5.0 OBSIDIAN HYDRATION STUDIES

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5.1 INTRODUCTION

5.1.1 Sites and Samples

In addition to the obsidian characterization studies described in Chapter 4, complementary obsidian hydration studies were also adopted as an important chronologic component of PGT-PG&E Pipeline Expansion Project (PEP) research strategies. In Oregon and California, the Project 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.

A total of 9,210 obsidian samples from 131 Idaho, Oregon, and California archaeological sites was selected for obsidian hydration measurements as a part of Project testing and data recovery. Of the samples prepared for obsidian hydration analysis, 7,910 yielded measurable hydration rims. The geologic sources of all samples prepared for obsidian hydration measurements were determined through trace element characterization techniques and, for a limited number of samples, through visual characterization methods. The results of these obsidian characterization studies are reported in Chapter 4 and Appendices C.1 and C.2 of this volume.

In this section, the results of all PEP obsidian hydration studies are summarized from a Project-wide perspective. The significance of obsidian hydration studies to individual site chronologies is discussed in conjunction with the descriptions of individual sites that appear elsewhere in this report. Sites and sample size information is summarized in Tables 5-1, 5-2, and 5-3. The distribution of PEP sites selected for obsidian hydration studies is shown in Figure 5-1. Descriptions and locations of all obsidian sources addressed here are found in Appendix C.5.

Table 5-1 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	5,193	990	1	6,184
California	57	2,238	786	0	3,024
Total	131	7,424	1,776	1	9,210

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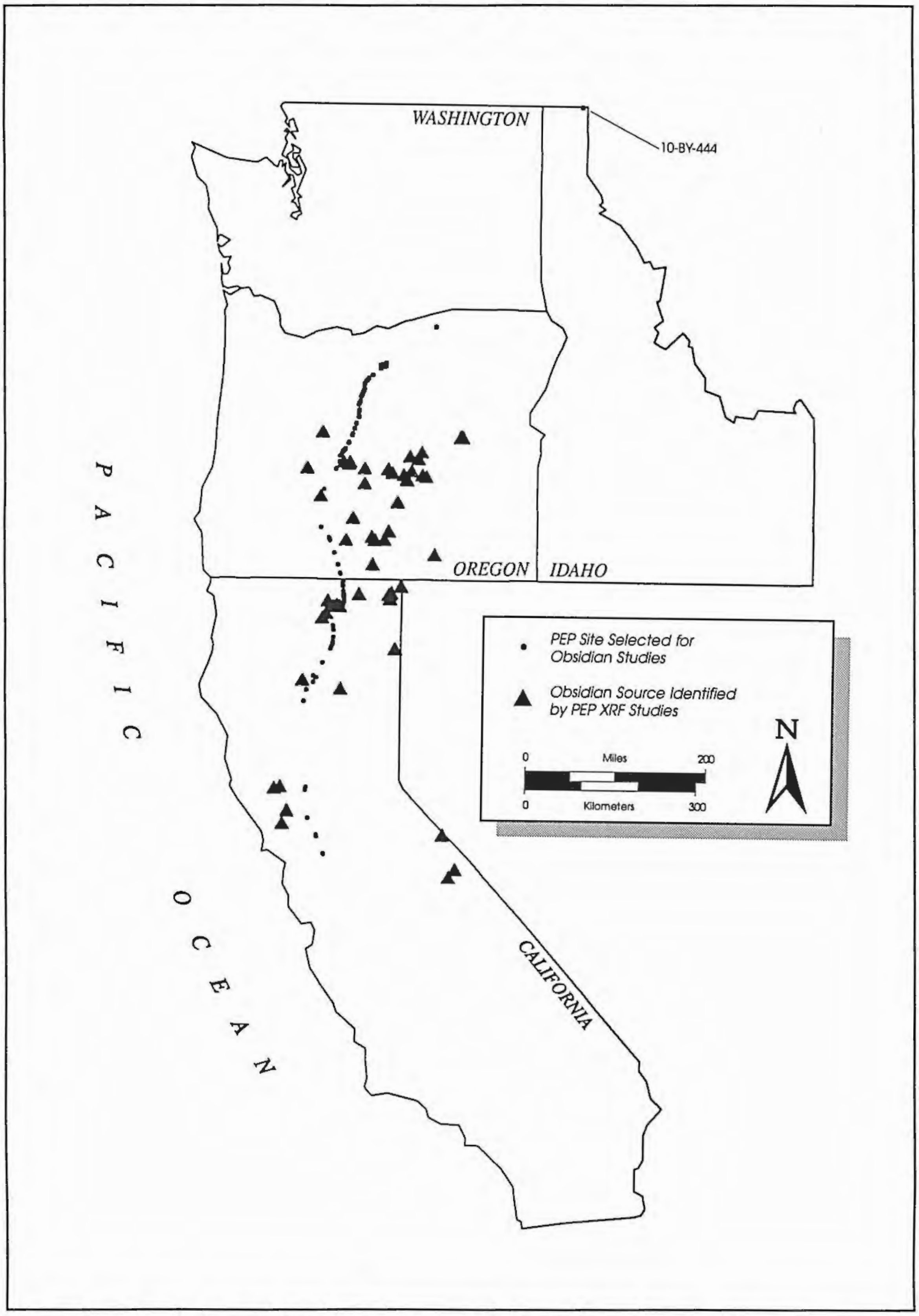

Figure 5-1 Distribution of Project sites selected for obsidian hydration studies.

Table 5-2 Summary of Northwest PEP Sites and Samples Selected for Obsidian Hydration Studies.

Site	Total OH[a]	Success[b]	Success (%)[c]	Tools[d]	Debitage[e]
IDAHO					
10-BY-444	2	1	50.0	0	1
Total Idaho	2	1	50.0	0	1
OREGON					
35-CR-626	104	99	95.2	2	97
35-CR-627	4	3	75.0	2	1
35-DS-33	964	787	81.6	154	633
35-DS-116	44	33	75.0	5	28
35-DS-263	408	324	79.4	19	304
35-DS-429	29	18	62.1	0	18
35-DS-554	23	11	47.8	1	10
35-DS-555	137	114	83.2	17	97
35-DS-557	652	386	59.2	71	315
35-DS-558	33	21	63.6	1	20
35-DS-559	53	49	92.5	21	28
35-DS-808	45	33	73.3	1	32
35-DS-809	11	9	81.8	1	8
35-DS-865	22	10	45.5	3	7
35-DS-866	25	21	80.0	0	21
35-DS-917	101	62	61.4	0	62
35-DS-983	37	34	91.9	15	19
35-DS-985	16	11	68.8	2	9
35-GM-25	132	130	98.5	22	108
35-JE-49	465	421	90.5	69	352
35-JE-50	42	39	92.9	10	29
35-JE-51B	500	470	94.0	55	415
35-JE-281	4	4	100.0	4	0
35-JE-282	2	2	100.0	1	1
35-JE-283	96	95	99.0	4	91
35-JE-284	6	6	100.0	0	6
35-JE-285	15	14	93.3	0	14
35-JE-286	1	1	100.0	1	0
35-JE-287	2	1	50.0	1	0
35-JE-288	6	6	100.0	2	4
35-JE-290	2	2	100.0	1	1
35-JE-291	13	13	100.0	3	10
35-JE-293	23	22	95.7	11	11
35-JE-296	88	83	94.3	14	69
35-JE-297	45	45	100.0	7	38
35-JE-298	33	33	100.0	11	22
35-JE-300	1	1	100.0	1	0

Table 5-2 (continued)

Site	Total OH[a]	Success[b]	Success (%)[c]	Tools[d]	Debitage[e]
35-JE-301	4	4	100.0	0	4
35-JE-302	83	78	94.0	2	76
35-JE-305	1	1	100.0	1	0
35-KL-810	356	273	76.7	54	219
35-KL-811	12	8	66.7	0	8
35-KL-812	153	122	79.7	26	96
35-KL-813	108	88	81.5	23	65
35-KL-814	254	226	89.0	61	165
35-KL-815	22	17	72.3	5	12
35-KL-816	1	0	0.0	0	0
35-KL-817	1	1	100.0	0	1
35-KL-818	41	29	70.7	11	18
35-KL-832	11	11	100.0	7	4
35-KL-834	9	5	55.6	0	5
35-KL-835	27	23	85.2	3	20
35-KL-865	2	2	100.0	0	2
35-SH-135	7	6	85.7	0	6
35-SH-137	3	3	100.0	3	0
35-SH-140	2	2	100.0	1	1
35-SH-145	41	41	100.0	3	38
35-SH-149	1	1	100.0	1	0
35-SH-150	3	3	100.0	0	3
35-UM-154	4	4	100.0	1	3
35-WS-120	20	18	90.0	3	15
35-WS-223	1	1	100.0	0	1
35-WS-224	7	7	100.0	1	6
35-WS-225	342	292	85.4	43	249
35-WS-226	15	14	93.3	1	13
35-WS-227	21	21	100.0	4	17
35-WS-230	3	3	100.0	1	2
35-WS-231	436	422	96.8	28	394
35-WS-232	1	1	100.0	0	1
35-WS-233	5	5	100.0	1	4
35-WS-239	1	1	100.0	1	0
PEP 6-23	1	1	100.0	0	1
PEP 7-3	1	1	100.0	1	0
Total Oregon	6,184	5,148	83.2	818	4,329
Total Northwest	6,186	5,149	83.2	818	4,330

[a] Number of samples prepared for obsidian hydration measurements; total may include non-artifacts.
[b] Number of prepared samples with measurable obsidian hydration rims.
[c] Percent of samples with measurable hydration rims.
[d] Number of tools with measurable hydration rims.
[e] Number of items of debitage with measurable hydration rims.

Table 5-3 Summary of California PEP Sites and Samples Selected for Obsidian Hydration Studies.

Site	Total OH[a]	Success[b]	Success (%)[c]	Tools[d]	Debitage[e]
CA-CCO-129	6	5	83.3	0	5
CA-CCO-368	52	43	82.7	4	39
CA-COL-165	62	58	93.5	5	53
CA-COL-178	31	26	83.9	0	26
CA-MOD-77	64	61	95.3	9	52
CA-MOD-128	5	5	100	2	3
CA-MOD-129	97	88	90.7	17	71
CA-MOD-1205	44	43	97.7	13	30
CA-MOD-1206/07	215	194	90.2	52	142
CA-MOD-1461	78	62	79.5	42	20
CA-MOD-2555	97	88	90.7	11	77
CA-MOD-2556	24	20	83.3	7	13
CA-MOD-2557	19	15	78.9	1	14
CA-MOD-2558	4	3	75	1	2
CA-MOD-2559	139	127	91.4	27	100
CA-MOD-2560	199	174	87.4	47	127
CA-MOD-2561	40	39	97.5	0	39
CA-MOD-2562	159	139	87.4	39	100
CA-MOD-2563	111	99	89.2	29	70
CA-MOD-2564	36	33	91.7	10	23
CA-MOD-2565	70	66	94.3	15	51
CA-MOD-2566/67	158	144	91.1	22	122
CA-MOD-2568	32	31	96.9	2	29
CA-MOD-2569	14	14	100	4	10
CA-MOD-2570	46	43	93.5	6	37
CA-MOD-2571	25	23	92	4	19
CA-MOD-2572	55	51	92.7	7	44
CA-MOD-2573	32	31	96.9	3	28
CA-MOD-2574	39	34	87.2	9	25
CA-MOD-2575	30	27	90	6	21
CA-MOD-2627	40	36	90	12	24
CA-MOD-2646	31	30	96.8	1	29
CA-MOD-2904	1	1	100	1	0
CA-SHA-68/H	174	166	95.4	51	115
CA-SHA-1474	28	27	96.4	1	26
CA-SHA-1836	3	2	66.7	2	0

Table 5-3 (continued)

Site	Total OH[a]	Success[b]	Success (%)[c]	Tools[d]	Debitage[e]
CA-SHA-1837	12	12	100	3	9
CA-SHA-1838/H	133	130	97.7	12	118
CA-SHA-1839/H	35	32	91.4	8	24
CA-SHA-1840	1	1	100	1	0
CA-SHA-1841	65	63	96.9	19	44
CA-SHA-1842	136	126	92.6	97	29
CA-SHA-1843/H	21	18	85.7	5	13
CA-SHA-1891	15	14	93.3	9	5
CA-SHA-1966	27	27	100	8	19
CA-SHA-1975	21	20	95.2	20	0
CA-SHA-1976	13	13	100	13	0
CA-SIS-1552	75	72	96	15	57
CA-SIS-1553	17	16	94.1	2	14
CA-SOL-347	10	6	60	1	5
CA-SOL-348	6	4	66.7	1	3
CA-SOL-351	16	16	100	1	15
CA-TEH-1528	71	62	87.3	9	53
CA-TEH-1529/H	59	51	86.4	12	39
CA-TEH-1611	26	26	100	4	22
CA-YOL-161	4	3	75	0	3
CA-YOL-177	1	1	100	1	0
Total	3,024	2,761	91.3	703	2,058

[a] Number of samples prepared for obsidian hydration measurements.
[b] Number of prepared samples with measurable obsidian hydration rims.
[c] Percent of samples with measurable hydration rims.
[d] Number of tools with measurable hydration rims.
[e] Number of items of debitage with measurable hydration rims.

Artifact provenience, classification, obsidian source assignments (determined from XRF analyses—see Chapter 4), and obsidian hydration measurements for all analyzed samples are presented in Appendices C.3 and C.4. Obsidian debitage recovered from the same provenience unit (lot) was differentiated by assigning each individual specimen an alphabetic item code in addition to the specimen number given to the lot group. All analyzed items are flaked stone artifacts. Mean hydration rim measurements (e.g., RIM1, RIM2) are presented in microns (μm); the standard deviation (e.g., SD1, SD2) of the multiple hydration rim measurements used to compute the mean immediately follows the reported rim thickness.

The results of all obsidian hydration studies associated with the Project are presented in this chapter. Interpretation of the prehistoric chronologies reflected by the hydration values are discussed in Volume II with respect to individual sites or in Volume IV, *Synthesis of*

Findings. The results of obsidian characterization and hydration studies from earlier periods of the Project have been reported and discussed as part of individual site descriptions or as technical studies appendices in previous testing and evaluation reports (Atwell et al. 1993; Holson et al. 1991; Lebow et al. 1991; Romano et al. 1993; Speulda 1993; Speulda et al. 1993). Results of the 1991 obsidian studies were also summarized by Skinner (1993a).

5.1.2 Principles of Obsidian Hydration Dating Methods

Introduction. 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 initially was developed in conjunction with geologic studies of the hydration of natural glass and the formation of perlite (Friedman et al. 1966; Ross and Smith 1955). Its application to archaeological chronologic problems was quickly recognized, however, and research concerning the effect of different variables on the rate of hydration has been 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 μm, 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 1 μm for items from the early historic period to nearly 30 μm for early sites in Africa (Michels et al. 1983; Origer 1989).

Once a hydration layer has been measured, it can be used to determine the relative ages of items or, in some circumstances, 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 typically is 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 determined directly through thermoluminescence or fission-track geochronologic methods (Fleischer et al. 1975; Huntley and Bailey 1978). The hydration rate also can be determined experimentally, an approach that has shown increasing promise in recent years (Friedman and Trembour 1983; Michels, Tsong, and Nelson 1983; Michels, Tsong, and Smith 1983; Tremaine 1989, 1993).

