not attempt to calculate hydration rates. Radiocarbon dates are few among the Deschutes County sites and it is not possible to precisely correlate the Mazama temporal horizon with micron hydration values.

Hydration Rate Research in Oregon

Most obsidian hydration studies in Oregon have been limited to brief discussions of the patterning of rim measurements. Exceptions to this trend, in which attempts were made to calculate the rate of hydration of particular sources, include Bergland et al. (1982), Connolly and Byram (1992), Friedman (1977), Johnson (1969), Layton (1972), Minor (1977), and Pettigrew and Lebow (1987)(also see Figure 9). In one of the few instances where pre-existing hydration rates have been used in Oregon archaeological studies, Cheatham (1993:23-25) used rates for Newberry Volcano and Obsidian Cliffs to help establish a site chronology in the Bend area.

Relative Hydration Rates in the Newberry Volcano Region

Sites 35-DS-263 and 35-DS-557, located at the western base of Newberry Volcano contain large quantities of glass from McKay Butte, the Unknown X source, and Newberry Volcano. McKay Butte and Unknown X were extensively used as sources of raw material prior to the eruptions of Mount Mazama, but were rapidly displaced by glass from the Newberry Volcano group that was erupted not long after the climactic eruption of Mount Mazama. The cessation of prehistoric use of glass from the McKay Butte and Unknown X sources is thought to be due to the burial of the sources by Mazama ash. McKay Butte is located only a few kilometers from the two sites and the Unknown X source is probably also located nearby.

McKay Butte

The distribution of hydration rim values for McKay Butte artifacts from pre- and post-Mazama components is striking. Rim values of pre-Mazama items from both sites range from 3.3 to 8.7 μm and glass from the source virtually disappears in the period after the ashfall (Figure 8). It is apparent that the Mazama ash horizon of about 6,850 radiocarbon years is equivalent to a hydration width of no less than about 3.3 microns. Rim measurements of pre-Mazama McKay Butte glass at 35-DS-263, however, begin at 4.4 microns and the potential for vertical displacement allows the possibility that the Mazama ash horizon falls even higher on the hydration scale. The uncertainty of the micron values

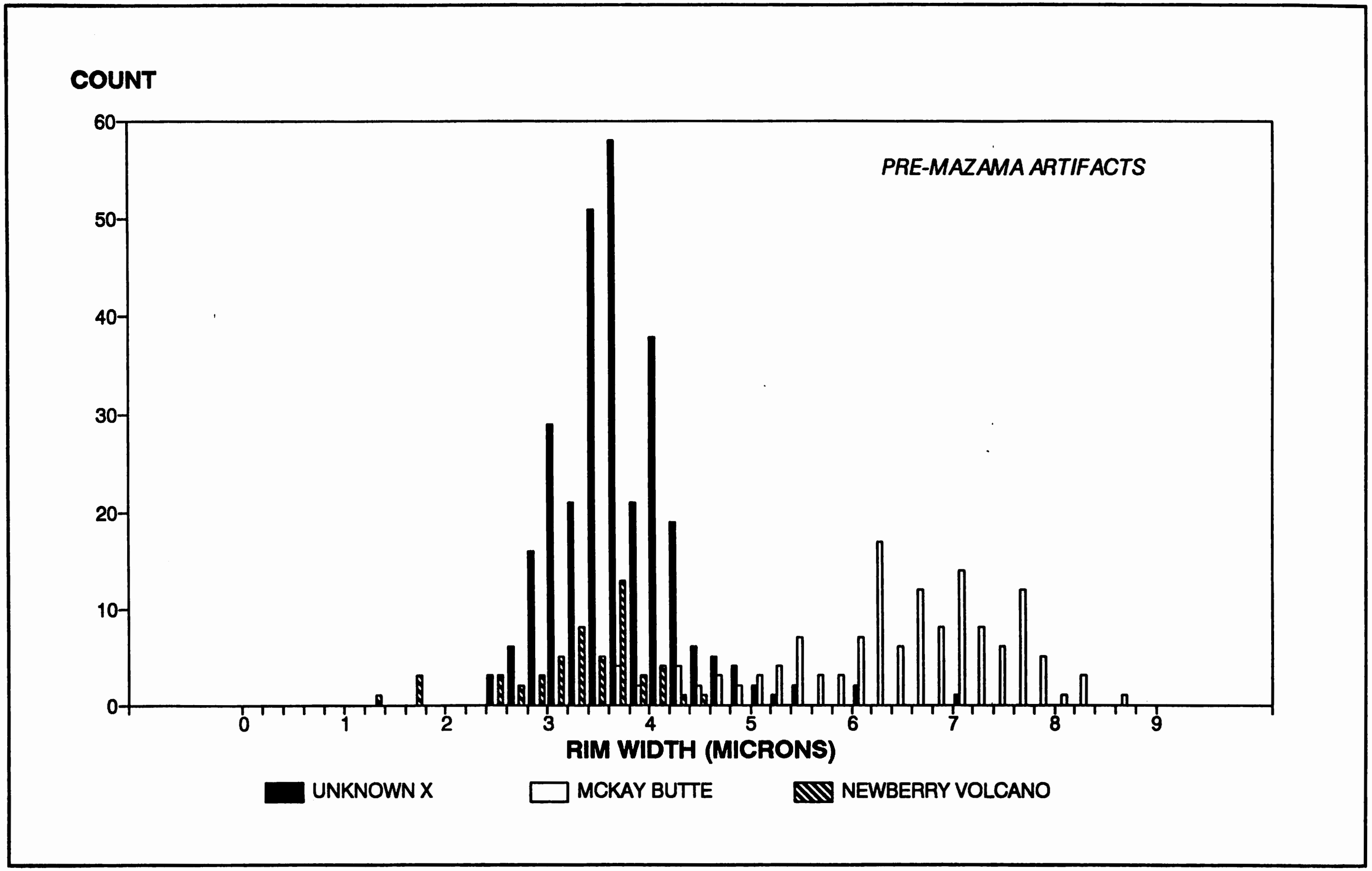


Figure 8. Distribution of hydration rim values for pre-Mazama artifacts correlated with the McKay Butte, Unknown X, and Newberry Volcano sources.

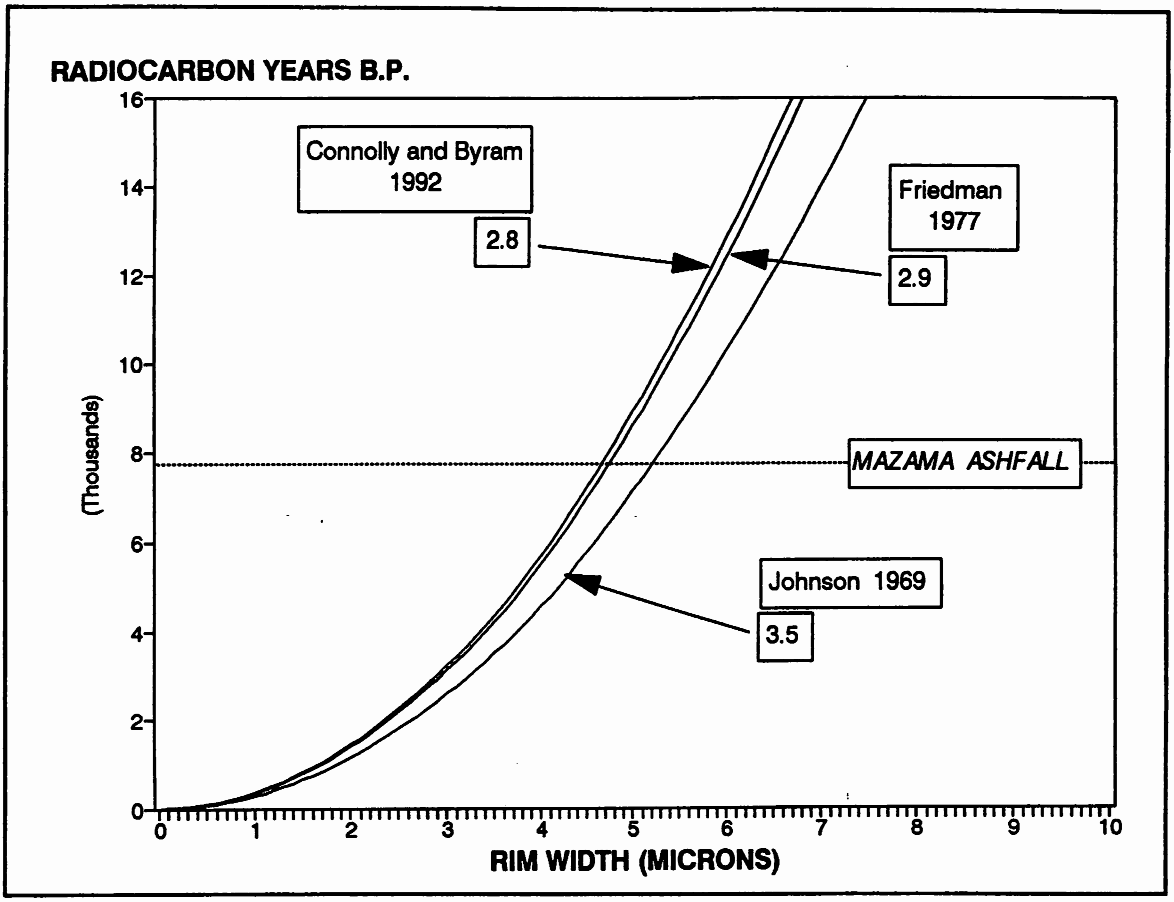


Figure 9. Published and proposed obsidian hydration rates for selected sources. (The numbers refer to rates in $\mu m^2/1000$ years, e.g., 2.9 $\mu m^2/1000$ years).

associated with the Mazama boundary leaves the estimation of the age range of McKay Butte artifacts very speculative, but it seems likely that use of glass from this source extends into the early Holocene and perhaps earlier.