Sample Preparation. Although nondestructive techniques for measuring hydration rims have been used occasionally (Lanford 1978; Lee et al. 1974; Lowe et al. 1984), the primary method of artifact preparation for hydration rind measurement uses a petrographic thin section made from a piece of glass removed from the sample. A narrow slice of obsidian is cut from the edge of an artifact with a thin diamond-impregnated saw blade, ground flat using a powdered corundum slurry, and glued to a slide. The sample is then carefully trimmed to a thickness of approximately 30 μm and is covered with a glass cover slip (Friedman and Smith 1960; Michels and Tsong 1980). After preparation, the thickness of intact portions of hydration bands located along the edge of the artifact is recorded using a microscope.

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 5-2).

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

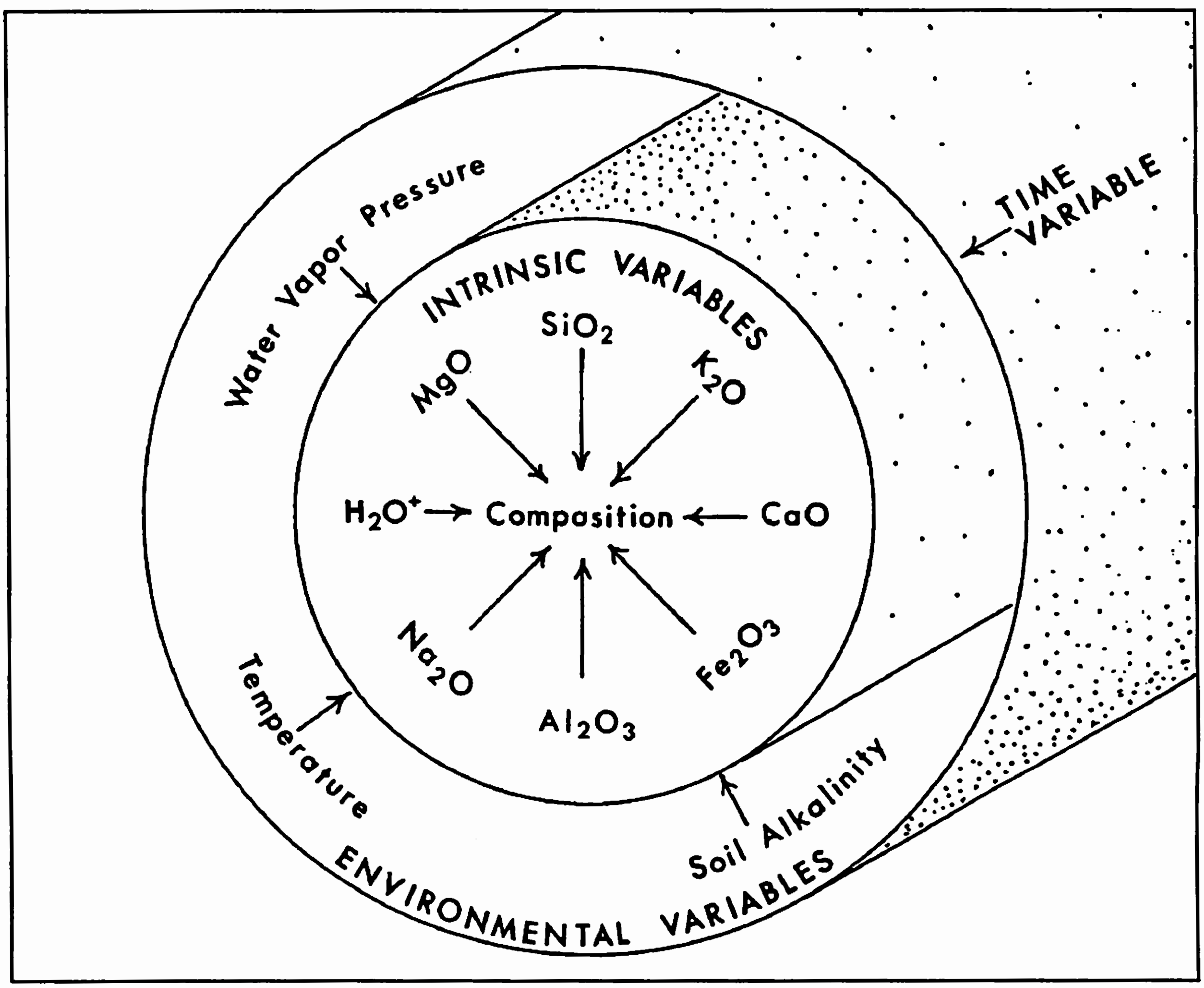

Figure 5-2 Major variables affecting the rate of hydration (from Skinner 1983:45).

Friedman and Trembour (1983) to be about 10 percent for each 1°C rise in temperature. It is clear from these data that the most effective use of obsidian hydration measurements is made among artifacts that have experienced very similar thermal histories.

It originally was 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). Buried diffusion cells that record long-term temperature and humidity information have been used in a few studies, but this technique 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 as a variable that might affect the rate of diffusion of water into the surface of obsidian. Their suggestion, despite subsequent archaeological evidence (Aiello 1969; Clark 1961; Kimberlin 1971), was largely ignored until the mid-1970s when it finally became widely accepted that the chemical composition of the glass was often the most important variable influencing hydration rate. Until this time, it was assumed that meaningful regional hydration rates, applicable over large geographic areas with similar temperature and environmental conditions, were possible. Following general recognition of the importance of composition, the concept of source-specific obsidian characterization studies was adopted for most archaeological obsidian hydration studies (Ericson 1975). Using the source-specific approach, the geologic source (i.e., the chemical composition) is determined through characterization studies prior to analysis and interpretation of hydration data. The results of Friedman and Long's attempts to calculate hydration rates using a combination of EHT and major element or refractive index data were encouraging (Friedman and Long 1976), but follow-up studies have not been undertaken.

Intrinsic Water Content: A New Complication. Recent research by Stevenson et al. (1993) indicates 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 infrared (IR) 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 for 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 impact of this research on obsidian hydration studies is 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.

<u>Relative Humidity</u>. 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 adsorption of water was clearly shown to be dependent upon 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.

<u>Soil Alkalinity</u>. 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 during the 30 years since the introduction of the method.

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 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 years, and k is a constant at a given temperature (the hydration rate expressed as $\mu m^2/1{,}000$ yrs). In Figure 5-3, different rates of hydration (t) are applied to this same diffusion equation.

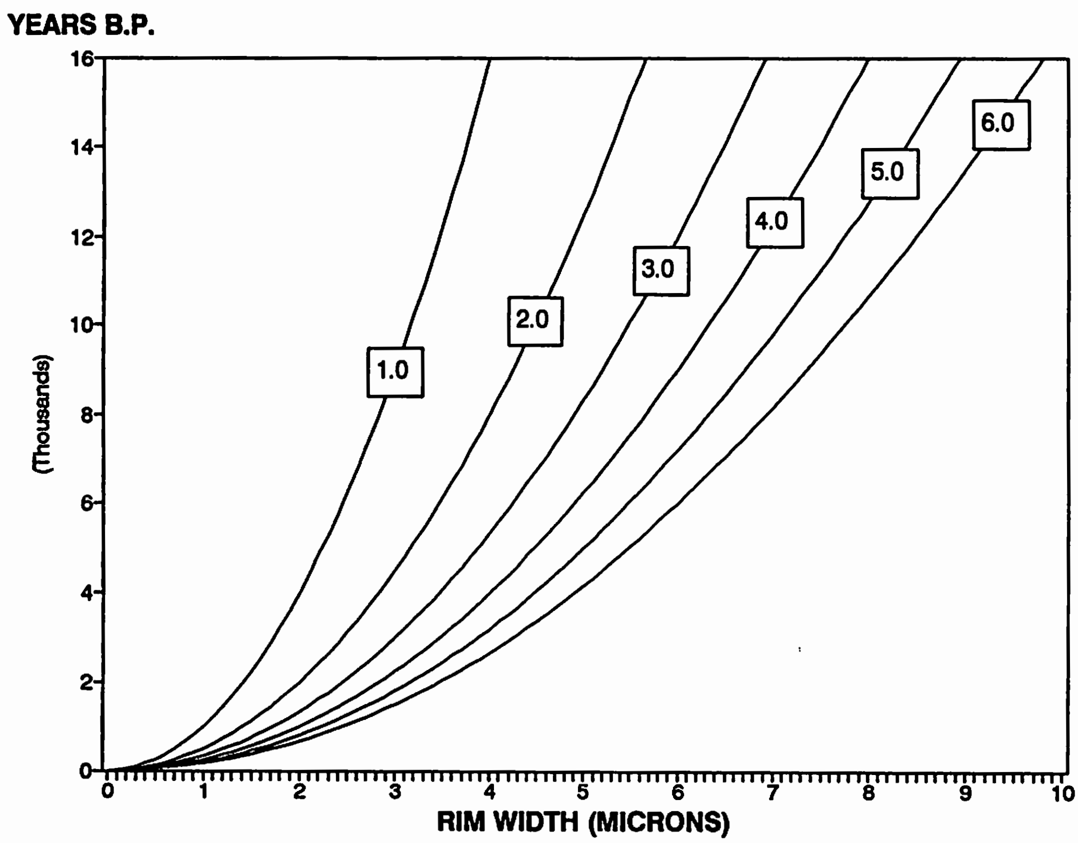

Figure 5-3 Examples of the results of different hydration rates applied to the diffusion model (x^2=kt) of hydration developed by Friedman and his associates. (1.0 = rate of 1 μm^2 /1,000 years, and so on).

Alternative hydration models based on linear, parabolic, square root, cubic, and other functions also have 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 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 provenances have shared similar cultural and thermal histories.

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 noncultural variables. In this chapter, 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 typically is 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 related to probable prehistoric behavior such as amplitude, kurtosis, range, and modality. A normal unimodal distribution of hydration rim readings (such as displayed in Figure 5-14 for Newberry Volcano) 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 periods. Multiple peaks in the distribution of rim values can suggest multiple periods of occupational intensity or, when the chemical source is controlled as in the example of Figure 5-7, the presence of glass from sources with different hydration rates. 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 (Tables 5-4 and 5-5) 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 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. Using the large sample sizes and descriptive methods outlined here, we can explore the prehistoric use of glass from 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.

What's in a Number? Obsidian hydration measurements are typically reported as a mean rim value (i.e., the average of several readings taken along the edge of an artifact). This is usually accompanied by an uncertainty figure, usually the standard deviation of the series of readings used to compute the average rim width. This uncertainty, however, reveals only the reading error and does not reflect the many other sources of variability or error that may affect the final reported rim measurement. The sense of precision that may be conveyed by the mean hydration rim value and reported uncertainty is something of an illusion—the actual uncertainty accrued through a variety of processes is almost certain to be greater than the reported error.

How precise are obsidian hydration measurements? Uncertainty in hydration rind values originate from several possible sources:

- *Problems in sample preparation and measurement.* Although the hydration front in a band is often fairly conspicuous, it can be confused with other optical effects by an inexperienced viewer, and highly inaccurate readings have occasionally been reported (Meighan 1981). An interlaboratory investigation by Stevenson et al. (1989) showed that even among experienced operators, significant differences in measurements of identical slides are sometimes found. Interlaboratory differences have also been reported by Bergland et al. (1992) and Jackson (1984a).

Table 5-4 Summary of Results of Obsidian Hydration Measurements of Northwest PEP Artifacts.

Site	Success[a]	Mode[b]	Median[c]	Range		
				All[d]	Tools[e]	Debitage[f]
IDAHO						
10-BY-444	1	ND	1.7	ND	ND	ND
OREGON						
35-CR-626	99	3.2 (14)	3.6	2.0–4.9	3.3–3.5	2.0–4.9
35-CR-627	3	ND	3.1	1.9–4.2	1.9–3.2	ND
35-DS-33	787	2.4 (80)	2.3	0.8–4.5	1.0–4.2	0.8–4.5
35-DS-116	33	2.6 (7)	2.5	1.3–3.7	1.5–3.0	1.3–3.7
35-DS-263	324	3.2,3.6,3.7 (26)	3.6	1.1–6.9	1.2–6.6	1.1–6.6
35-DS-429	18	6.1,6.3,6.4 (3)	5.6	3.4–6.4	ND	3.4–6.4
35-DS-554	11	1.7,1.8 (2)	2.2	1.5–4.0	ND	1.5–4.0
35-DS-555	114	3.1 (10)	3.0	1.0–5.6	1.1–5.3	1.0–5.6
35-DS-557	386	3.7 (19)	4.5	1.1–8.7	1.1–8.4	1.2–8.7
35-DS-558	21	3.0 (4)	3.1	1.2–4.7	ND	1.6–4.7
35-DS-559	49	2.6,4.2,4.3,4.5 (4)	3.8	1.8–7.0	1.8–7.0	2.3–5.0
35-DS-808	33	1.8 (5)	2.3	1.2–3.7	ND	1.2–3.7
35-DS-809	9	ND	3.1	2.5–3.8	ND	2.5–3.8
35-DS-865	10	2.4 (2)	4.3	2.2–6.6	2.4–5.9	2.2–6.6
35-DS-866	21	5.0 (5)	5.2	3.5–6.8	ND	3.5–6.8
35-DS-917	62	5.3,6.3 (5)	5.9	1.8–8.6	ND	1.8–8.6
35-DS-983	34	4.8 (5)	4.0	1.8–6.3	1.8–6.3	3.7–5.1
35-DS-985	11	1.4 (3)	2.8	1.1–5.4	3.4–5.0	1.1–5.4
35-GM-25	130	5.0 (13)	5.1	1.2–7.4	3.0–6.6	1.2–7.4
35-JE-49	421	2.5 (30)	2.8	0.9–8.5	0.9–7.3	0.9–8.5
35-JE-50	39	4.2,4.7 (6)	4.0	1.5–5.3	1.8–5.3	1.5–5.2
35-JE-51B	470	2.4 (30)	3.4	1.1–7.6	1.2–6.7	1.1–7.6
35-JE-281	4	ND	4.8	3.4–6.5	3.4–6.5	ND
35-JE-282	2	ND	4.4	4.0–4.8	ND	ND
35-JE-283	95	4.2 (15)	4.4	2.8–6.2	4.2–5.2	2.8–6.2
35-JE-284	6	ND	4.7	3.8–5.6	ND	3.8–5.6
35-JE-285	14	4.6 (3)	4.9	4.2–5.6	ND	4.2–5.6
35-JE-286	1	ND	5.7	ND	ND	ND
35-JE-287	1	ND	4.1	ND	ND	ND
35-JE-288	6	ND	3.9	1.4–6.6	1.4–2.9	3.7–6.6
35-JE-290	2	ND	2.8	2.3–3.4	ND	ND
35-JE-291	13	3.2,3.5 (3)	3.3	2.4–4.3	2.4–2.8	3.2–4.3
35-JE-293	22	2.1 (4)	2.7	2.0–4.3	2.0–2.4	2.2–4.3
35-JE-296	83	5.0 (7)	4.3	2.5–7.6	2.5–5.0	2.8–7.6
35-JE-297	45	4.4 (8)	4.3	2.9–6.1	3.0–4.4	2.9–6.1
35-JE-298	33	2.6 (4)	2.9	1.3–4.4	1.3–4.3	2.1–4.4
35-JE-300	1	ND	4.4	ND	ND	ND

Table 5-4 (continued)