Unknown X

The obsidian frequency distribution curve plotted for pre-Mazama artifacts from 35-DS-263 and 35-DS-557 exhibits a strong unimodal distribution (Figure 8). Band measurements range from 2.5-7.1 μm, indicating a minimum micron value for the Mazama ashfall of about 2.5 microns. The range of rim widths is similar for both sites. Although it is difficult to mark the Mazama eruption with a precise micron figure, the distinct bimodality of the frequency distribution curve illustrated in Figure 8 clearly demonstrates that the Unknown X and McKay Butte sources hydrate at significantly different rates.

Newberry Volcano

Not long after the Mazama ashfall, obsidian flows belonging to the Newberry Volcano chemical type erupted at several locations within Newberry Caldera (Friedman 1977; Friedman and Obradovich 1981). This chemical source was widely used prehistorically in the Lower and Upper Deschutes River drainages and accounts for over 2,000 Oregon PEP artifacts. When the samples are plotted as a simple distribution curve, the rim values are found to abruptly begin at about 5.0-5.2 μm (Figure 14). We suggest that the abrupt appearance and rise in the obsidian hydration rim frequency curve at this point marks the approximate position of the Mazama ashfall. This conclusion implies a hydration rate of 3.3 to 3.6 μm^2/1000 years, somewhat faster that the hydration rates calculated by Connolly and Byram (1992) and Friedman (1977), respectively, of 2.8 and 2.9 μm^2/1000 years for the higher elevation Newberry Caldera area.

Big Obsidian Flow Chemical Group

Seven pre-Mazama Big Obsidian Flow group artifacts from 35-DS-263 and 35-DS-557 were also found to have hydration rims ranging from 2.5 to 3.4 microns. This suggests that the Big Obsidian Flow group glass hydrates at a slower rate than the Newberry Volcano chemical type, a prediction supported by the findings of Friedman (1977) in his original obsidian hydration investigation of the caldera obsidian sources. A single split nodule of variegated red and black obsidian with a hydration measurement of 6.9 μm was found to originate from the Big Obsidian Flow chemical group, probably the Buried Obsidian Flow. The rim thickness of the possible Buried Obsidian Flow nodule also supports Linneman's contention that the age of the flow, although it is not known, must be greater than 10,000 years (Linneman 1990:29-31). The slow hydration rate of the glass and the 6.9 μm hydration rim suggests that the age of eruption of the Buried Obsidian Flow may lie somewhere in the range of 30,000 years ago or older.

Obsidian Cliffs

Unfortunately, few PEP artifacts originating from Obsidian Cliffs were recovered from pre-Mazama sites components. Limited evidence from 35-JE-51B suggests, however, that the hydration band equivalent of the Mazama ashfall lies in the range of approximately 4.8 to 5.2 microns. Rim measurements varying from 4.8 to 7.6 μm for five artifacts recovered from just below the ash point to this range as comparable to the Mazama eruption. This Mazama ashfall range is also supported by early obsidian hydration studies at Baby Rock Shelter, a pictograph site located in the McKenzie River drainage of the Western Cascades (Fagan 1975; Olsen 1975). Rim values of eight artifacts from this site varied from 3.5 to 5.1 microns in width, with most values lying near 5 microns. Although the artifacts were not chemically characterized, Skinner and Winkler (1991) found that most prehistoric obsidian in this drainage originated from Obsidian Cliffs and it is likely that most of the Baby Rockshelter items also originated from that source.

PREHISTORIC TEMPORAL PATTERNS OF OREGON OBSIDIAN SOURCE USE

The overall regional distribution of obsidian hydration rim values for specific sources of glass is influenced by many different variables: the size of the sample, the temporal bias introduced by collection methods, the different relative rates of hydration for varied geologic sources of glass, the thermal history of the artifacts, and the age range of included sites are some of the major factors that must be considered. The general range and frequency distribution of rim measurements associated with any particular source of obsidian also presents, however approximately, the span of time that the source was prehistorically utilized. Changes in the intensity of use can also be inferred from the changes in relative counts of artifacts within specified hydration ranges.

Unless relative or absolute ages can be associated with the range of hydration rind measurements, each source must be considered independently, much like floating tree-ring chronologies, that are clearly related but which lack an anchor to a known date. If relative rates of hydration are available for sources of glass, it may be possible to examine the relative use of those sources through time. Three different well-dated Holocene geologic volcanic events can be associated with obsidian from the characterized PEP sites, and we initially thought that all three could be used to investigate the rate of hydration. These events were the Mazama ashfall of about 6,800 ^{14}C years ago (equivalent to about 7,630 calibrated years B.P.), the eruption of the Glass Mountain obsidian flow about 900 years ago, and the eruption of the Big Obsidian Flow in Newberry Caldera about 1,350 years B.P. All three would have provided known windows of prehistoric availability. Because of the previously discussed problem with the Big Obsidian Flow chemical type, however, only the Mazama ashfall temporal horizon could be initially used to examine the relative rates of hydration for several of the flows.

In this section, we very briefly look at the temporal utilization of major Oregon sources of obsidian, sources that yielded at least 100 successful hydration rind measurements (Figures 10 and 11). Artifacts from the John Day River and Lower Deschutes River drainages are combined in the figures because of their similar obsidian source assemblages and because of the small sample sizes from the John Day drainage PEP sites. The use of the sources with larger numbers of rim values, in addition to indicating obsidian sources that were of significant prehistoric use, also mitigate some of the effects of sample size that are often present in small numbers of artifacts.

Glass Buttes

Obsidian from Glass Buttes, a complex of rhyolite domes located in the Northwestern Great Basin, was identified primarily in Lower Deschutes River Basin PEP sites. Only a few items came from the John Day or Upper Deschutes River drainage area. Hydration values range from 1.2 to 6.6 μm and show a fairly normal distribution (Figure 12). No Glass Buttes artifacts were recovered from pre-Mazama components, although the range of use of the source is known to be a long one. Fagan (1990) found that Glass Buttes was the source of

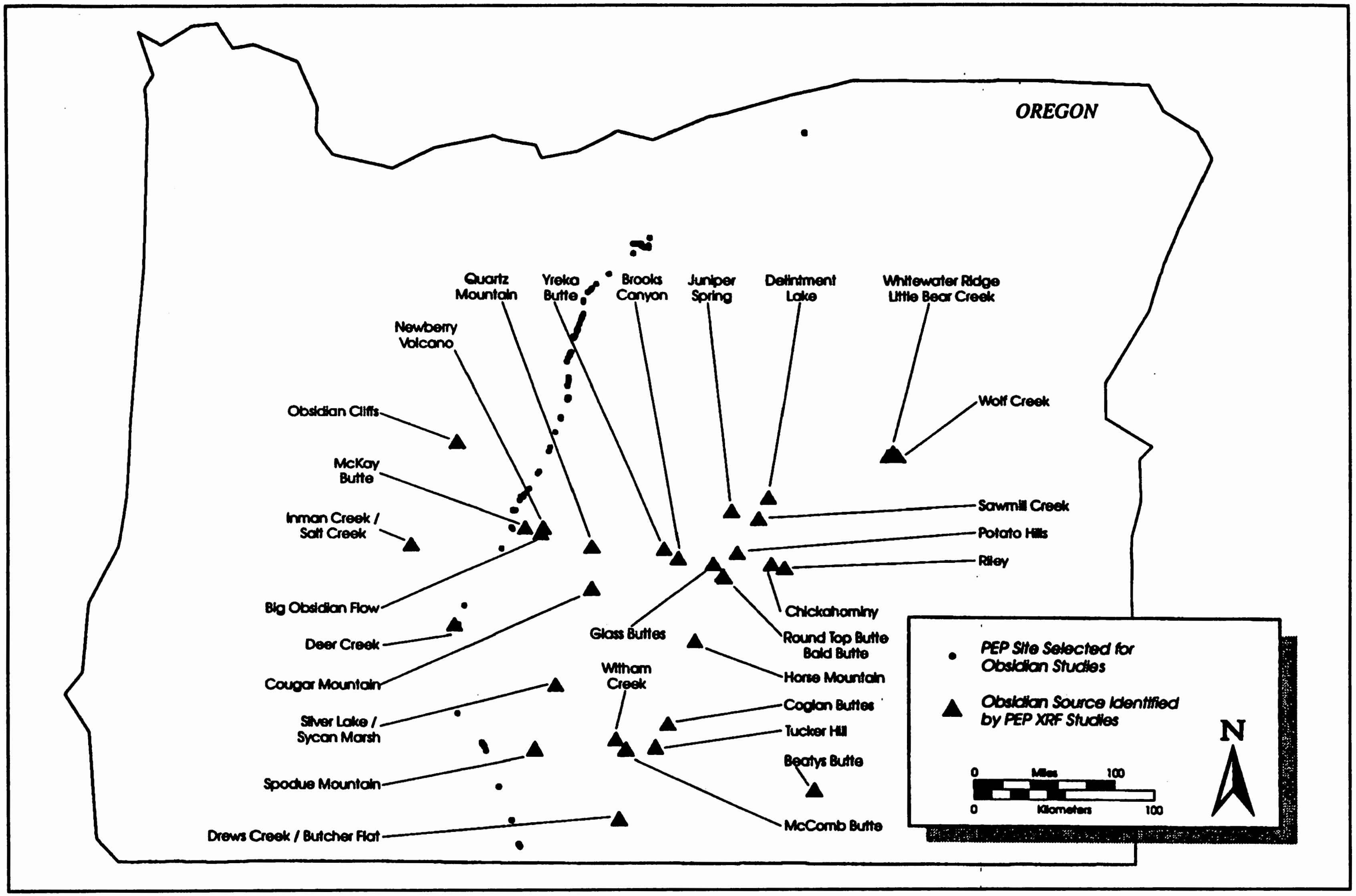


Figure 10. Location of major Oregon sources of obsidian identified during PEP Obsidian studies.

Table 2. Characteristics of obsidian hydration frequency distribution curves for major Oregon sources (all values are in microns).

Chemical Type	Figure	Total OH [a]	Minimum OH Rim	Maximum OH Rim	Mean	Median	Mode	Comments
OREGON SOURCES								
Glass Buttes	5-12	175/181	1.2	6.6	3.9	3.8	3.6	Normal distribution.
McKay Butte	5-13	378/750	1.1	8.7	5.2	5.3	7.2	Bimodal distribution by geographic region; source may have been covered by Mazama ashfall of 6,845 ^{14}C yrs. B.P.
Newberry Volcano	5-14	2,057/ 2,389	0.8	5.7	2.8	2.6	2.4	Normal distribution; obsidian not available until about 6,600 ^{14}C yrs. B.P.
Obsidian Cliffs	5-15	451/472	0.9	7.6	3.7	3.8	4.4	Left-skewed distribution probably reflects paucity of pre-Mazama artifacts recovered.
Quartz Mountain	5-16	246/267	1.1	6.4	3.1	3.1	2.6	Normal distribution; possible low hydration rate.
Silver Lake/Sycan Marsh	5-17	385/486	0.8	8.8	3.2	3.2	2.6,4.2	Poorly-defined bimodal distribution.
Spodue Mountain	5-18	407/484	0.6	9.9	3.1	3.2	1.2	Bimodal distribution may reflect shift to this source in late periods from previous combined Spodue Mountain - Silver Lake/Sycan Marsh source use.
Unknown X	5-19	320/347	1.3	7.1	3.7	3.7	3.8	Normal distribution; slow hydration rate; source may have been covered by Mazama ashfall of 6,850 C^{14} yrs. B.P.
Whitewater Ridge	5-20	178/180	1.1	6.7	4.0	4.2	5.0	Bimodal distribution by geographic region; shift from earlier John Day to later Lower Deschutes River drainage

[a] Total number of successfully measured samples/total number of samples prepared for hydration analysis.

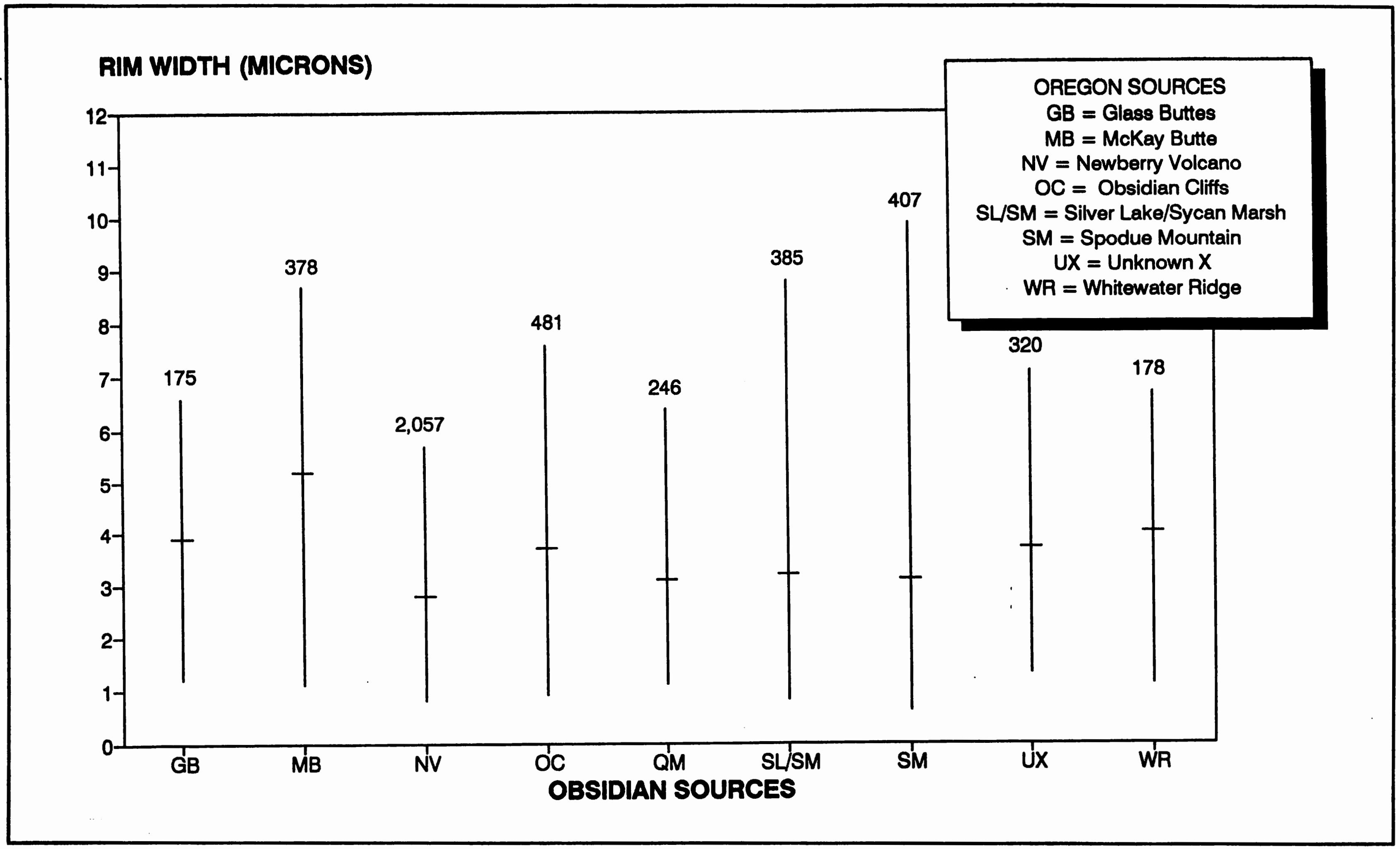


Figure 11. Range of obsidian hydration measurements for PEP artifacts from major sources of obsidian in Oregon. (The vertical bar spans the maximum to minimum hydration values; the horizontal tic is placed at the mean value. The number above each bar marks the size of the data set. When the values of outliers (empty circles) fall outside the range of the y-axis, the rim measurements are indicated).

several Clovis and Western Pluvial Lakes Tradition tools recovered at the Dietz Site in southeastern Oregon.

McKay Butte

The distribution of characterized McKay Butte artifacts exhibits a marked bimodality related to the geographic locality of the sites from which the items were recovered (Figure 13). Thicker hydration bands are associated primarily with PEP sites near the source while thinner rims are concentrated in Lower Deschutes River sites some distance to the north. The distribution of the thicker bands, associated primarily with pre-Mazama artifacts from Deschutes County sites, has been discussed previously. We speculate here that the McKay Butte source was covered by Mazama tephra and that it was almost completely replaced as a source of raw material by the post-Mazama obsidian of the Newberry Volcano chemical type. If this scenario is correct, the thin bands from the Lower Deschutes Basin sites may represent reuse of previously collected McKay Buttes glass. It must be noted that nearly 95 percent of the 109 Lower Deschutes Basin McKay Butte artifacts were found at only two sites, 35-WS-225 and 35-JE-51B. Eighty-four of the artifacts (78%) came from 35-WS-225, a pattern unique among sites in this region. The hydration rim measurements span from 1.1 to 8.7 μm, indicating a long use life for the material from this source, one that certainly extends back at least to the early Holocene.

Geographically, the overall distribution of artifacts from McKay Butte is largely clustered in the source vicinity and in the Lower Deschutes River drainage. Only a few scattered samples have been found in the John Day Canyon PEP sites and in previously characterized collections from the Western Cascades (Skinner and Winkler 1990). Use of glass from this source drops very quickly to the south and is completely absent in the Klamath Basin.

Newberry Volcano

After the eruption of the Newberry Volcano chemical group flows shortly after the Mazama ashfall, glass from this group of sources spread rapidly throughout the Upper and Lower Deschutes River drainages (Figure 14). In Deschutes County Sites, Newberry Volcano glass nearly completely replaces the older McKay Butte and Unknown X sources. In the Lower Deschutes River region, Newberry Volcano obsidian accounts for about 40 percent of the characterized artifacts; glass from Obsidian Cliffs, the northwestern Great Basin, and several unknown groups accounts for most of the remainder. Prehistoric use of Newberry Volcano glass declines very quickly to the south and southeast of the volcano and is replaced by obsidian from Klamath Basin sources. The obsidian hydration rim frequency distribution curve is normal in both the Upper and Lower Deschutes River drainages.