Site	Success[a]	Mode[b]	Median[c]	Range All[d]	Range Tools[e]	Range Debitage[f]
35-JE-301	4	4.2 (2)	4.7	4.1–6.3	ND	4.1–6.3
35-JE-302	78	4.8 (15)	4.5	2.6–5.7	4.4–4.9	2.6–5.7
35-JE-305	1	ND	3.3	ND	ND	ND
35-KL-810	273	4.2 (15)	3.3	0.8–6.9	0.8–5.0	0.9–6.9
35-KL-811	8	3.1 (2)	2.5	1.1–3.6	ND	1.1–3.6
35-KL-812	122	1.3 (16)	2.1	0.9–5.8	1.0–4.5	0.9–5.8
35-KL-813	88	0.9 (15)	1.7	0.6–4.2	1.1–4.2	0.6–4.2
35-KL-814	226	3.7 (13)	4.1	0.9–9.9	0.9–8.8	0.9–9.9
35-KL-815	17	1.3,1.8 (2)	2.4	1.2–4.9	1.2–2.8	1.3–4.9
35-KL-816	0	ND	ND	ND	ND	ND
35-KL-817	1	ND	1.2	ND	ND	ND
35-KL-818	29	1.2 (4)	2.1	1.0–4.3	1.0–4.3	1.2–4.2
35-KL-832	11	1.7, 3.0 (2)	3.1	1.7–4.9	1.7–4.9	3.0–4.1
35-KL-834	5	ND	2.1	1.0–3.8	ND	1.0–3.8
35-KL-835	23	1.2,1.4 (3)	2.3	1.1–4.7	1.3–4.2	1.1–4.7
35-KL-865	2	ND	1.9	1.5–2.4	ND	1.5–2.4
35-SH-135	6	4.7 (3)	4.7	4.1–5.7	ND	4.1–5.7
35-SH-137	3	ND	2.5	2.0–3.1	2.0–3.1	ND
35-SH-140	2	ND	2.5	2.2–2.8	ND	ND
35-SH-145	41	3.9,5.0 (3)	3.5	1.1–5.1	3.0–4.9	1.1–5.1
35-SH-149	1	ND	3.7	ND	ND	ND
35-SH-150	3	ND	5.6	5.0–5.9	ND	5.0–5.9
35-UM-154	4	1.2 (2)	1.4	1.2–1.7	ND	1.2–1.7
35-WS-120	18	3.5 (5)	3.5	2.8–4.4	3.3–4.4	2.8–4.0
35-WS-223	1	ND	4.5	ND	ND	ND
35-WS-224	7	ND	4.3	3.1–5.3	ND	3.1–5.3
35-WS-225	292	1.9 (27)	3.0	1.2–7.7	1.5–5.1	1.2–7.7
35-WS-226	14	4.4 (2)	3.6	1.2–4.9	ND	1.2–4.9
35-WS-227	21	3.2 (5)	3.3	1.2–4.5	3.4–4.2	1.2–4.5
35-WS-230	3	ND	3.6	3.5–3.7	ND	3.6–3.7
35-WS-231	422	3.0,3.6 (35)	3.2	1.2–5.0	1.2–4.7	1.2–5.0
35-WS-232	1	ND	3.8	ND	ND	ND
35-WS-233	5	ND	4.3	3.5–5.0	ND	4.0–5.0
35-WS-239	1	ND	2.3	ND	ND	ND
PEP 6-23	1	ND	6.3	ND	ND	ND
PEP 7-3	1	ND	2.6	ND	ND	ND

[a] Number of artifacts from the site with measurable obsidian hydration rims.
[b] Modal value of rim measurements for all samples from the site; number of modal samples in parentheses.
[c] Median value of hydration rim measurements for all samples from the site.
[d] Range of obsidian hydration measurement for all samples from the site.
[e] Range of hydration rim measurements for all tools from the site.
[f] Range of hydration rim measurements for all debitage from the site.

Table 5-5 Summary of Results of Obsidian Hydration Measurements of California PEP Artifacts.

Site	Success[a]	Mode[b]	Median[c]	Range All[d]	Range Tools[e]	Range Debitage[f]
CA-CCO-129	5	ND	2.6	1.8–3.9	ND	1.8–3.9
CA-CCO-368	43	1.3,1.8,2.4 (4)	2.4	1.2–5.87	1.3–3.8	1.2–5.8
CA-COL-165	58	3.4,4.7,5.0,5.1,5.5 (4)	4.8	2.5–11.3	3.6–6.4	2.5–11.3
CA-COL-178	26	3.9 (3)	4	1.2–7.0	ND	1.2–7.0
CA-MOD-77	61	3.6,3.7,5.1 (4)	3.6	1.5–6.2	1.8–5.1	1.5–6.2
CA-MOD-128	5	ND	4	2.5–4.5	4.1–4.5	2.5–4.0
CA-MOD-129	88	6.2 (6)	4.9	1.0–13.1	1.2–5.2	1.0–13.1
CA-MOD-1205	43	3.7,3.9,5.9 (3)	4.4	1.1–7.8	1.1–4.5	2.0–7.8
CA-MOD-1206/07	194	5.1 (12)	4.3	0.8–8.6	0.9–7.4	0.8–8.6
CA-MOD-1461	62	1.7 (7)	1.9	0.9–4.8	0.9–4.8	1.0–2.3
CA-MOD-2555	88	3.6 (10)	3.6	1.3–7.1	1.3–6.3	1.6–7.1
CA-MOD-2556	20	2.8 (3)	2.8	1.4–3.9	2.6–4.5	1.4–3.9
CA-MOD-2557	15	1.7,2.0,2.4,3.4 (2)	2.4	1.7–3.4	1.8-1.8	1.7–3.4
CA-MOD-2558	3	2.7 (2)	2.7	2.0–2.7	2.0-2.0	2.7-2.7
CA-MOD-2559	127	5.3,5.6 (7)	5	1.1–24.0	1.6–7.1	1.1–24.0
CA-MOD-2560	174	1.8 (13)	2.6	1.1–6.6	1.2–4.9	1.1–6.6
CA-MOD-2561	39	2.4,2.5,2.7 (4)	2.8	1.4–5.0	ND	1.4–5.0
CA-MOD-2562	139	2.4,2.5,3.1 (10)	3.2	1.1–7.1	1.1–7.0	1.2–7.1
CA-MOD-2563	99	2.8,3.1 (7)	3.5	1.1–6.3	1.1–5.7	1.2–6.3
CA-MOD-2564	33	4.8 (4)	4.8	1.8–7.4	1.8–7.4	1.8–7.4
CA-MOD-2565	66	1.1,1.2,3.5,4.9,5.1, 5.5,5.6,6.0 (3)	4.4	1.1–6.6	1.5–6.3	1.1–6.6
CA-MOD-2566/67	144	5.0,6.2,6.4 (6)	5.7	1.3–10.2	3.1–8.1	1.3–10.2
CA-MOD-2568	31	2.6,2.7 (4)	2.7	1.8–5.0	2.7-3.4	1.8–5.0
CA-MOD-2569	14	3.7 (3)	3.3	0.8–4.6	1.5–4.2	0.8–4.6
CA-MOD-2570	43	5 (5)	5	1.1–7.7	2.0–5.7	1.1–7.7
CA-MOD-2571	23	4.4 (3)	4.6	1.1–5.7	3.6–4.8	1.1–5.7
CA-MOD-2572	51	4.8 (8)	4.7	1.0–6.5	1.0–4.9	1.0–6.5
CA-MOD-2573	31	6.6,8.0 (3)	7.2	1.6–10.5	6.5–9.2	1.6–10.5
CA-MOD-2574	34	2.5 (3)	2.9	1.3–5.8	1.6–4.6	1.3–5.8
CA-MOD-2575	27	2.7,3.6 (3)	3.2	1.4–7.2	1.4–4.7	1.8–7.2
CA-MOD-2627	36	4.3 (4)	3.8	1.1–7.1	1.1–7.14	1.8–5.9
CA-MOD-2646	30	3.4 (4)	3.5	1.8–4.8	4.1-4.1	1.8–4.8
CA-MOD-2904	1	ND	5	5.0-5.0	5.0-5.0	ND
CA-SHA-68/H	166	4.1 (10)	3.5	0.9–5.9	0.9–5.8	1.0–5.9
CA-SHA-1474	27	6.1 (3)	4.8	0.9–6.9	4.6-4.6	0.9–6.9
CA-SHA-1836	2	ND	3	2.9–3.0	ND	ND
CA-SHA-1837	12	2.0,3.1 (2)	3.1	1.9–4.1	2.1–4.1	1.9–3.7
CA-SHA-1838/H	130	3.6,4.9 (8)	4.1	1.2–7.3	2.2–8.9	1.2–7.3

Table 5-5 (continued)

Site	Success[a]	Mode[b]	Median[c]	Range		
				All[d]	Tools[e]	Debitage[f]
CA-SHA-1839/H	32	1.3 (6)	2	1.1-14.6	1.1-5.3	1.1-14.6
CA-SHA-1840	1	ND	1	1.0-1.0	1.0-1.0	ND
CA-SHA-1841	63	1.8 (5.0)	2.7	1.1-7.4	1.1-7.4	1.2-4.6
CA-SHA-1842	126	1.8 (14)	1.8	0.9-5.4	0.9-5.4	1.0-4.7
CA-SHA-1843/H	18	1.2 (6)	1.2	1.1-2.5	1.1-2.5	1.1-2.0
CA-SHA-1891	14	1.3,1.5 (3)	1.5	1.1-3.7	1.1-2.3	1.5-3.7
CA-SHA-1966	27	1.3 (4)	1.7	1.0-4.3	1.1-2.9	1.0-4.3
CA-SHA-1975	20	1.3 (7)	1.3	0.9-3.1	ND	ND
CA-SHA-1976	13	2.1,2.2,2.4 (2)	2.3	1.1-3.7	1.1-3.7	ND
CA-SIS-1552	72	2.5 (7)	3	0.9-6.7	1.0-6.4	0.9-6.7
CA-SIS-1553	16	0.8,1.0 (3)	1.6	0.8-4.4	1.1-2.5	0.8-4.4
CA-SOL-347	6	ND	3.4	1.0-18.8	4.1-4.1	1.0-18.8
CA-SOL-348	4	ND	5.4	3.2-7.1	5.0-5.0	3.2-7.1
CA-SOL-351	16	1.7 (3)	1.8	1.2-3.8	3.3-3.3	1.2-3.8
CA-TEH-1528	62	2.5,2.7 (6)	3.1	1.3-10.0	1.8-6.3	1.3-10.0
CA-TEH-1529/H	51	3.1 (7)	3.8	1.9-5.1	2.5-7.1	1.9-5.1
CA-TEH-1611	26	5.4 (5)	3.8	1.0-9.5	1.1-5.4	1.0-9.5
CA-YOL-161	3	ND	4.2	4.1-4.3	ND	4.1-4.3
CA-YOL-177	1	ND	3.2	3.2-3.2	3.2-3.2	ND

[a] Number of artifacts from the site with measureable obsidian hydration rims.
[b] Modal value of rim measurements for all samples from the site; number of modal samples in parentheses.
[c] Median value of hydration rim measurements for all samples from the site.
[d] Range of obsidian hydration measurement for all samples from the site.
[e] Range of hydration rim measurements for all tools from the site.
[f] Range of hydration rim measurements for all debitage from the site.

- *Failure to adequately consider the thermal variable.* After more than 30 years, the effects of temperature have still proven difficult to account for when analyzing archaeological collections. Temperature studies and the determination of EHT at individual sites provide a potential solution to part of the problem. The effects of microenvironmental factors and site modification processes during and after occupation, however, may prove significant. It is, in summary, often difficult to know the relationship between the provenience in which an artifact is recovered, the time of deposition, and the thermal history of the item.

- *Failure to adequately consider the compositional variable.* Failure to control for the chemical composition of analyzed artifacts, a major weakness in early hydration studies, is still occasionally seen today. Without characterization studies, it is always risky to assume the presence of only a single chemical source with a single hydration rate. Even at quarry locations, the process of "dumping" during retooling may lead to the discard of foreign materials (Andrefsky 1994). The effects of water content reported by Stevenson et al. (1993) adds another uncertainty to the compositional equation and only time will tell how their observations will affect previous and future obsidian hydration investigations.

- *The calculation of an incorrect rate of hydration.* The empirical construction of an accurate hydration rate requires several dates spread over a considerable time span that can be closely associated with measurable artifacts. The use of too few dates and/or those which are not in direct association with the artifacts in question can very easily lead to the calculation of erroneous rates. Depending on the rate used, as pointed out by Meighan (1983), the degree of the error can also become increasingly magnified through time, sometimes to preposterous proportions.

- *The use of inappropriate rates of hydration.* In any region where hydration rates already exist, there is a tendency for later researchers to uncritically adopt those rates, no matter how tentative their construction. Diffusion models and rates borrowed from other regional archaeological studies, although providing a tempting solution to the often difficult problems encountered in developing archaeological chronologies, must be applied with considerable caution.

- *Reuse and recycling of obsidian.* In the current investigation, two unexpectedly large hydration rims were recorded on what were considered to be temporally-sensitive projectile point styles. In both cases, careful reexamination of the original slides revealed the presence of a second thinner rim that was more congruent with the expected age of the artifact. The most reliable measurements result when the placement of hydration cuts, particularly on tools, is accompanied by a technological analysis of the item.

- *Inadequate sample size.* Many obsidian hydration studies have been based on small sample sizes. The effects of sample size on interpretation are a problem that has not been adequately addressed to date.

Clues from Conjoinable Artifacts and Caches. Hydration studies of conjoinable artifacts and obsidian artifacts from caches also provide us with some clues about the precision and reliability of obsidian hydration measurements.

At 35-KL-810, two conjoinable bifaces were identified after the completion of characterization and hydration analyses (Atwell et al. 1993). Although only one pair of refitted fragments (Specimens 999-3 and 1071-2) yielded readable hydration bands, the results are intriguing. Hydration rims at the break point were found to be, respectively, 3.6 and 3.7 μm; bands measured elsewhere on the fragments were found to be 3.4 and 4.1 μm. The fragments showed no sign of reuse or reworking, clearly demonstrating that an artifact may develop variability in rim thicknesses through time.

Other evidence comes from caches of bifaces recovered in Oregon and California. In describing a portion of a buried cache of over 30 obsidian bifaces from the Western Cascades of Oregon, Rogers (1993) reports that hydration rim values of 10 characterized specimens ranged from 2.3 to 2.4 μm. All the bifaces likely were manufactured at the same point in time and have experienced identical thermal environments since burial. However, even under these identical environmental circumstances, some small variability in rim measurements is evident. In another study, the Caballo Blanco Cache of 16 obsidian bifaces from the Mt. Konocti source in California's North Coast Range was analyzed by Gary and McClear-Gary (1990). Hydration values for these artifacts, recovered from a much more disturbed context than the Oregon cache, range from 3.3 to 4.0 μm with an outlier of 4.9 μm.

In spite of the problems encountered with obsidian hydration dating, research continues. The simplicity and potential value of the technique far outweighs the possible problems. Keeping in mind the dangers of overinterpretation of obsidian hydration data, the method is one that will see continued and refined use in Far Western archaeological applications.

Multiple Hydration Rims. Sources of lithic material are not confined to natural deposits and may include cultural deposits as well. The debris left by former groups may provide a rich source of usable lithic materials for subsequent inhabitants of the same sites (Waechter and Origer 1983). Specific ethnographic examples of the scavenging and reuse of obsidian tools have been reported by Lowie (1924) and Murdock (1980); it is likely that the practice was common. Michels (1969) attributed the existence of stratigraphic discrepancies in hydration rim values to reuse. The presence of more than one thickness of hydration band, however, may occasionally be due to the measurement of rims on a combination of natural cortex and cultural surfaces, particularly when anomalously large values are encountered for one of the rinds. We attribute most of the multiple rims identified during the Project to the scavenging and reuse of previously utilized cultural materials. The problem of multiple hydration bands has been most recently addressed by Waechter and Origer (1993).