Obsidian Cliffs

Located in the central High Cascades of Oregon, this Pleistocene obsidian flow was a major source of obsidian for the prehistoric inhabitants of both western and north central Oregon

(Skinner and Winkler 1990). Use of this source in central Oregon was greatest in north central Oregon sites, where it was used along with glass from Newberry Volcano and other sources to the southeast. The distribution of Obsidian Cliffs glass in PEP sites is somewhat skewed and probably results from a bias towards post-Mazama obsidian artifacts (Figure 15). Hydration band values range from 0.9 to 7.6 μm, indicating that Obsidian Cliffs was used in central and north central Oregon throughout much of the Holocene.

Quartz Mountain

The 1.1 million year-old complex of rhyolite domes and flows known as Quartz Mountain provided a source of high quality obsidian that was extensively used by the prehistoric inhabitants of north central Oregon. The source is located near the southeastern base of Newberry Volcano at the margin of the northwestern Great Basin. The hydration rim distribution is normal with a range of 1.1 to 6.4 microns (Figure 16). The artifacts were recovered almost entirely from post-Mazama site components and the relatively restricted range of values is probably related to a temporally biased sample rather than to the overall prehistoric utilization of the source material. A single provisionally assigned Quartz Mountain sample from a pre-Mazama context at 35-JE-51B has a hydration rim of 6.0 microns. We are unable, however, to estimate the micron equivalent of the Mazama ashfall at this time.

Silver Lake/Sycan Marsh and Spodue Mountain

Glass from these two sources is widely distributed in secondary deposits throughout the Klamath Basin of Oregon. Not surprisingly, over 92 percent of the successfully measured Klamath Basin PEP artifacts originated from one of these two chemical groups. While glass from these two sources is extensively used in the Klamath Basin, its frequency in other areas drops away rapidly in all directions in which competing sources are available. In southwest Oregon, natural sources of glass are not found and obsidian from Klamath Basin and northern California sources make up most of the obsidian artifacts found there (Pettigrew and Lebow 1987; Skinner and Winkler 1990)

The distribution curves for the Spodue Mountain and Silver Lake/Sycan Marsh artifacts are very similar, suggesting that the two sources share a similar rate of hydration (Figure 17). This same observation has been previously made by Pettigrew and Lebow et al. (1987).

Hydration rind ranges are also similar for both sources, 0.6 to 8.8 μm for Silver Lake/Sycan Marsh artifacts and 0.8 to 9.9 μm for Spodue Mountain items. We suspect that the Mazama ashfall is approximately equivalent to about five microns for the two sources, although the degree of disturbance at pre-Mazama Klamath Basin site components makes it difficult to be more precise.

The similar span of rind values and intensity shown in the obsidian hydration frequency distribution histograms suggests that both sources had been used in about the same proportion

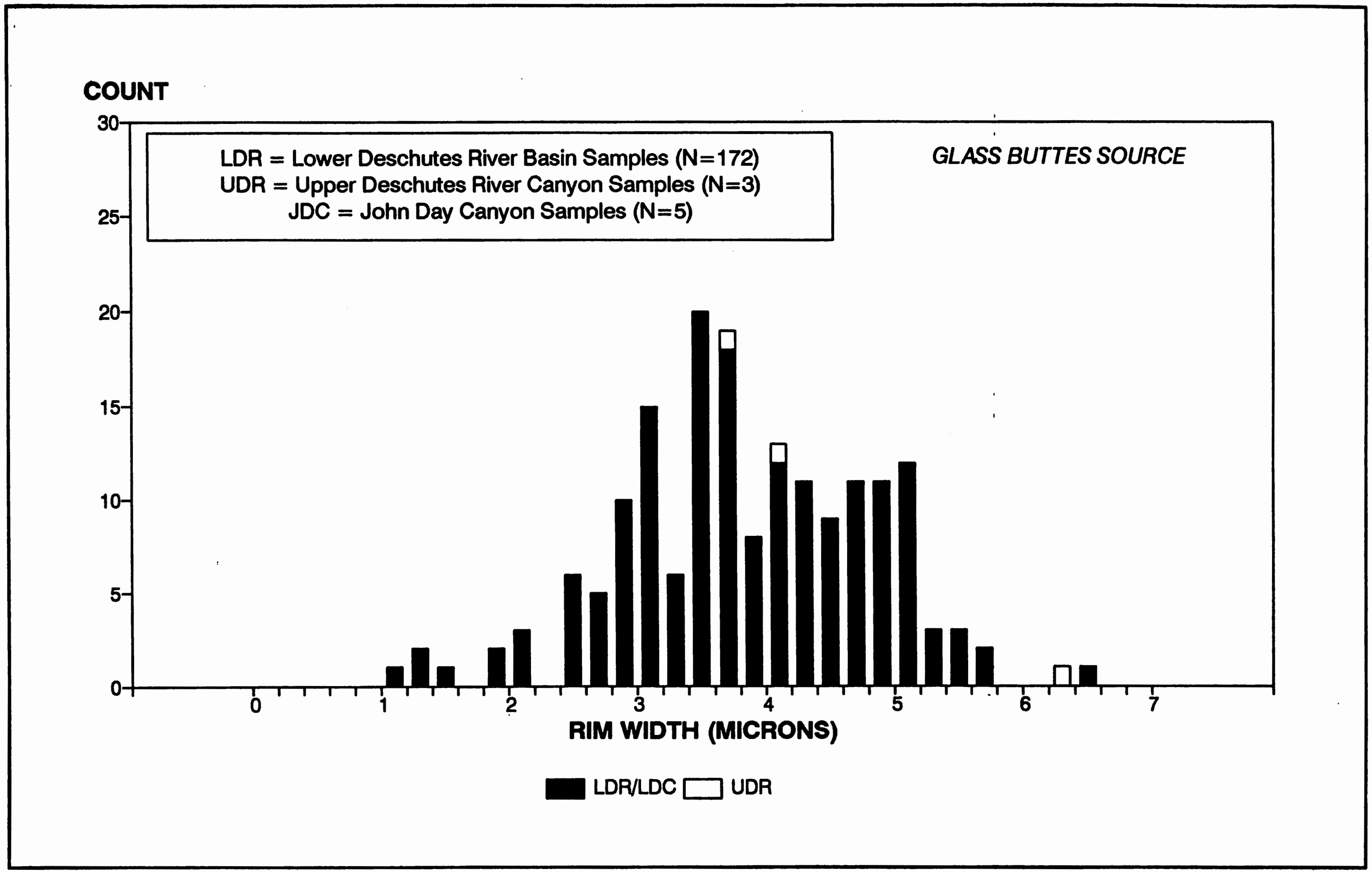


Figure 12. Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Glass Buttes source.