Multiple hydration bands of different thicknesses were found on 132 obsidian artifacts from 59 California and Oregon PEP sites, less than 2 percent of the successfully measured artifacts. The percentage of artifacts with more than one band was slightly higher among California than Oregon sites—39 percent of the multiple rims were found on 29 percent of the analyzed artifacts. Similarly, Oregon sites located farther from natural sources of glass typically had larger numbers of reused items. Conversely, sites in areas of abundant glass showed very low frequencies of reused items. Of 1,923 artifacts with hydration bands from Deschutes County sites, for instance, only six showed evidence of reuse. The relationship of source availability and reuse suggested by these data intimate, not surprisingly, that raw material reuse is more intensive in areas of relative raw material scarcity.

5.1.3 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 6,845 ± 50 B.P. eruption of Mount Mazama (Bacon 1983) also can 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 throughout the Deschutes and John Day drainages and provides an important regional chronostratigraphic marker (see Chapter 7). No attempt was made here to determine hydration rate equations or to use previously published hydration rates, such as those 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 the previously discussed investigations of the effect of intrinsic water content on hydration rates 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.

5.2 METHODS

5.2.1 Sample Selection

With the exception of 396 visually characterized artifacts from several California sites (n=347) and Oregon site 35-JE-49 (n=49), sources for all samples selected for obsidian hydration measurements were determined through trace element studies (see Appendices C.1 and C.2 for results).

5.2.2 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 of BioSystems Analysis and Dr. Christopher Stevenson of 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 ground until any damage created by the saw blade during cutting was eliminated, and 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 with 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 Appendices C.3 and C.4 as the hydration rim width. The hydration measurements also have an uncertainty of about $\pm$ 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.

5.2.3 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 (Table 5-2). 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. The possible origin of the encrustation is discussed in Chapter 4. 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 other areas of the project, the success rate for measurable rims was often greater than 90 percent.

5.2.4 Induced Hydration Experiments

Given the importance of the compositional variable in the hydration rate of obsidian, it is assumed that chemically-similar obsidians from different sources will hydrate at similar rates. In previous archaeological studies, the hydration rate of glass from three of the four Grasshopper Group sources of the Medicine Lake Highlands has been assumed to be identical (Basgall and Hildebrandt 1989). The comparability of rates among these sources, however, had not yet been empirically demonstrated.

Samples from the geochemically indistinguishable Grasshopper Flat, Lost Iron Well, and Red Switchback sources were sent to Diffusion Labs, Inc. for induced hydration experiments. Obsidian flakes from each location were hydrated at 160° for 24 days in 500 ml of distilled ionized water containing 500 g of amorphous silica. At the end of the reaction period, samples were prepared as thin sections and were examined for hydration rims. Rims from Grasshopper Flat samples averaged 5.92 μm; Lost Iron Well samples averaged 6.01 μm and Red Switchback specimens averaged 6.02 μm. Based on these results, we conclude that the hydration rate of obsidian from these three sources is, as expected by their geochemical similarities, virtually identical (Holson et al. 1991).

5.3 RESULTS

The results of the obsidian hydration analyses of the 9,210 analyzed and 7,910 successfully measured PEP artifacts are presented in Appendices C.3 and C.4. The range and average value of analyzed specimens are graphically summarized in Figures 5-4 and 5-5. The mode, median, and range of values for all sites in which obsidian artifacts were successfully measured are presented in Tables 5-4 and 5-5.

When the mode and median are approximately equivalent, a normal distribution of obsidian hydration can often be assumed. Modal and median values that are substantially different usually indicate a bimodal or skewed distribution and the resultant production curves may yield significant cultural information. The range of hydration rind values for debitage and tools is also presented separately. The range of rim measurements can be influenced by

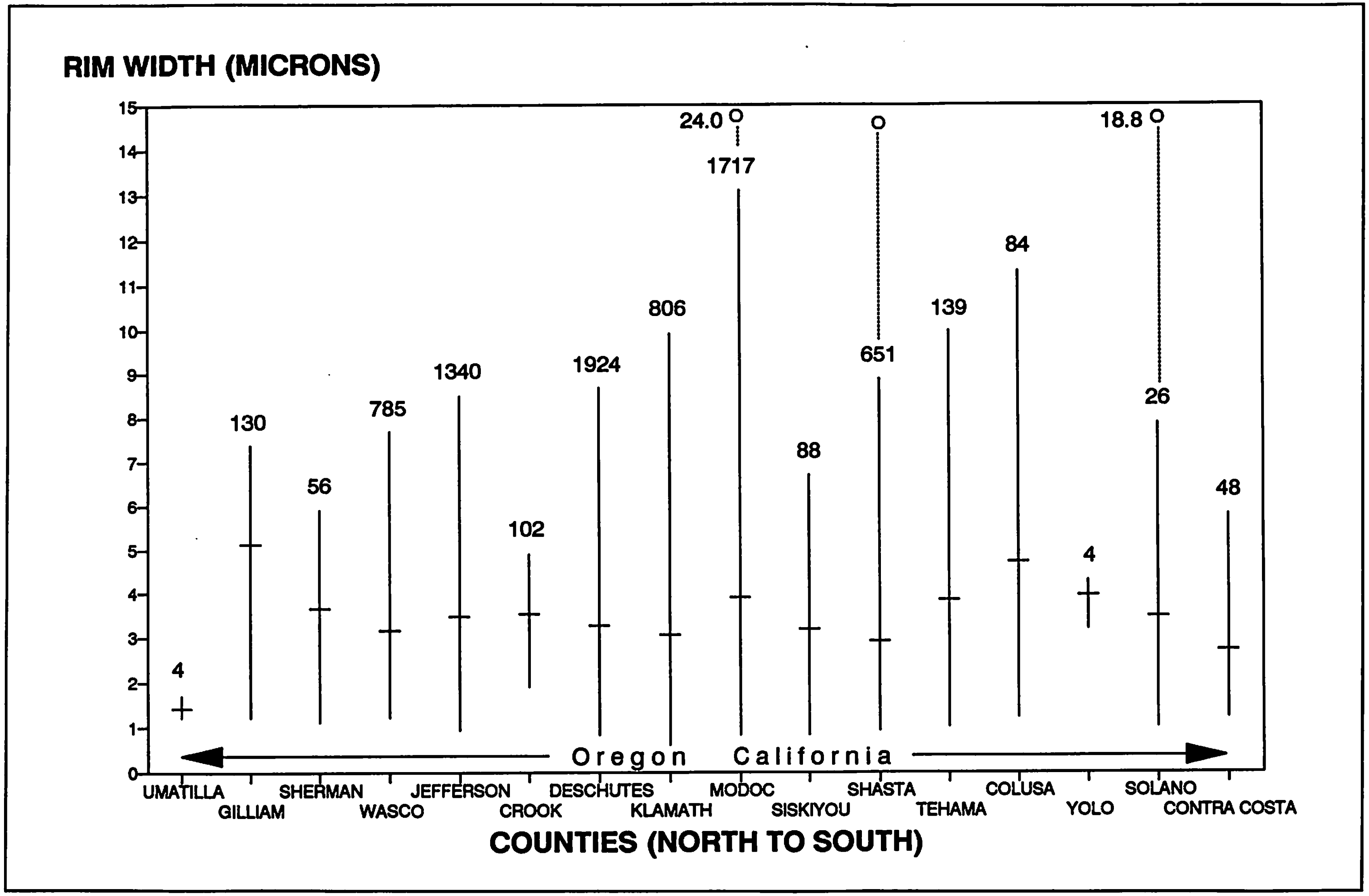

Figure 5-4 Ranges of obsidian hydration measurements for artifacts from PEP sites located in different Oregon and California counties. (The vertical bar spans the maximum to minimum hydration values; the horizontal tic is placed at the mean value. The number above each bar marks the size of the data set. When the values of outliers (empty circles) fall outside the range of the y-axis, the rim measurements are indicated).

numerous factors including the overall time span and intensity of site occupation, the differential curation value of different artifact categories, ease of availability and value of specific raw materials, and sample size. In most cases, the differences in sample size between debitage and tools obscures any real variability in rim values for these two broad artifact categories.

5.3.1 Idaho

The hydration rim for a single artifact, one of only two prepared for hydration analysis from Idaho sites, was determined (Table 5-4). The rim value of 1.7 μm falls easily within the long period of prehistoric use of glass from Obsidian Cliff, Yellowstone National Park, the geologic source of the artifact.

5.3.2 Oregon

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. Of 193 prepared slides, measurable rims were found on 190 artifacts (Table 5-4). The high source diversity in this region, however, makes these 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 and Jefferson counties along the Lower Deschutes River drainage also produced a high rate of success in measurements (Table 5-4). Of 2,284 analyzed artifacts, hydration rinds on 2,126 items were successfully recorded. Source diversity, while still high in this region, is lower than for sites 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. 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. However, the dominant use of only a few sources—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 also are 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 Volcano area sources. The results of initial investigations of hydration rates are discussed later in this section. The major Upper Deschutes sources, including the yet to be relocated Unknown X source, used primarily in pre-Mazama times, are reviewed in Chapter 4.

The occupational span represented by the range of hydration measurements found in the Upper Deschutes River drainage sites is considerable. Bands of less than 1 μm from 35-DS-33 point to early historic or very late prehistoric use of that site, while artifacts with rims exceeding 8 μm 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.

Big Obsidian Flow Chemical Group Rim Anomalies. Prior to the Project, relatively few Oregon artifacts had been correlated with the ca. 1,350-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 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 μm. 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 μm (Flenniken and Ozbun 1988:133–135). Up to 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 (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 anticipated (Figure 5-5). These data led to a successful search for an older source of glass geochemically similar to the recent Big Obsidian Flow—the Buried Obsidian Flow (see Chapter 4 for a discussion of this new combined chemical group). This early Holocene to late Pleistocene flow, located about 1 km east of the Big Obsidian Flow, is largely covered by later tephra deposits. Ongoing geochemical studies carried out by Tom Connolly (Oregon State Museum of Anthropology) and Richard Hughes (Geochemical Research) will eventually reveal whether it will prove possible to 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 (see Chapter 4) 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

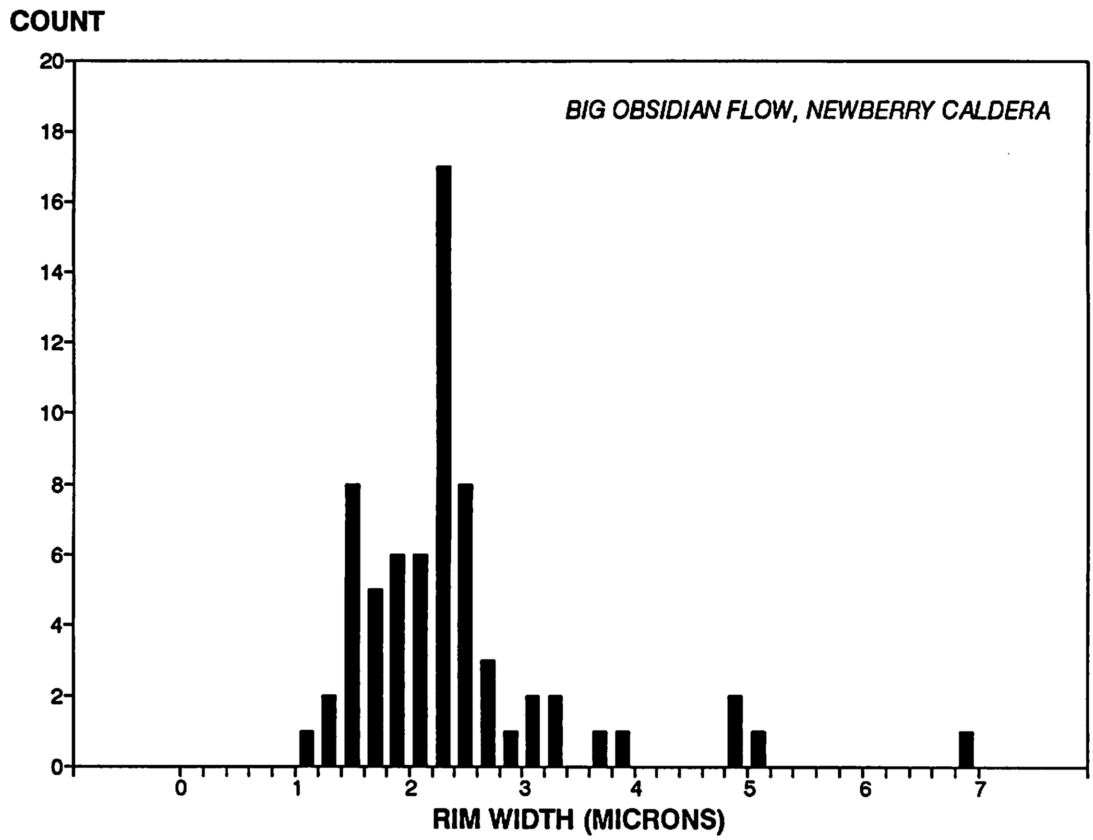

Figure 5-5 Frequency distribution of hydration rims associated with Big Obsidian Flow chemical group artifacts.

35-DS-557 (Figure 5-6). 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 2.6–4.0 μm. Up to 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 5 μm 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 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 5 μm.

When the frequency distribution characteristics of the pre-Mazama Newberry Volcano and the pre-Mazama artifacts Unknown X source artifacts are compared, however, a simpler explanation presents itself (Figure 5-7). 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 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 glass from either the

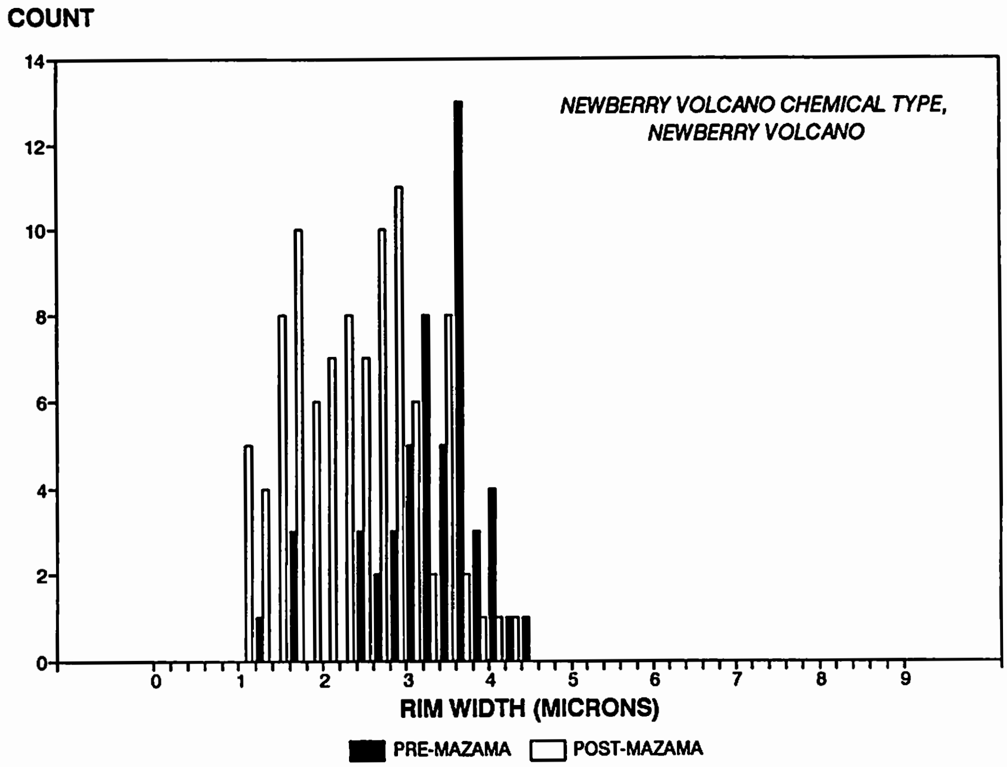

Figure 5-6 Frequency distribution of hydration rim values for pre- and post-Mazama artifacts from sites 35-DS-263 and 35-DS-557 that were correlated with the Newberry Volcano chemical group.