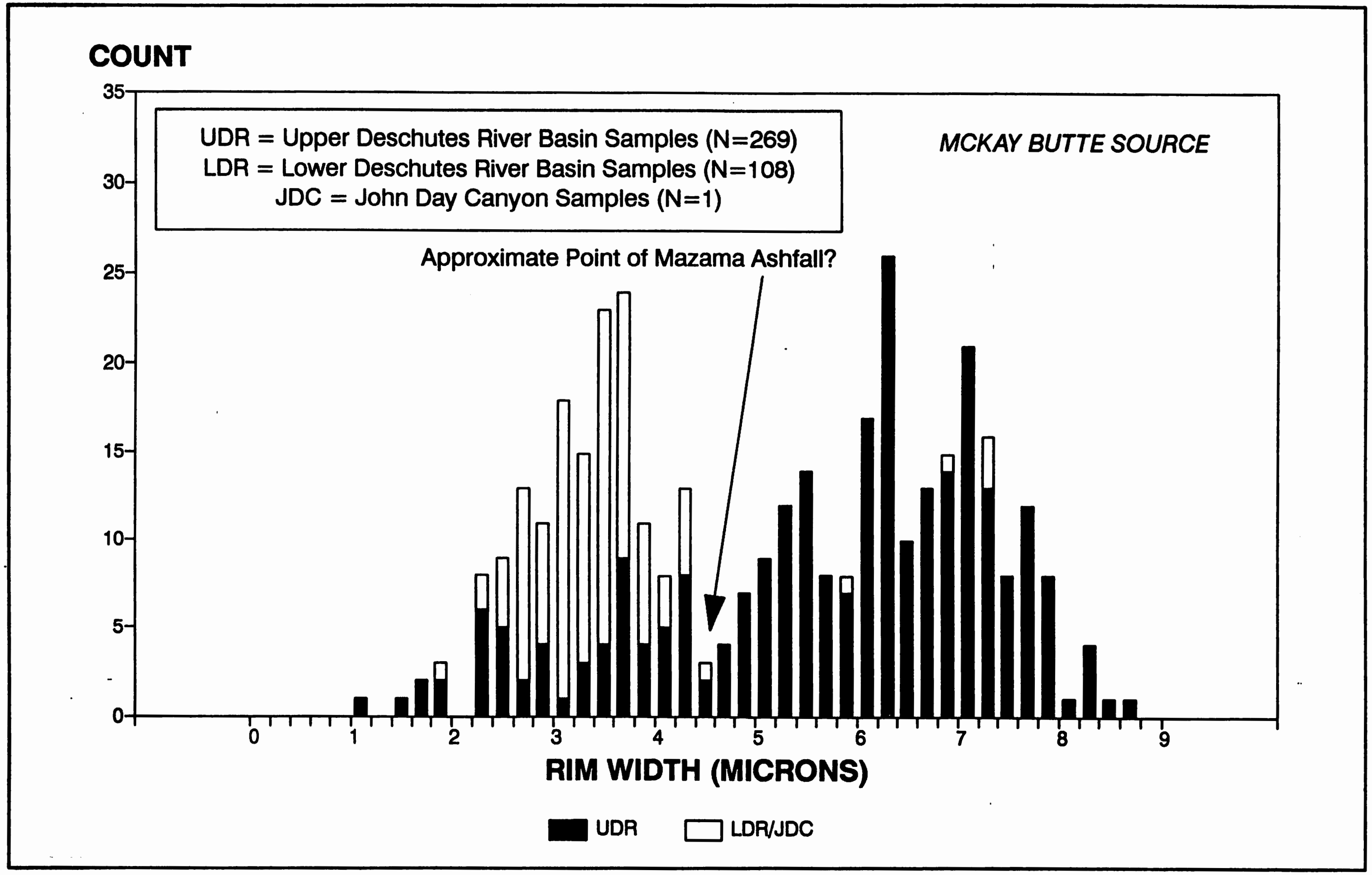
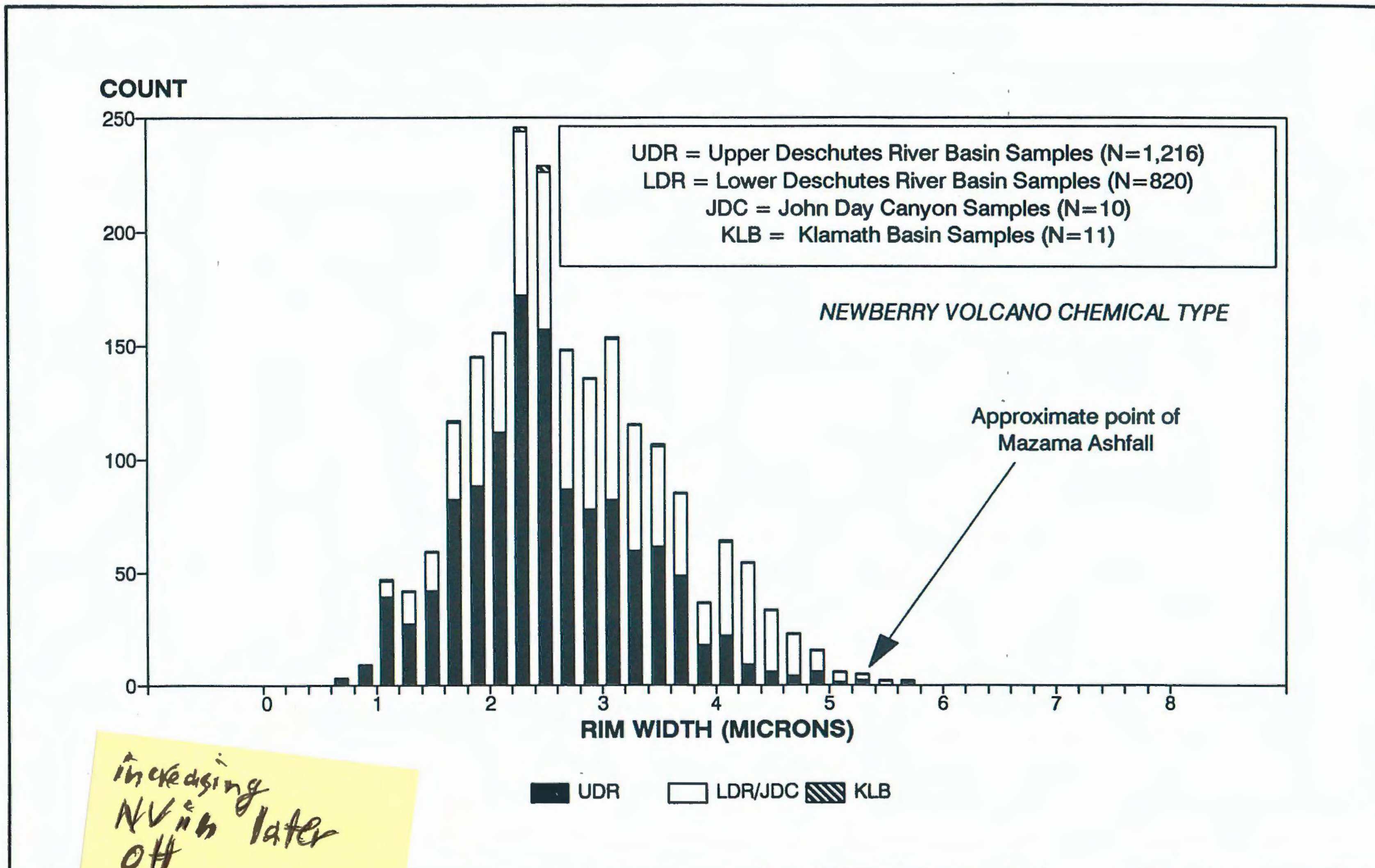


Figure 13. Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the McKay Butte source.



increasing
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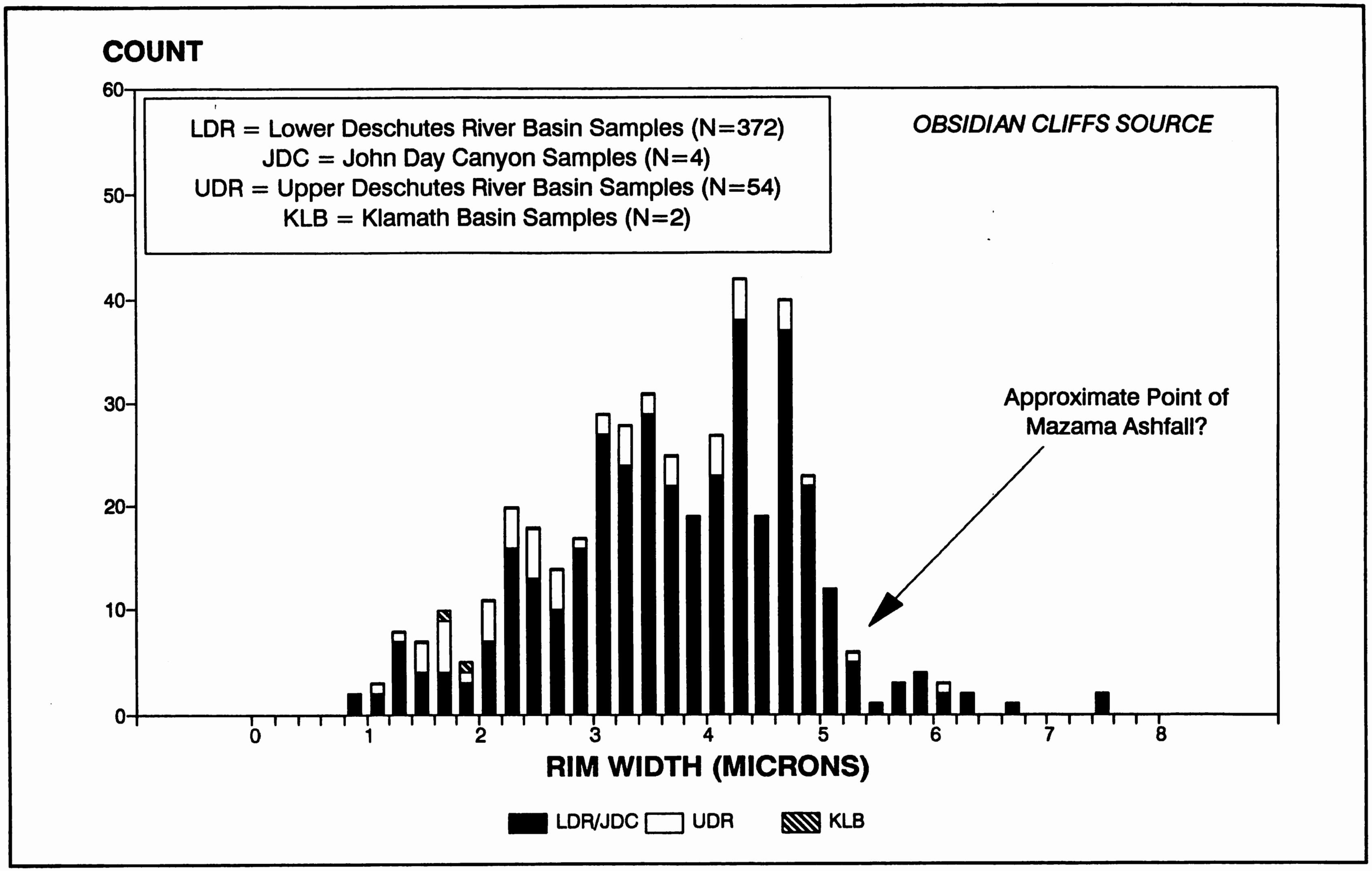

Figure 15. Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Obsidian Cliffs source.

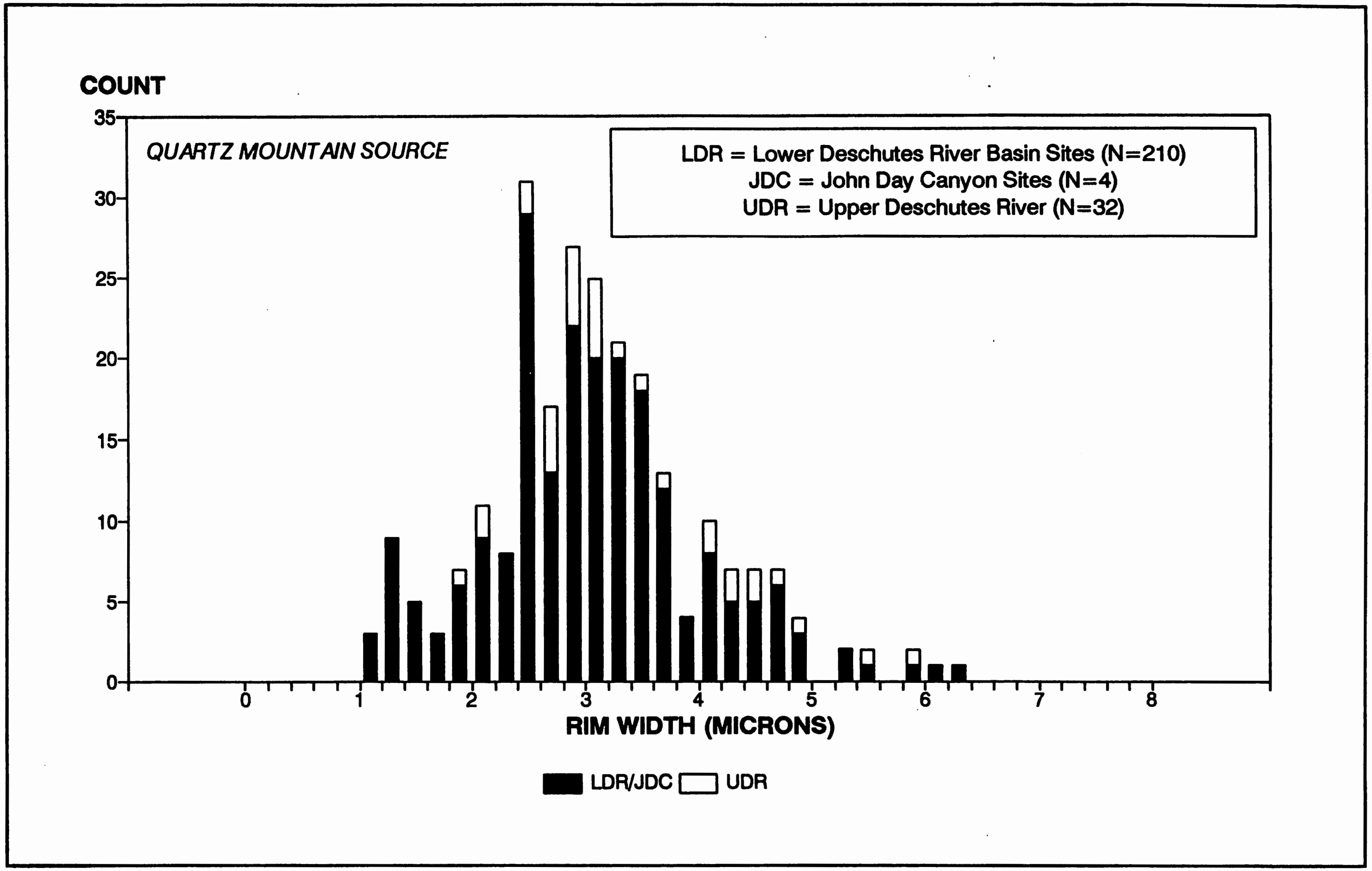

Figure 16. Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Quartz Mountain source.

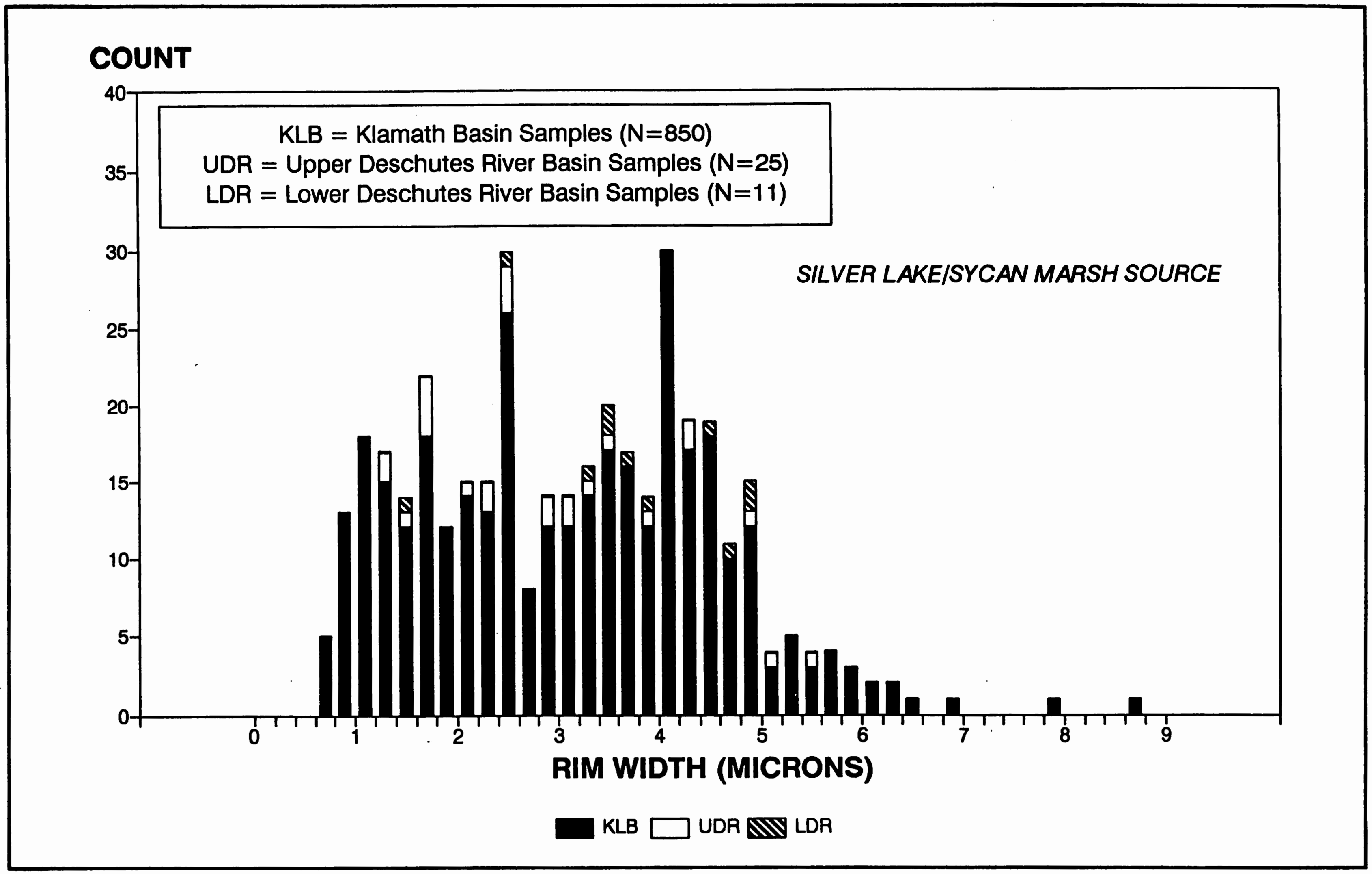

Figure 17. Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Silver Lake/Sycan Marsh source.