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, discussed in more detail in Chapter 4, will remain incompletely known until the source itself is located and sampled.

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 obsidian from 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 (Table 5-4). Measurable rims were found on over 80 percent (n=806) of the 998 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.

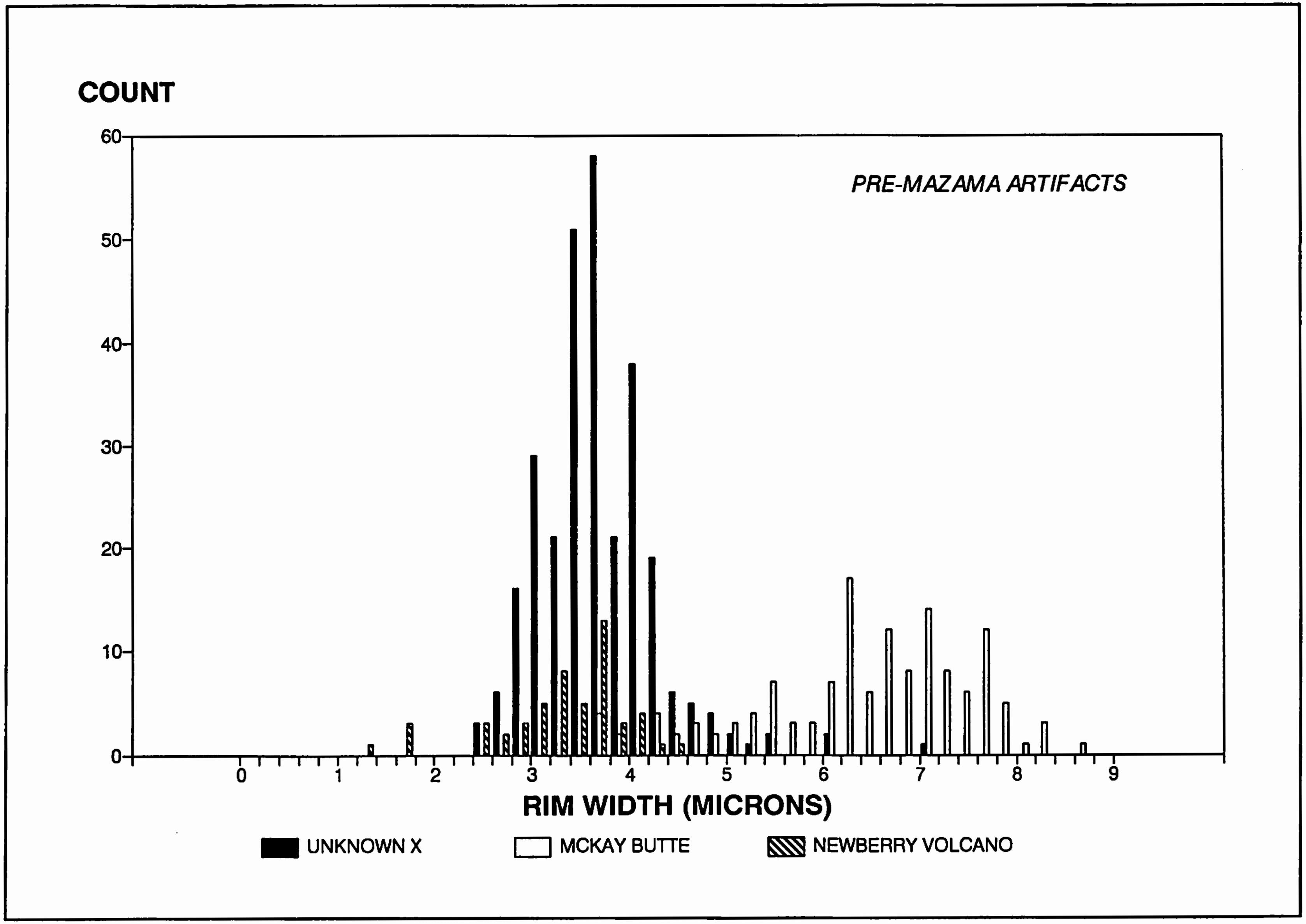

Figure 5-7 Distribution of hydration rim values for pre-Mazama artifacts correlated with the McKay Butte, Unknown X, and Newberry Volcano sources.

5.3.3 California

Modoc Plateau and Adjoining Regions. Because of similarities in obsidian procurement patterns (see Chapter 4), the 41 California sites from Modoc, Siskiyou, Shasta, and Tehama counties are considered here as a whole. These sites produced 2,599 hydration rim measurements, a success rate of over 90 percent.

Glass from the Grasshopper Group chemical type—the Grasshopper Flat, Lost Iron Well, Red Switchback, and East Medicine Lake sources—was dominant in the Modoc Plateau region. Over 75 percent of the artifacts that produced hydration rim measurements originated from sources included in this broad chemical group. Artifacts from the Blue Mountain, Buck Mountain, Cougar Butte, Glass Mountain, and Tuscan sources also made up large numbers of artifacts with recorded hydration bands. Hydration bands were recorded in significant quantities varying in width from 0.8 μm to more than 10 μm. Based on these findings, it is almost certain that human occupation in this region spanned the period from late historic times to the early Holocene.

Anomalous Hydration Readings at Glass Mountain, Medicine Lake Highlands. As pointed out by Hughes (1982), the presence of obsidian from the late Holocene Glass Mountain source provides a convenient temporal window restricted to the period following the eruption of the flow. Recent work summarized by Donnelly-Nolan et al. (1990) places the age of this eruption at about 850 B.P.

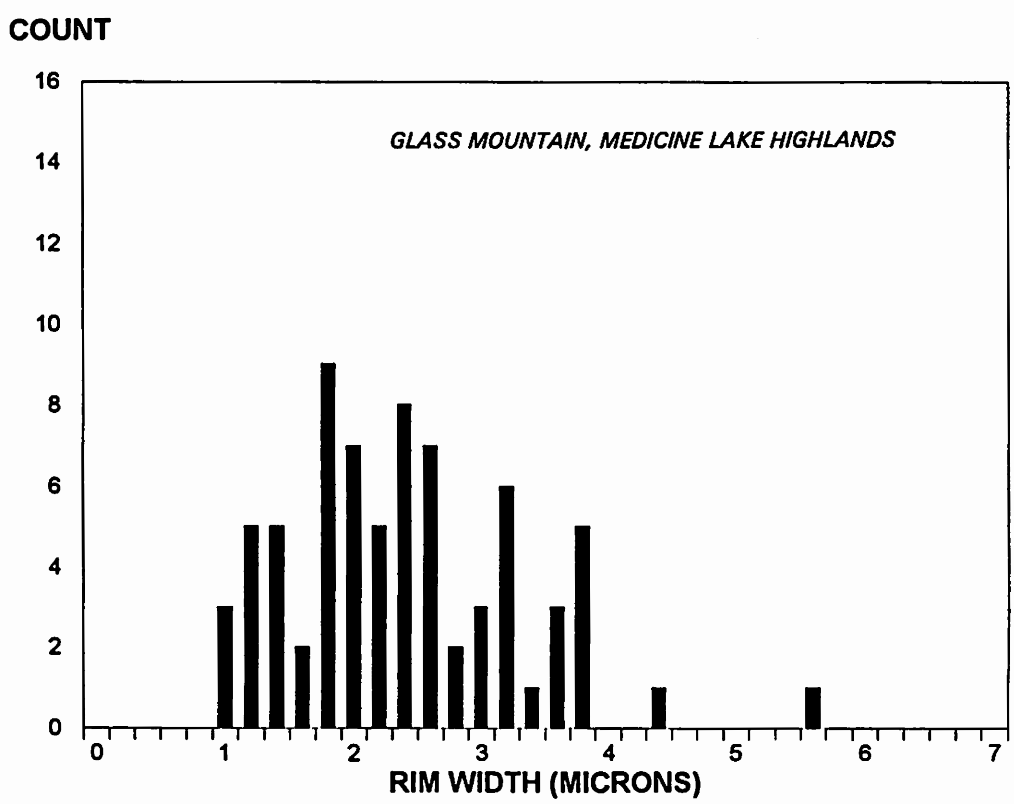

Figure 5-8 Frequency distribution of hydration rim values for samples correlated with the Glass Mountain source.

During the course of the Project, 133 artifacts from California and the southern Klamath Basin of Oregon were assigned to the Glass Mountain source. Of these items, 89 were prepared for hydration measurements and 74 rim readings were successfully made. Given the recent volcanic history of the flow and the rim measurements at the source reported by Friedman (1968) of 1.3 ± 0.2 μm, maximum hydration rim values of Glass Mountain artifacts were not expected to exceed about 1.5 μm. This did not, however, prove to be the case. Hydration measurements from Glass Mountain items ranged from 1.0 μm to 5.5 μm and 60 samples produced rims greater than 1.6 μm (Figure 5-8). Similar to the problem with anomalous rims that arose at Newberry Volcano, it appears that another older and as yet unknown source may exist that is very similar in chemical composition to the younger Glass Mountain flow. The abundance of obsidian sources in northern California and southern Oregon, many of which remain unsampled and uncharacterized, make this a possibility that must be considered seriously.

5.3.5 Central Valley

Hydration analysis of 95 artifacts from seven sites in Solano, Yolo, and Contra Costa counties produced 78 measurable hydration bands. The Napa Valley source was dominantly represented in these Central Valley sites; 69 percent of the successfully recorded rinds were from Napa Valley artifacts.

5.4 THE ONE MICRON FACTOR

Until the current investigation, hydration values of less than 1 μm were virtually unknown in Far Western obsidian hydration studies. There is no technical reason for the absence of these very thin bands and an explanation for their scarcity is almost certainly cultural in nature (Hall and Jackson 1989, Jackson 1984). Indeed, the lack of thin hydration bands was suggested by Origer (1989) as a factor contributing to the difficulty of determining hydration rates for California obsidian sources—few very small hydration values were available with which to construct and calibrate hydration diffusion curves.

During the PEP hydration studies, 60 artifacts yielded hydration rims of less than 1.0 μm (Table 5-6) and 109 rinds were found to be less than or equal to 1.0 μm. The small hydration measurements were found on artifacts from 20 Oregon and northern California sites, although over half were found in the Klamath Basin. The presence of numerous small bands has also been reported elsewhere in the Klamath Basin region in northern California (Picken 1988). The presence of hydration bands of less than 1.0 μm on the PEP artifacts suggests a relatively recent age of manufacture. Origer (1989) notes, in an investigation of obsidian chipping waste created by Ishi in about 1915, that the first micron of hydration often develops within 100 years of manufacture. It is likely, therefore, that the most recent artifacts from the sites listed in Table 5-6 probably date from the late prehistoric or early historic period.

Jackson (1984), in a discussion of the lack of thin hydration rinds from Eastern Sierra artifacts, speculated that the rapid decline of the native population in the early historic period may have been a major contributing factor. Jackson estimated that the first micron of hydration band formed in about 250 years, placing the hypothesized period of depopulation as coeval with the establishment of Spanish missions in southern California in the late eighteenth century. Hall and Jackson (1989), after reviewing Origer's Ishi study (1989), later argued that the population decline during the early mission period was not severe enough to account for the infrequent sub-micron rims. They concluded, however, that more recent population decreases recorded for the period after A.D. 1820 were supported by Origer's conclusions and would coincide with the low numbers of small bands. It is likely, then, that the low frequency of sub-micron rim measurements found in the large sample of analyzed PEP artifacts is related to overall native population decline throughout the Project area. The appearance of many of these thin rims in the Klamath Basin may well be accounted for by the presence of a sizeable Indian population throughout the historic period (Spier 1930).

Table 5-6 Obsidian Hydration Bands Less Than One Micron in Thickness.

Site	N<1 micron	Site Total OH[a]
CA-MOD-1206/07	6	215
CA-MOD-1461	1	78
CA-MOD-2569	1	14
CA-SHA-68/H	1	174
CA-SHA-1474	1	28
CA-SHA-1842	2	136
CA-SHA-1975	2	21
CA-SIS-1552	2	75
CA-SIS-1553	3	17
35-DS-33	6	787
35-JE-49	2	421
35-KL-810	3	273
35-KL-812	1	122
35-KL-813	27	88
35-KL-814	2	226
Total	60	2,675

[a] Number of successfully measured artifacts.

5.5 RATES OF HYDRATION FOR SELECTED SOURCES

Some of the best temporal and hydration data for establishing relative obsidian hydration rates come from Deschutes County sites 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 in 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 almost nonexistent for the Deschutes County sites and it is not possible to precisely correlate the Mazama temporal horizon with micron hydration values.

Without strong rim measurement associations with a long span of radiocarbon or tephrochronologic dates, any attempt at this stage of research to speculatively calculate hydration rates is liable to do more harm than good.

5.5.1 Hydration Rate Research in Oregon and California

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 hydration rate 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 5-9). In one of the few instances where preexisting 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.

Unlike Oregon hydration studies, California obsidian research has produced a plethora of hydration rates for different sources, often several different rates for the same source (Bettinger 1989; Ericson 1981:35–37, 1989; Hall and Jackson 1989; Jackson 1984b; Jackson 1984; see Skinner and Tremaine [1993] for many others).

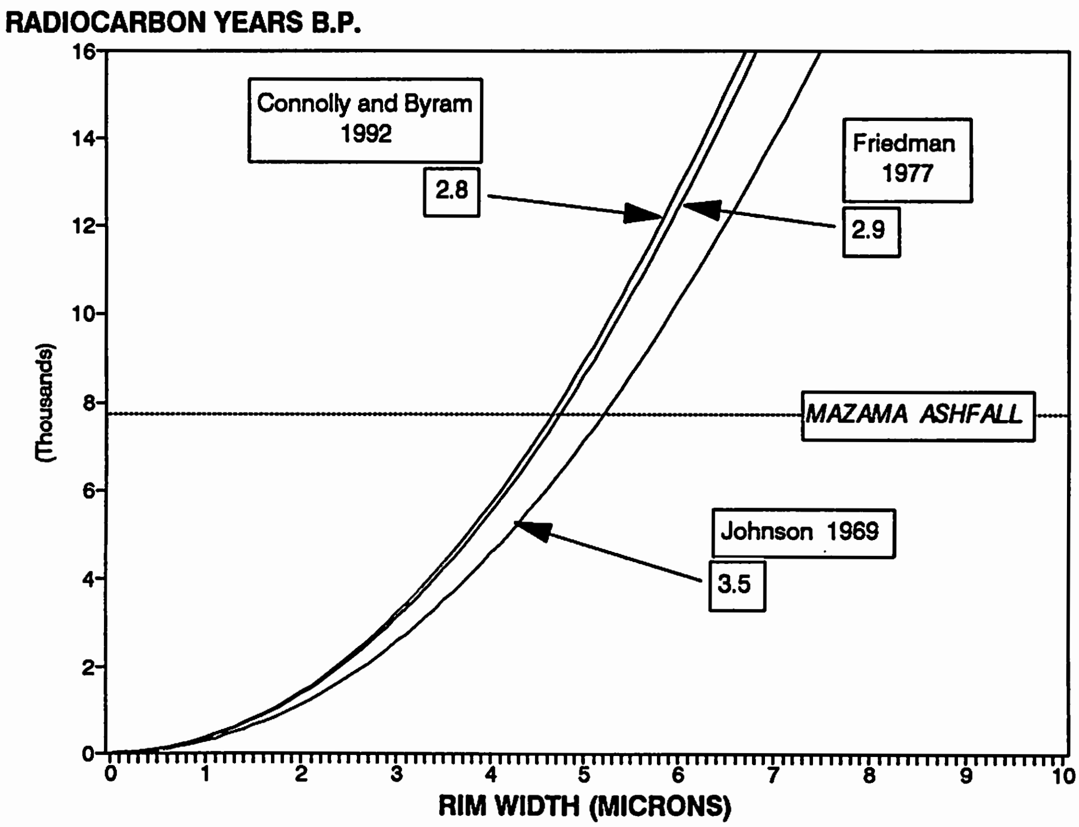

Figure 5-9 Published and proposed obsidian hydration rates for selected sources. (The numbers refer to rates in $\mu m^2/1{,}000$ years, e.g., 2.9 $\mu m^2/1{,}000$ years).