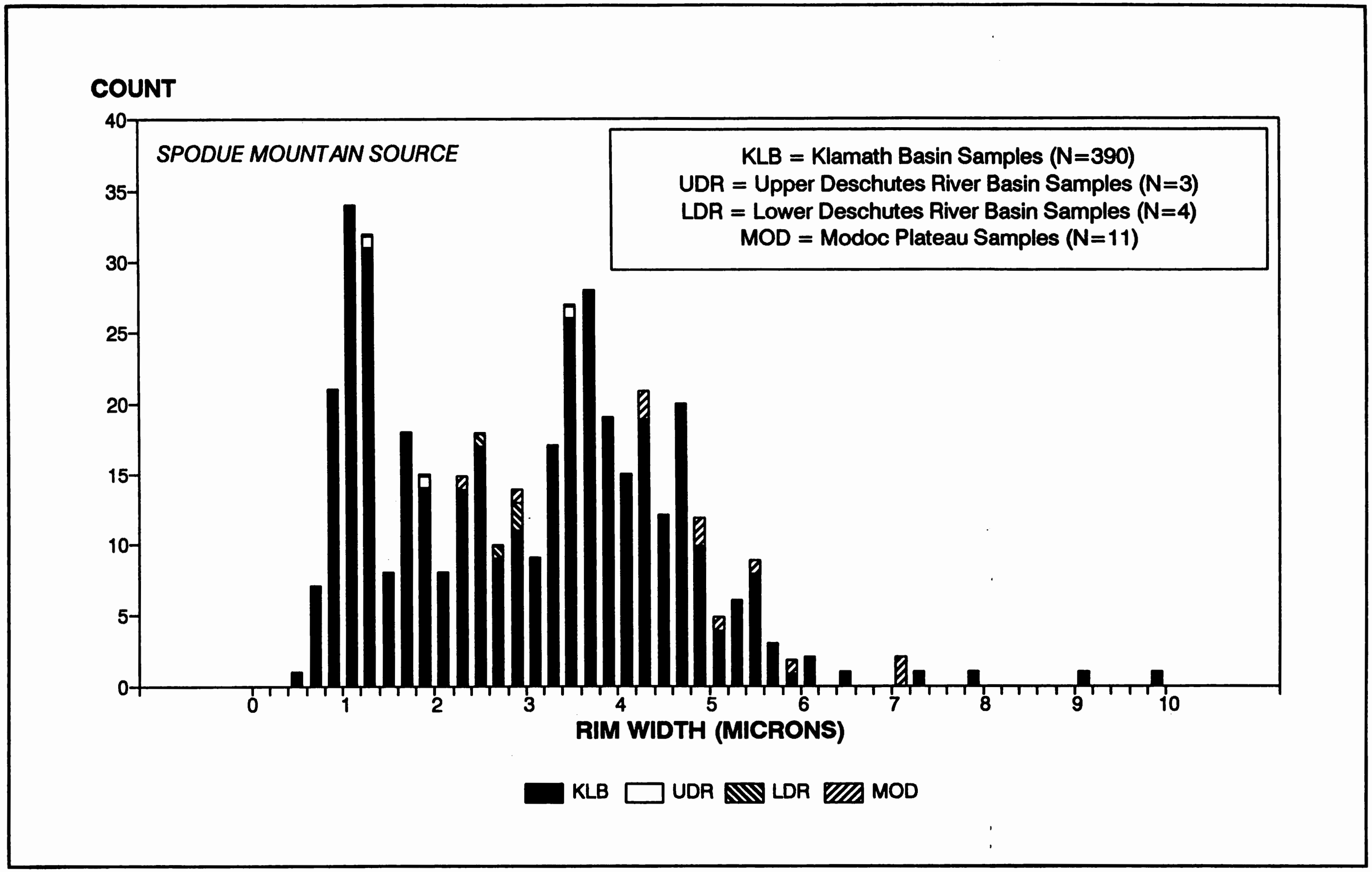

Figure 18. Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Spodue Mountain source.

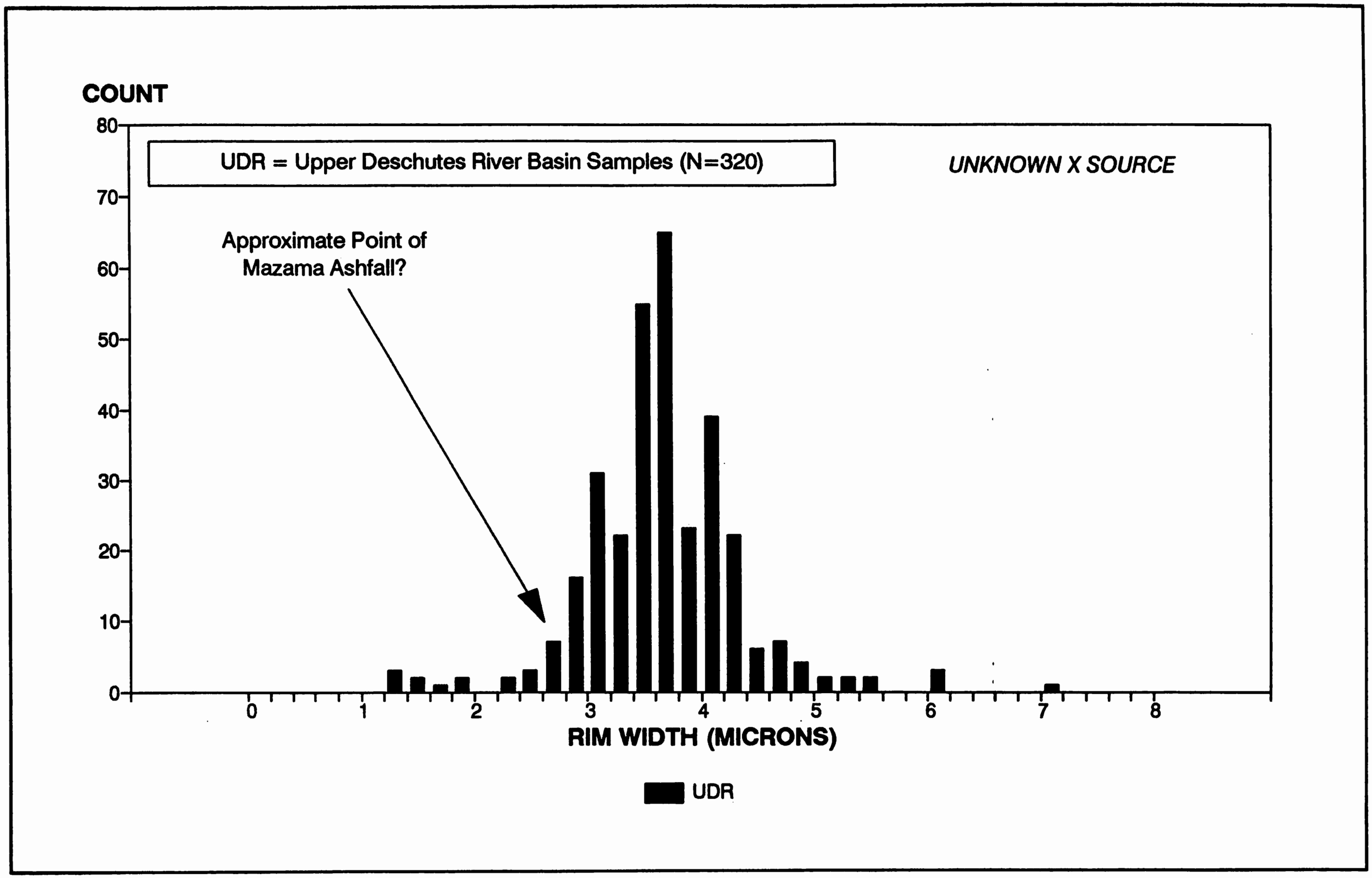

Figure 19. Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Unknown X Source.

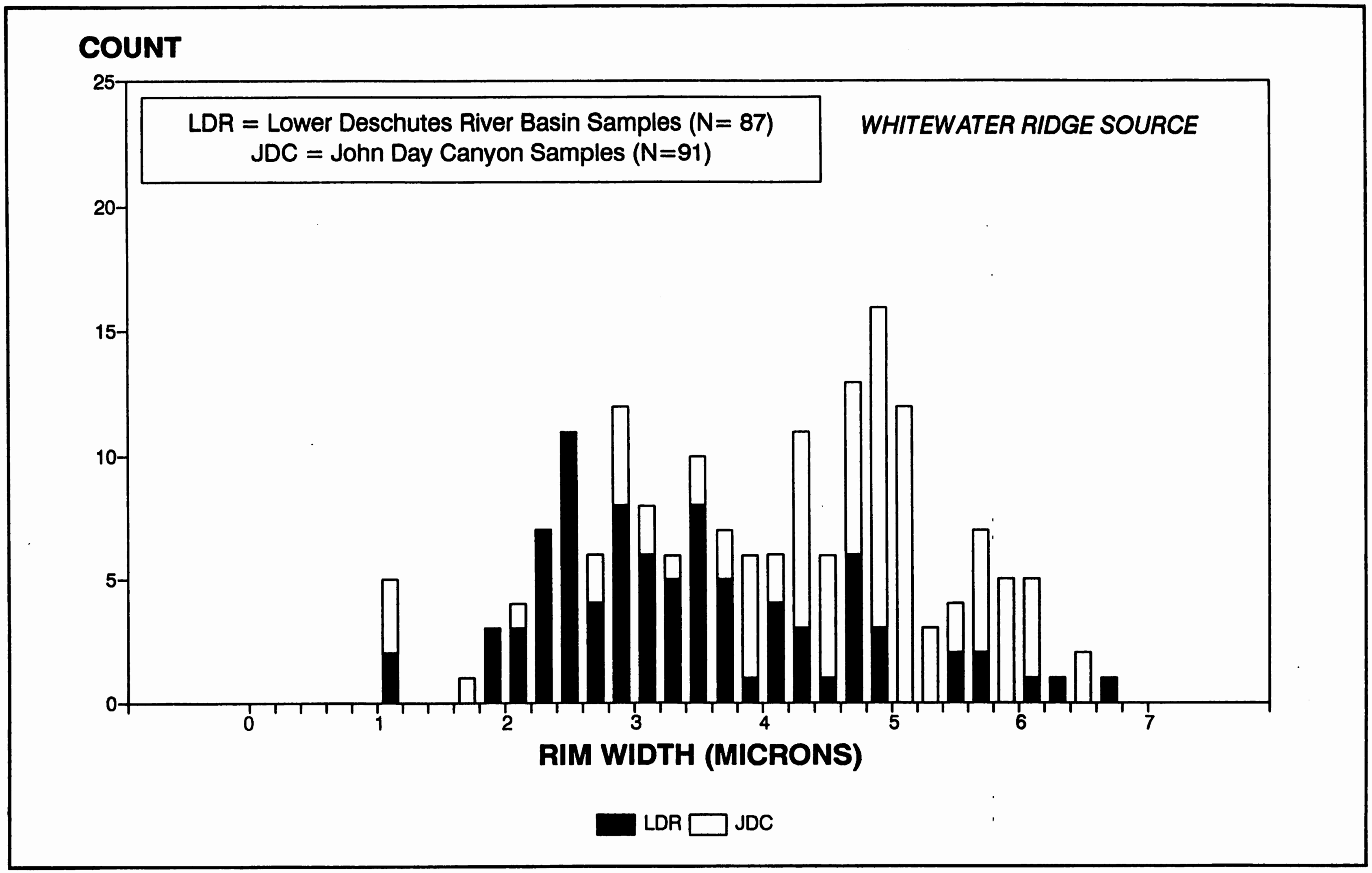

Figure 20. Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Whitewater Ridge source.

throughout most of the period of prehistoric Klamath Basin occupation sampled by the Pipeline Project. While the Silver Lake/Sycan Marsh source distribution frequency is relatively normal, the Spodue Mountain curve shows a tendency towards bimodality, with a peak in source intensity at about 1.0 microns. This may be attributable to an increasing dependency on Spodue Mountain glass during the historic period. Deposits of obsidian from the Silver Lake/Sycan Marsh source are found primarily in the uplands on the northeast margins of the Basin.