5.5.2 Relative Hydration Rates in the Newberry Volcano Region

Sites 35-DS-263 and 35-DS-557 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. Speculations about the dramatic temporal shift in the use of the sources are outlined in Chapter 4. McKay Butte is located only a few kilometers from the two sites and the Unknown X source also is thought to be 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 5-7). It is apparent that the Mazama ash horizon of about 6,850 ^{14}C years is equivalent to a minimum hydration width of about 3.3 μm. Rim measurements of pre-Mazama McKay Butte glass at 35-DS-263, however, begin at 4.4 μm and the unequivocal sub-Mazama provenience of artifacts at 35-DS-263 leads us to suspect that the Mazama ash horizon probably lies closer to the 4.4 μm mark. The uncertainty of the micron values associated with the Mazama boundary leaves the estimation of the age range of McKay Butte artifacts as very speculative, but it seems likely that use of glass from this source extends into the early Holocene and perhaps farther.

Unknown X. The obsidian production rate curve plotted for pre-Mazama artifacts from 35-DS-263 and 35-DS-557 exhibits a strong unimodal distribution (Figure 5-7). Band measurements range from 2.5 to 7.1 μm, indicating a minimum micron value for the Mazama ashfall of about 2.5 μm. 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 production curve illustrated in Figure 5-7 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 drainage—over 2,000 Oregon PEP artifacts were found to originate from the Newberry Volcano chemical group. 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 (see Figure 5-14). We suggest that the abrupt appearance and rise in the obsidian production rate curve at this point marks the approximate position of the Mazama ashfall. This conclusion is consistent with the rim values produced by the hydration rates calculated by Connolly and Byram (1992) and Friedman (1977), respectively, of 2.8 and 2.9 μm^2/1,000 years.

Big Obsidian Flow Chemical Group. 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. 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 μm. 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. 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 site components. Limited evidence from 35-JE-51B suggests, however, that the hydration band equivalent of the Mazama ashfall lies in the range of approximately 4.5–5.0 μm. Rim measurements varying from 4.8 to 7.6 μm from 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 Rockshelter, a pictograph site in the McKenzie River drainage of the Western Cascades (Fagan 1975). Rim values of eight artifacts from this site varied from 3.5 to 5.1 μm, with most values lying near 5 μm. 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.

5.6 PREHISTORIC PATTERNS OF OBSIDIAN SOURCE USE THROUGH TIME

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 rim 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 radiocarbon 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 problems with the Glass Mountain and Big Obsidian

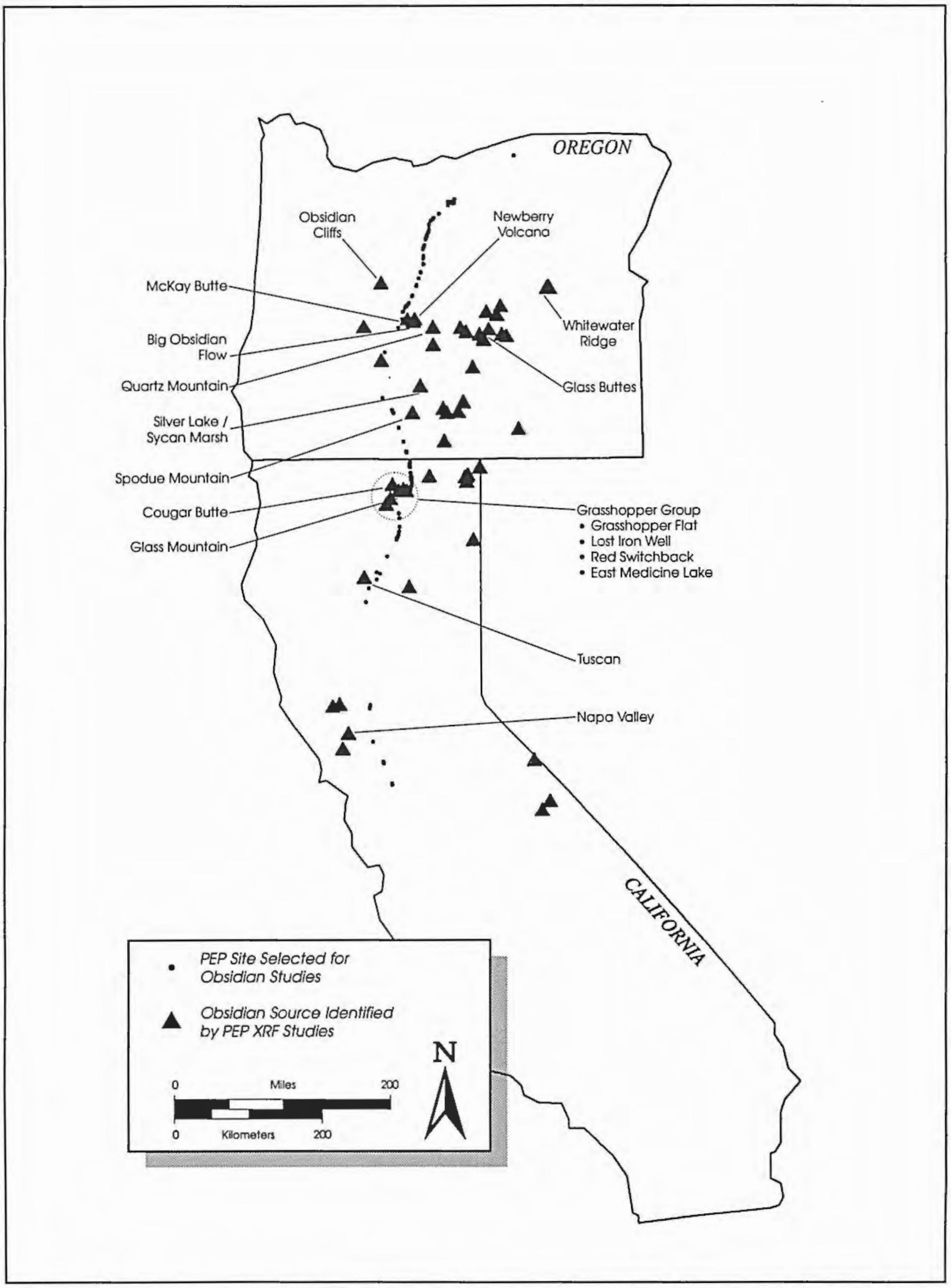

Figure 5-10 Location of major sources of obsidian identified during PEP obsidian studies.

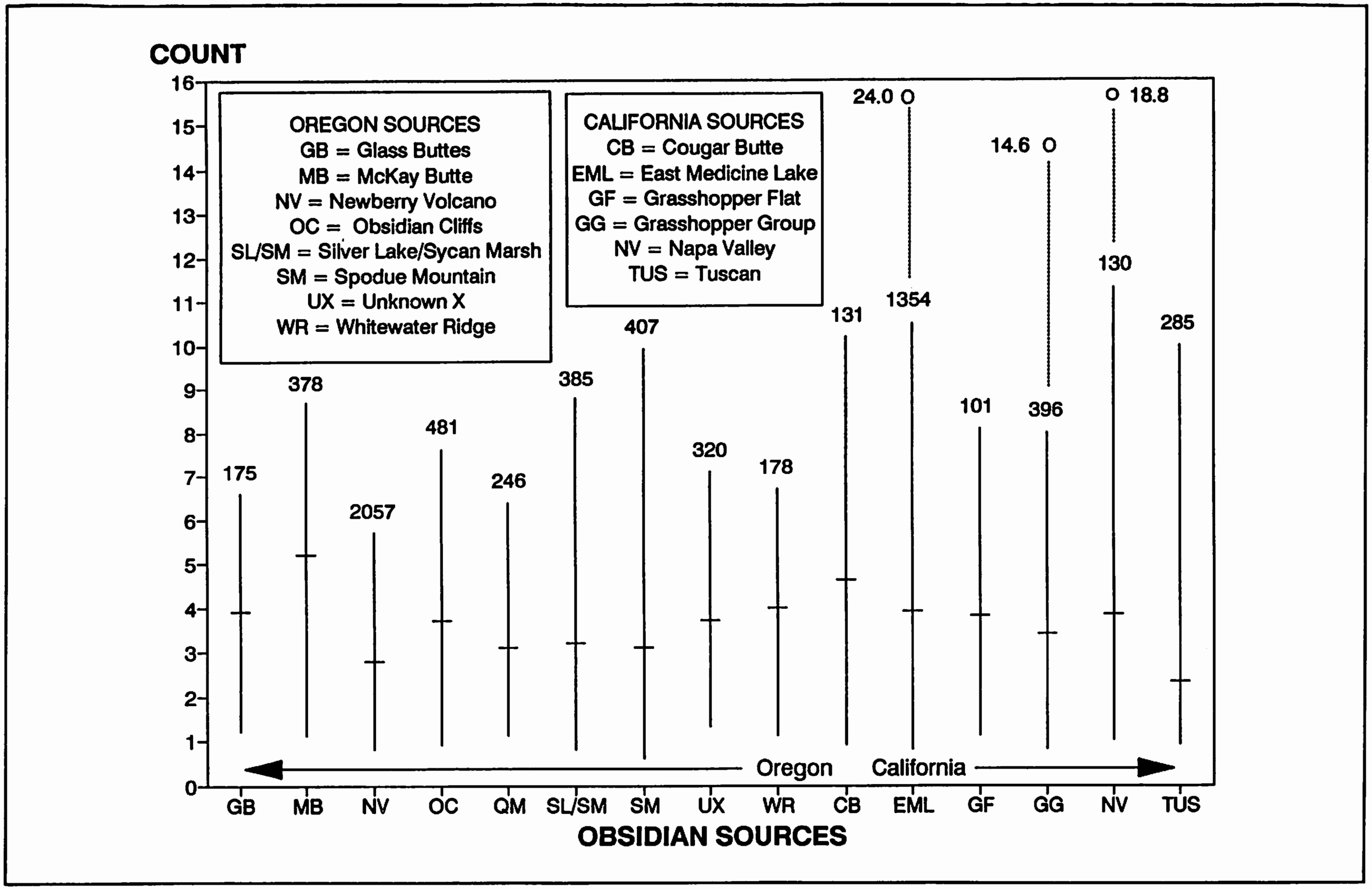

Figure 5-11 Range of obsidian hydration measurements for PEP artifacts from major sources of obsidian in Oregon and California. (The vertical bar spans the maximum to minimum hydration values; the horizontal tic is placed at the mean value. The number above each bar marks the size of the data set. When the values of outliers [empty circles] fall outside the range of the y-axis, the rim measurements are indicated.)

Table 5-7 Characteristics of Obsidian Production Rate Curves for Major Oregon and California Obsidian Sources.

Chemical Type	Figure	Total OH [a]	Minimum OH Rim (μm)	Maximum OH Rim (μm)	Mean (μm)	Median (μm)	Mode (μm)	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	378/747	1.1	8.7	5.2	5.3	6.3	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, 4.8	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	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	3.6, 3.7	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	3.0	Bimodal distribution by geographic region; shift from earlier John Day to later Lower Deschutes River drainage
CALIFORNIA SOURCES								
Cougar Butte	5-21	131/147	0.9	10.2	4.6	4.0	3.6	Poorly-defined normal distribution; relatively low sample size.
East Medicine Lake	5-22	101/105	1.1	8.1	3.8	3.8	3.7	
Grasshopper Flat	5-22	1,357/1,462	0.8	24.0	3.9	3.8	2.5	
Grasshopper Group	5-22	397/441	0.8	14.6	3.4	3.3	3.7	Somewhat right-skewed distribution; outlier rim bands of 14.6 and 24.0 μm.
Napa Valley	5-23	130/152	1.0	18.8	3.8	3.6	5.0	Irregular right-skewed distribution; intensive use over a long period of time; outlier rim band of 18.8.
Tuscan	5-24	285/316	0.9	10.0	2.3	1.9	1.3	Bimodal distribution by geographic region; later use in Modoc sites preceded by earlier use in Upper Central Valley sites; small sample size.

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

Flow chemical types, however, only the Mazama ashfall temporal horizon could be used initially to examine the relative rates of hydration for several of the flows.

In this section, we briefly examine the temporal utilization of 12 major sources of obsidian, sources that yielded at least 100 successful hydration rim measurements (Figures 5-10 and 5-11; Table 5-7). 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. Each of these sources is described in more detail in Chapter 4 and Appendix C.5.

5.6.1 Oregon Obsidian Sources

Glass Buttes. Obsidian from Glass Buttes, a complex of rhyolite domes 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 5-12). No Glass Buttes artifacts were recovered from pre-Mazama components, although the range of use of the source is known to be long. Fagan (1990) found that Glass Buttes was the source of several Clovis and Western Pluvial Lakes Tradition tools recovered at the Dietz Site in southeastern Oregon.

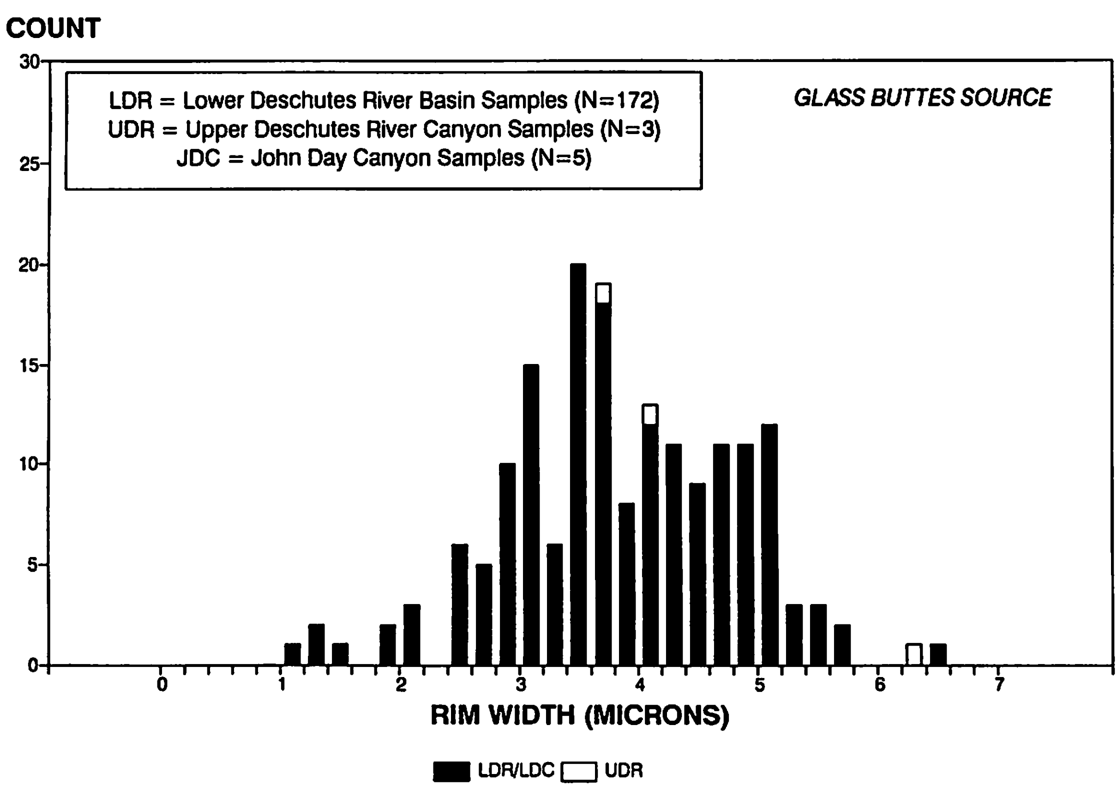

Figure 5-12 Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Glass Buttes source.