Spodue Mountain glass, on the other hand, is found much closer to Klamath Lake in alluvial deposits and in the highlands immediately north of the Sprague River Valley. As the Klamath Indians were increasingly concentrated in the immediate Klamath Lake area during historic times because of the increasing numbers of White settlers and territorial restrictions, access to the Silver Lake/Sycan Marsh materials may have become more difficult. This could have led to a historic shift in procurement behavior toward the use of more locally available Spodue Mountain obsidian.

Unknown X

Obsidian from the Unknown X source is concentrated within a relatively narrow range of hydration band values, although the narrowness of the peak is somewhat deceiving (Figure 19). The hydration rate of the Unknown X glass is slower than most other regionally-available sources and the micron equivalent of the Mazama ashfall may be as low as 2.5 microns (see the previous discussion). The Unknown X source was locally used throughout much of the Holocene prior to its possible burial by Mazama tephra. The restricted areal extent of Unknown X source use is clearly indicated by the geographic distribution of characterized artifacts. All samples assigned to this source came from Deschutes County sites, with over 95 percent originated from two proximate sources near McKay Butte, 35-DS-263 and 35-DS-557.

Whitewater Ridge

This recently identified chemical group has proven to be a major source of natural glass used by the prehistoric occupants of the John Day River Basin, and, to a lesser intensity, the Lower Deschutes River drainage. Many artifacts from north central Oregon sites that were previously not assignable to any known source have been found to correlate with the Whitewater Ridge chemical type.

The overall range of hydration band measurements varies from 1.1 to 6.7 μm, indicating that glass from the source was utilized over a comparatively long period of time (Figure 20). The obsidian hydration rim frequency curve, though, is bimodal by geographic region. There is a tendency for older items to be concentrated in the John Day River drainage (albeit, mostly from a single site, 35-GM-25) while later materials are more frequently found in Lower Deschutes River drainage sites. The large sample size from the Lower Deschutes Basin sites suggests that this pattern is real and not an artifact of differential site ages in the two regions. Gross examination of hydration rim values for John Day Basin artifacts suggests a shift in procurement from sources to the southeast (Glass Buttes, Whitewater Ridge) to sources located in the Newberry Volcano area. Whether this could be related to the eruption and subsequent wide use of Newberry Volcano raw materials or to shifting territorial and sociocultural changes must remain unanswered at this time.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In many areas of central Oregon, northern California, and central California, carbon suitable for radiocarbon determinations are often absent, while artifacts of natural glass are common. Obsidian hydration measurements provide a critical source of chronologic information in these regions. During the Pipeline Project, a total of 8,682 obsidian samples from 123 Idaho, Oregon, and California archaeological sites were selected for obsidian hydration studies. The geologic sources of the ensuing 7,409 successful hydration rim measurements were determined through characterization studies based primarily on the trace element composition of the obsidian.

Significant quantities of characterized artifacts with measurable hydration rims were originated from the Oregon sources of the Big Obsidian Flow, Glass Buttes, McKay Butte, Newberry Volcano, Obsidian Cliffs, Quartz Mountain, Silver Lake/Sycan Marsh, Spodue Mountain, Unknown X, and Whitewater Ridge.

Anomalous hydration rim values were recorded from artifacts correlated with the Big Obsidian Flow, Newberry Volcano. The discovery of a previously unrecognized older member of the Big Obsidian Flow chemical group provided an explanation for the Newberry source. Source production rate curves also indicate that obsidian from the McKay Butte and Unknown X sources, heavily used in the pre-Mazama period, falls off dramatically after the ashfall. We speculate that both sources may have been buried by Mazama tephra. After the Mazama ashfall, the newly erupted Newberry Caldera obsidian sources dominate the prehistoric landscape.

Using artifacts recovered from pre- and post-Mazama site components, it was possible to estimate the width of hydration bands for several different Deschutes County sources at the time of the ashfall. These hydration figures should prove useful in estimating site chronologies in future regional obsidian studies. The relative rates of hydration for several sources were also determined. Glass from Unknown X appears to hydrate at a considerably slower rate than other regional sources, while Newberry Volcano, McKay Butte, and Obsidian Cliffs artifacts hydrate at a notably faster rates.

Obsidian hydration rim frequency rate curves were examined as a means of initially determining the temporal depth and intensity of source use. The range in source-specific hydration values of analyzed artifacts provided clues about the overall temporal range of procurement at specific sources. Intensity of use, represented by modality and counts of artifacts, provides information about changes in use patterns over time and may have been caused by population changes, historical pressures, and/or differential use of sources in different geographic areas.

Recommendations for Further Research

Obsidian hydration studies in areas bisected by the Project corridor are still in their infancy, particularly for sites and sources located in Oregon. The hydration investigations undertaken during the analyses of PEP artifacts, while they go a long ways toward filling the gap in obsidian hydration data that formerly existed in central Oregon and northern California, also suggest improvements and directions to obsidian research in the Project area:

- *Explicit selection of obsidian artifacts found in association with datable materials.* The collection of obsidian artifacts found in association with materials suitable for radiocarbon dates or with temporal horizons such as the Mazama ashfall should be considered an explicit research objective when investigating archaeological sites in the Project area. When these items are not of sufficient size for standard XRF trace element analyses, the use of alternative characterization methods that use only very small samples is recommended. Resulting chronologic data will prove invaluable for the calculation of accurate future obsidian hydration rates.

- *Development of alternative obsidian characterization methods for small samples.* Reliable XRF techniques for obsidian artifact source identification are well established in the Far West and, because of this, little interest has been focused on the development of alternative characterization methods that would not be limited to the 0.8–1.0 mm minimum diameter now required for XRF analysis. Characterization techniques such as electron microprobe analysis or petrographic analysis of thin sections (already prepared during hydration sample studies) may prove useful, particularly in areas of lower source diversity (Merrick and Brown 1984; Skinner 1983).

- *Exploration of volcanic tephra hydration dating methods.* Deposits of well-dated silicic volcanic tephra are common throughout much of the Far West (Sarna-Wojcicki et al. 1983). Identical in chemical composition to obsidian, hydration measurements of shards of tephra from ash deposits have occasionally been used as a tephrochronologic technique (Davis 1984, Federman 1984, Steen-McIntyre 1977). Davis (1984), for instance, found rinds of 3.8 μm on shards of Mazama tephra from a Nevada archaeological site. Hydration studies of tephra deposits of known age could be used to provide important calibration data for the construction of obsidian hydration calibration curves and could also be used to explore the regional differences in rim measurements attributable to environmental influences such as elevation.

- *Experimental hydration studies of major obsidian sources.* Experimental high temperature and pressure studies of obsidian from different Far Western sources can provide valuable information about relative rates of hydration that can be applied to the construction of relative chronologies of sites for which hydration data already exist.

- *Careful exploration of obsidian hydration rates.* The calculation of valid obsidian hydration rates will be possible only when we have assembled an adequate database of analyzed obsidian artifacts that are closely associated with reliable chronologic information. The temptation to create and apply speculative and untested rates based on too few data, because of the tendency for any hydration rate to quickly become incorporated into the archaeological toolkits of regional researchers, should be assiduously avoided.

- *Sample size issues – how many is enough?* The issue of the relationship of the size of the sample to the reliability of obsidian hydration studies is one that has not been adequately addressed. How many samples is enough? At what point do more samples only produce redundancy? What is the role of source diversity and geographic location to sampling strategies?

- *Coordination of lithic technology and obsidian hydration studies.* Obsidian artifacts, particularly tools in areas where glass in not common, are subject to curation, scavenging, and retouch. Technological studies designed to guide the selection of the placement of hydration cuts are recommended so that the targeted use period is the one that is sampled during slide preparation.

- *Increased attention should be paid to the temperature variable during archaeological investigations.* There is little doubt that site temperature is a significant variable affecting the hydration rate of obsidian artifacts and that factors related to site temperature such as elevation must be considered. Despite this, little attention has been paid to the collection of detailed thermal site data with instruments such as Ambrose cells. What is the relationship of elevation and/or site temperature among different sites? Do intrasite differences in site microenvironments appreciably influence the hydration rate? How does depth of burial at specific sites affect the thermal history of an artifact? Without the careful collection of specific temperature-related data for sites under investigation, these important questions must remain unanswered.

- *Experimental investigation of the factors influencing the rate of hydration.* Although the basic variables that affect the hydration rate of obsidian glass are known, there is much still to be learned. The question of the role of intrinsic water content and hydration dating is one that urgently needs to be explored. The investigation of these variables under controlled experimental conditions can provide archaeologists with the necessary basic research information with which to successfully apply the obsidian hydration dating method to the imprecise environment of the archaeological site.

Beyond the immediate scope of the Pipeline Expansion Project, obsidian hydration studies offer an important chronologic approach to the study of archaeological materials. Many regions throughout the world are home to archaeologically important sources of obsidian and the lessons that we have learned in this Project can be applied to the interpretation of prehistoric chronologies in almost every continent on earth.

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