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 5-13). 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 John Day Canyon PEP sites and in previously characterized collections from the Western Cascades (Skinner and Winkler 1991). Use of glass from this source drops very quickly to the south and disappears from the archaeological record at the Deschutes-Klamath Basin divide.

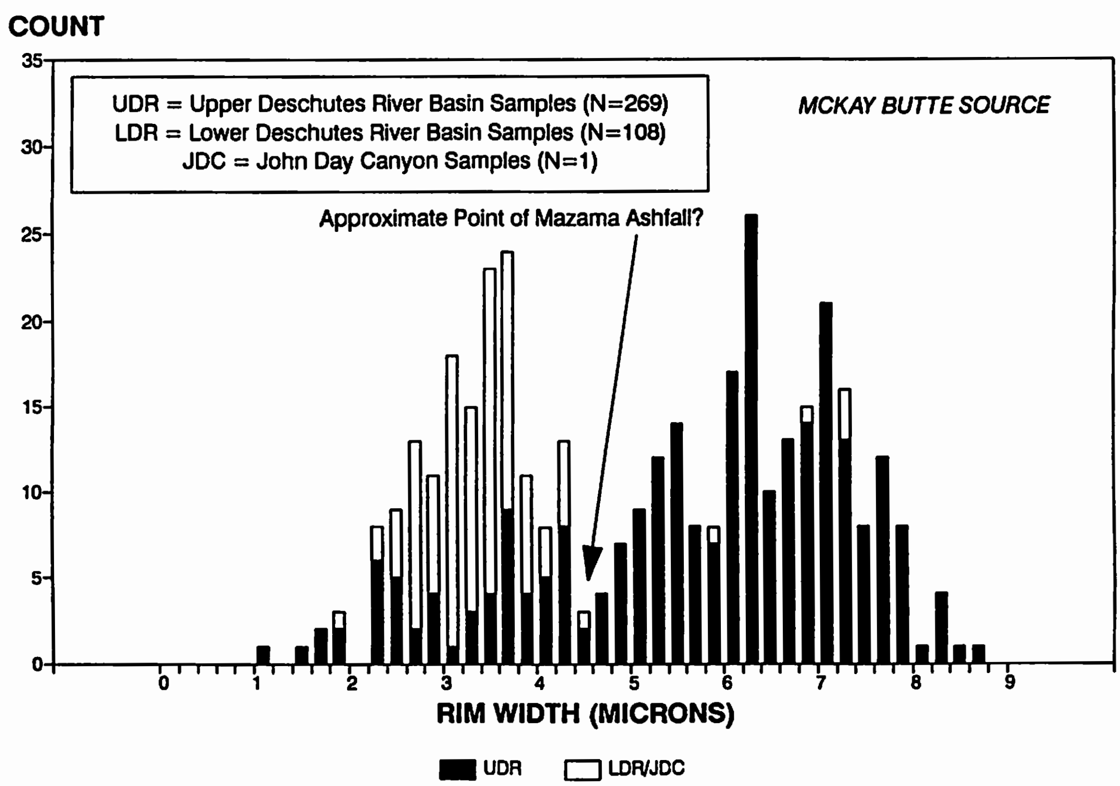

Figure 5-13 Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the McKay Butte source.

Newberry Volcano. After the eruption of the Newberry Volcano chemical group flows not long after the Mazama ashfall, glass from this group of sources spread rapidly throughout the Upper and Lower Deschutes River drainages (Figure 5-14). In Deschutes County sites, Newberry Volcano glass almost completely replaces the older McKay Butte and Unknown X sources. Only a few samples from the Northwestern Great Basin and Klamath Basin sources are found in the later Deschutes County artifact collections. 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. Evidence of prehistoric use of Newberry Volcano glass diminishes rapidly south and southeast of the volcano where it is completely replaced by obsidian from Klamath Basin sources. The obsidian production rate distribution curve is normal in both the Upper and Lower Deschutes River drainages, pointing to the uneventful spread of glass from the this major source area.

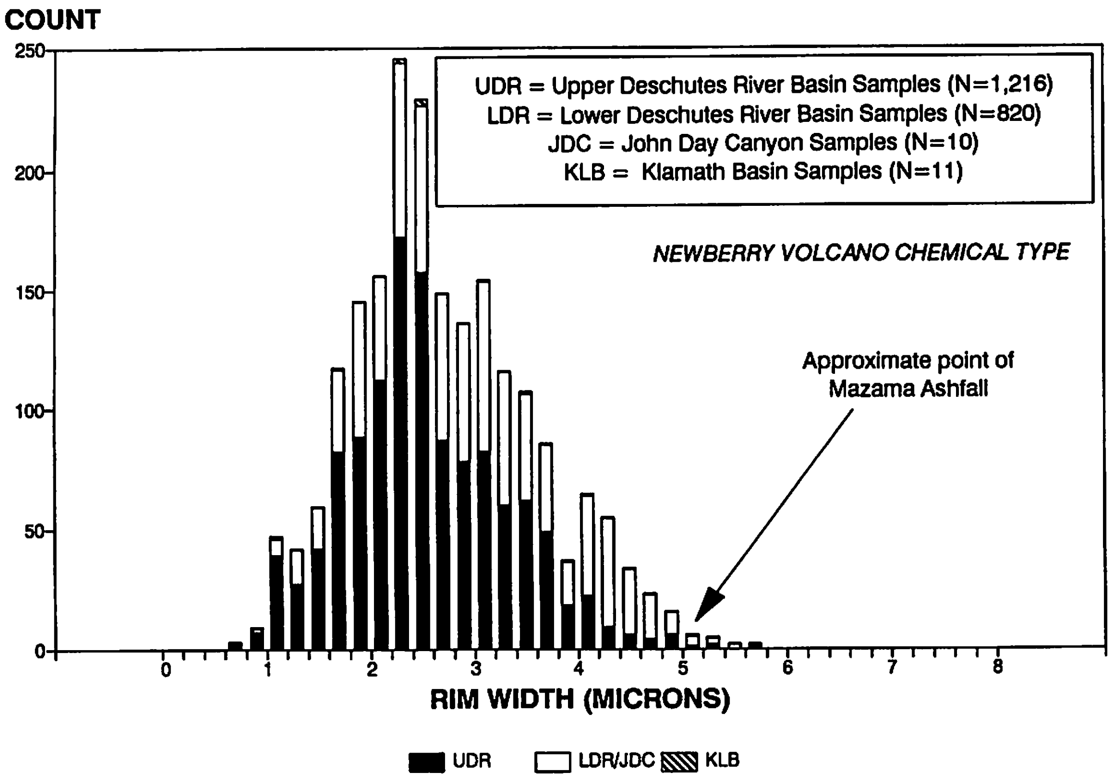

Figure 5-14 Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Newberry Volcano chemical group.

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 1991). Use of the raw material from this source 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 curve of Obsidian Cliffs glass in PEP sites is somewhat skewed and probably results from a bias towards post-Mazama obsidian artifacts (Figure 5-15). Hydration band values range from 0.9 to 7.6 μm, indicating

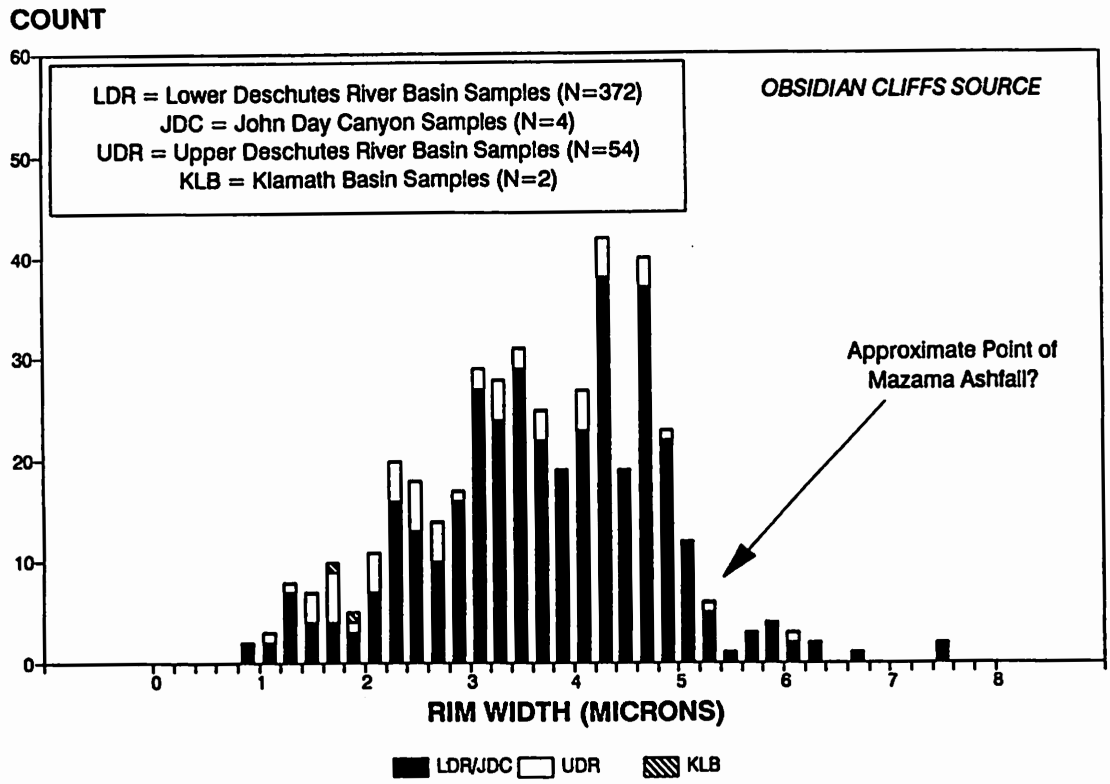

Figure 5-15 Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Obsidian Cliffs source.

that Obsidian Cliffs was a major source of glass 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 high quality obsidian that was used extensively 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 μm (Figure 5-16). 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 was found to have a hydration rim of 6.0 μm. We are unable, however, to estimate the micron equivalent of the Mazama ashfall. Two pre-Mazama Quartz Mountain artifacts from a Newberry Caldera site have previously yielded rim values of 2.5 and 2.9 μm, suggesting a relatively slow rate of hydration (Connolly and Byram 1992; Flenniken and Ozbun 1988). If this is the case, the restricted range of hydration values also may reflect a slower rate of hydration rather than source use more recent than other competing sources.

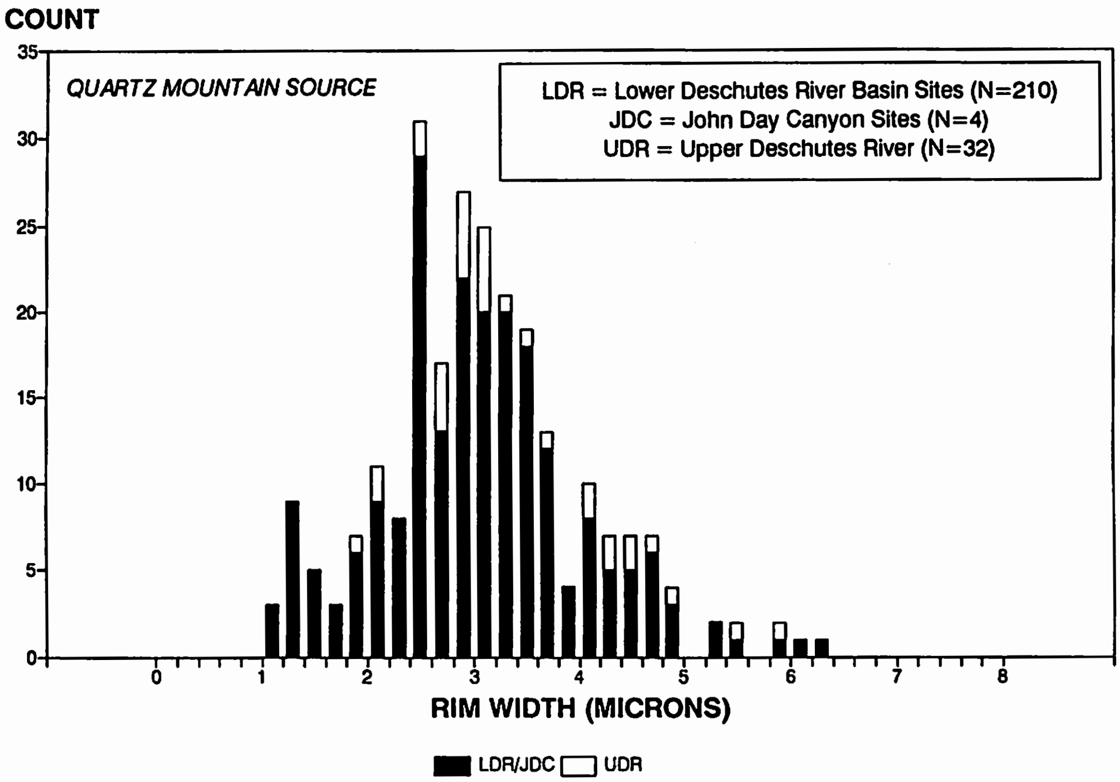

Figure 5-16 Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Quartz Mountain source.

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, source use outside the basin drops rapidly in all directions in which competing sources are available. In southwestern 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 1991).

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 (Figures 5-17 and 5-18). This same observation has been made previously by Pettigrew and Lebow et al. (1987). Hydration rim ranges also are similar for both sources, 0.8–8.8 μm for Silver Lake/Sycan Marsh artifacts and 0.8–9.9 μm for Spodue Mountain items. We suspect that the Mazama ashfall is approximately equivalent to about 5.0 μm for the two sources, although the degree of disturbance at pre-Mazama Klamath Basin site components makes it difficult to be more precise.

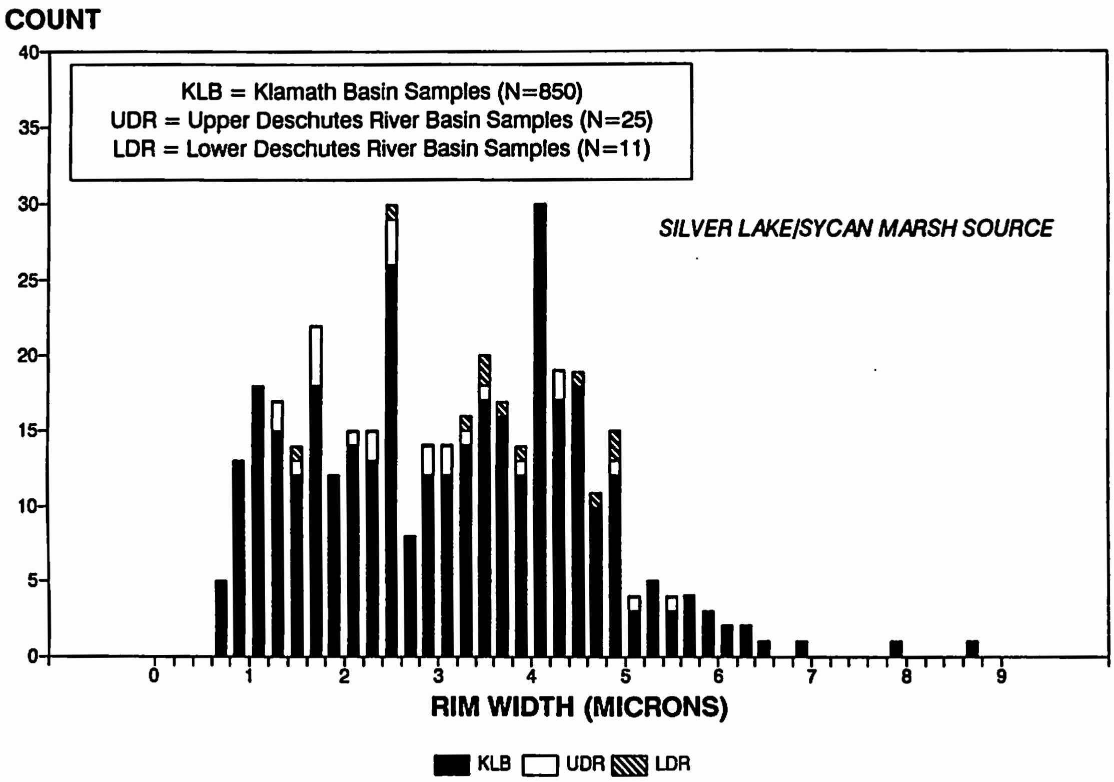

Figure 5-17 Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Silver Lake/Sycan Marsh source.

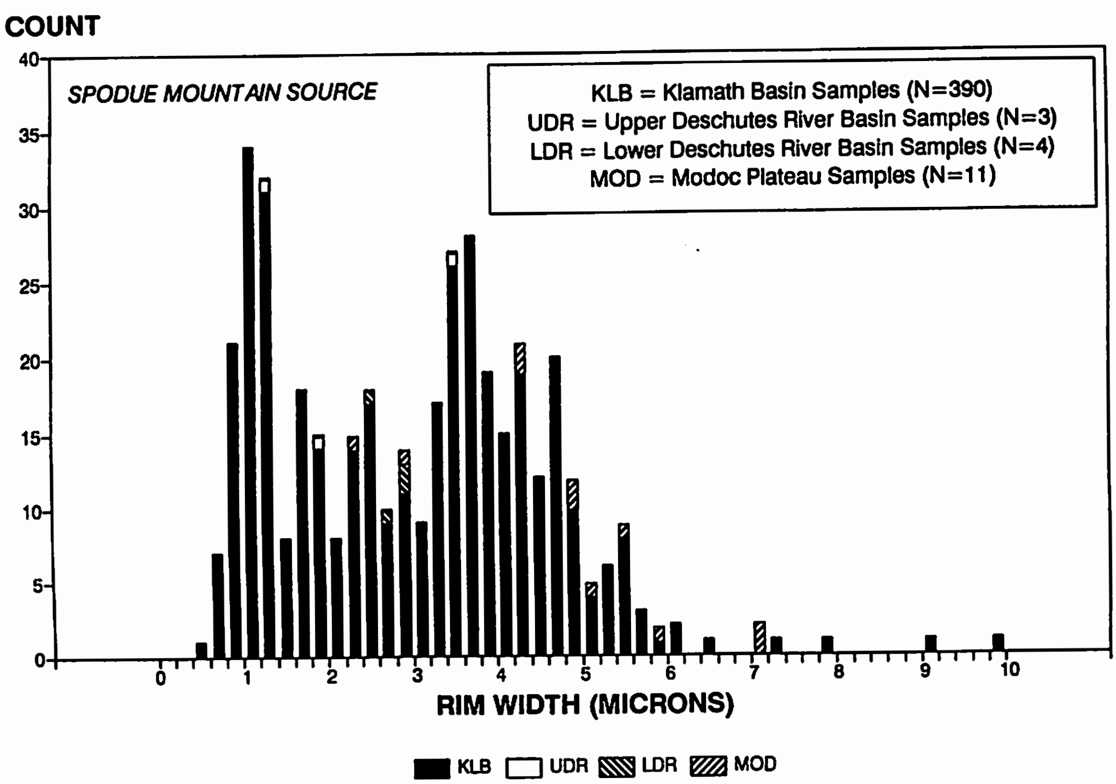

Figure 5-18 Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Spodue Mountain source.

The similar span of rim values and intensity shown in the obsidian production rate histograms suggests that both sources were used in about the same proportion throughout most of the period of prehistoric Klamath Basin occupation sampled by the 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 μm. 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 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 5-19). 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

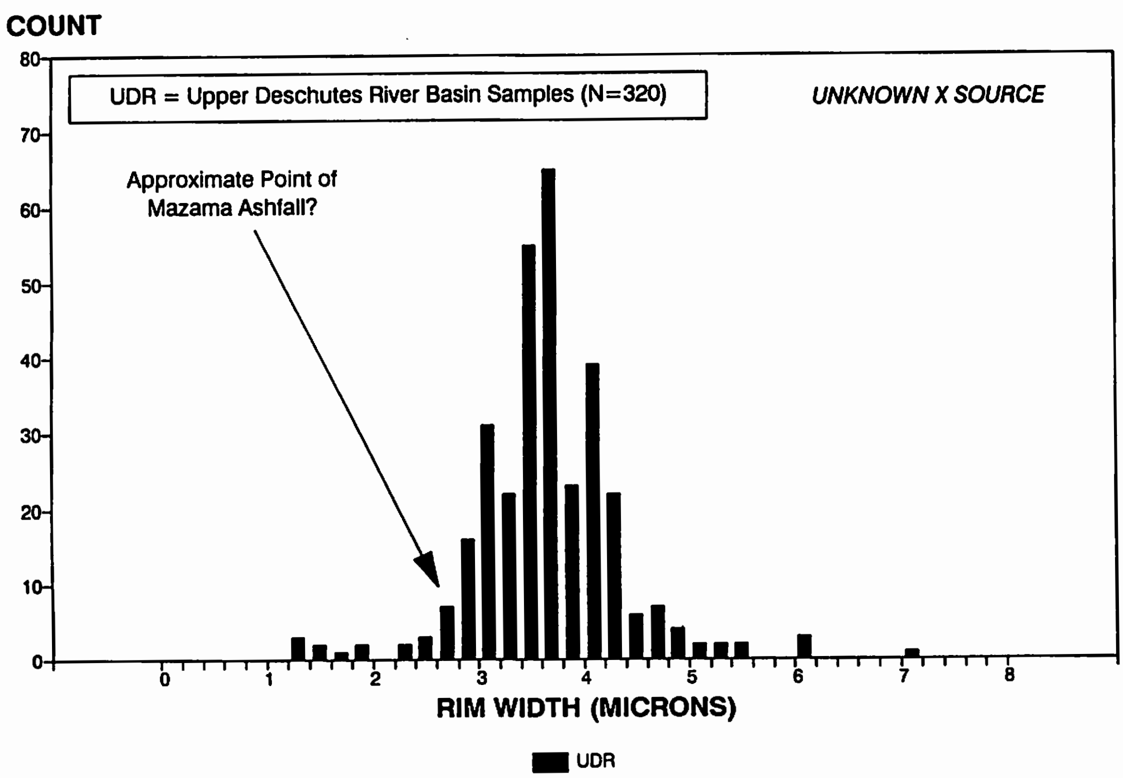

Figure 5-19 Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Unknown X source.

low as 2.5 μm (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 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 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 (Figure 5-20). The obsidian production rate curve, though, is bimodal by geographic region. There is a marked tendency for older items to be concentrated in the John Day River drainage 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 product 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

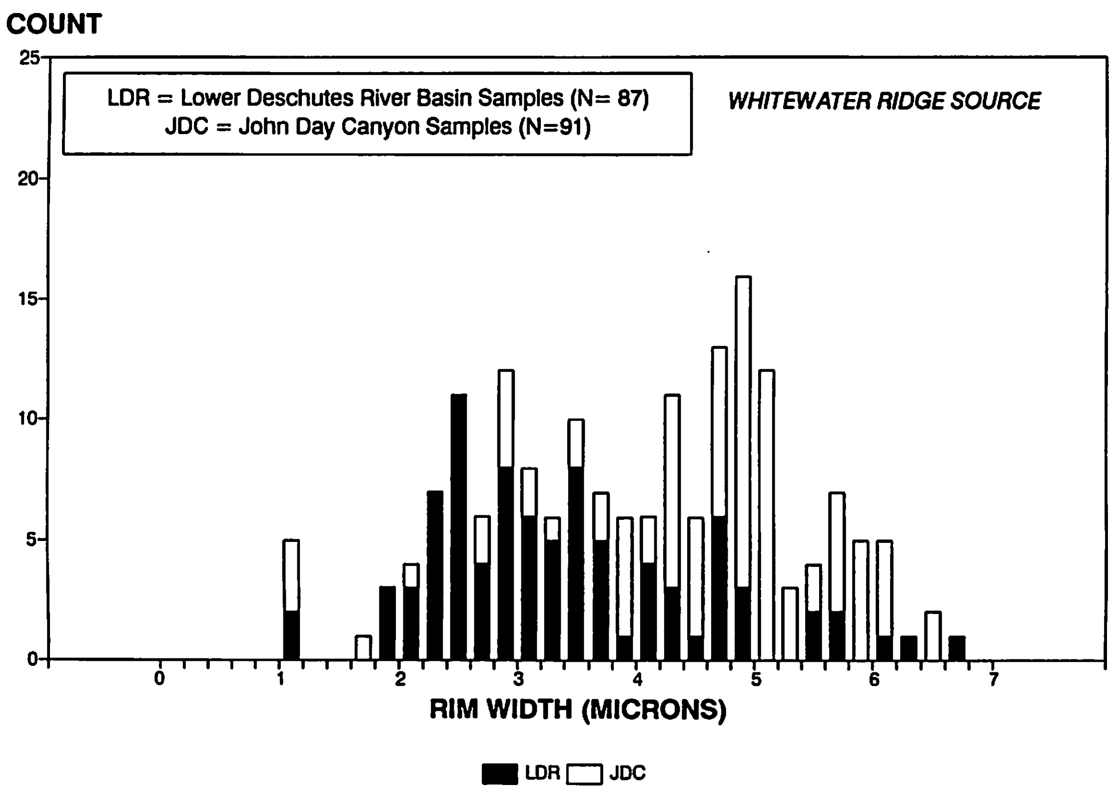

Figure 5-20 Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Whitewater Ridge source.

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 is unknown.

5.6.2 California Obsidian Sources

Cougar Butte. The production curve of glass from this Medicine Lake Highlands source can be characterized as irregular but normal, probably the result of the low sample size and wide span of hydration rim values (Figure 5-21). Rim values range from 0.9 to 10.2 μm; source use peaks at about 3.6 μm but the relative intensity is never high when compared to the utilization of other sources in this region (Figure 5-22 and 5-23). Several competing sources of high-quality glass, particularly those represented by the Grasshopper Group, are found in the immediate area.

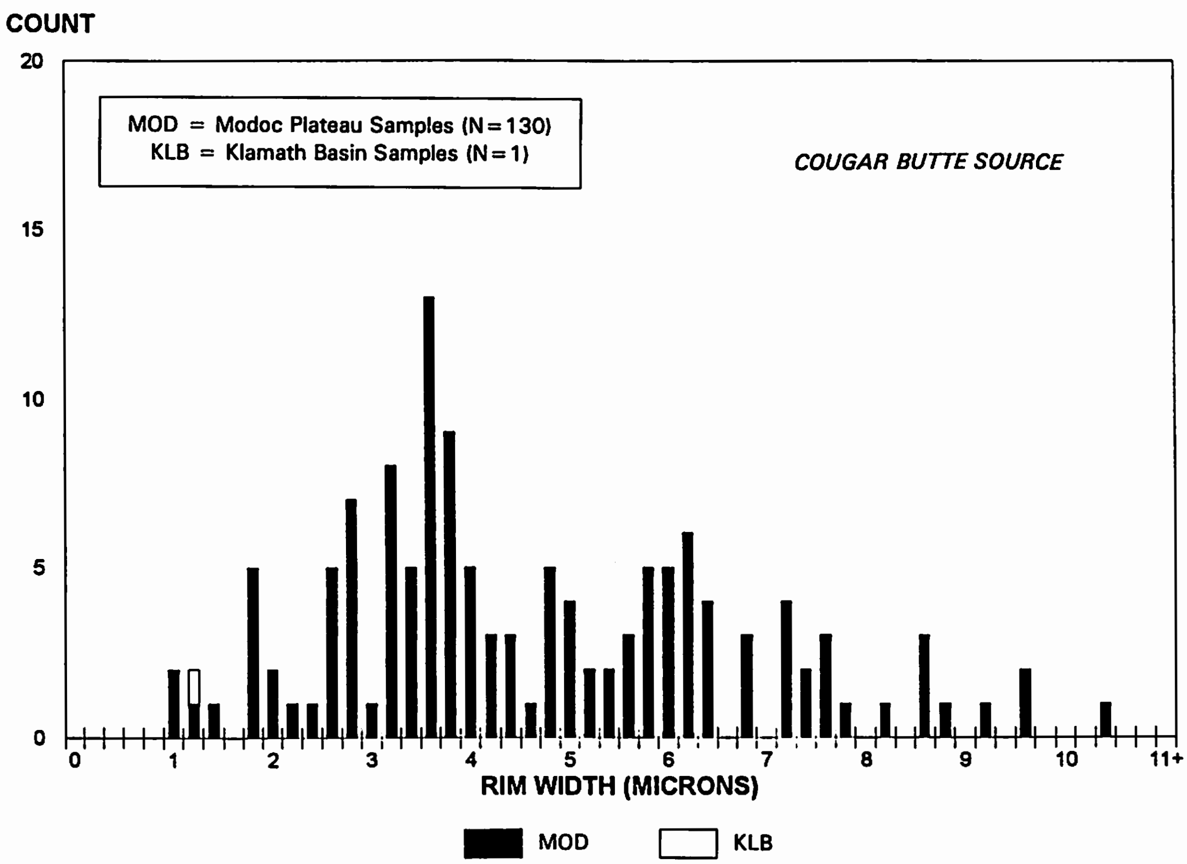

Figure 5-21 Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Cougar Butte source.

Grasshopper Group. The most commonly identified northern California obsidian identified during the PEP studies was the Grasshopper Flat/Lost Iron Wells/Red Switchback and East Medicine Lake sources, clustered in the Medicine Lake Highlands area of the Modoc Plateau. These high-quality obsidian sources make up 64.3 percent of the characterized artifacts from the Modoc Plateau region. The Grasshopper Flat, Lost Iron Wells, and Red Switchback sources are chemically indistinguishable and are analyzed as a single source

(GF), while East Medicine Lake obsidian can be distinguished from the others based on specific trace elements. Though a final distinction has been made between the two sources for this report (see Chapter 4), for the purpose of generalized source characterization as presented here, the undistinguished sources are referred to as Grasshopper Group (Figure 5-22).

Obsidian artifacts from this source are found throughout the Modoc Plateau, the Klamath Basin of Oregon, southwestern Oregon, and as far south as the northern end of California's Central Valley (Skinner and Winkler 1991).

The obsidian production rate curve is slightly skewed for the Grasshopper Group artifacts, probably reflecting a bias towards artifacts recovered from younger sites. The hydration rims from this chemical group range in width from 0.8 to 9.4 μm, with two outliers of 14.6 and 24.0 μm (the latter two values are not shown in Figure 5-22). The few artifacts from the Klamath Basin all fall within the lower range of the curve, again indicating the younger relative age of most of the sites from that region. Most hydration bands fall below 8.0 μm, indicating a long and intensive period of use of Grasshopper Group glass throughout this region.

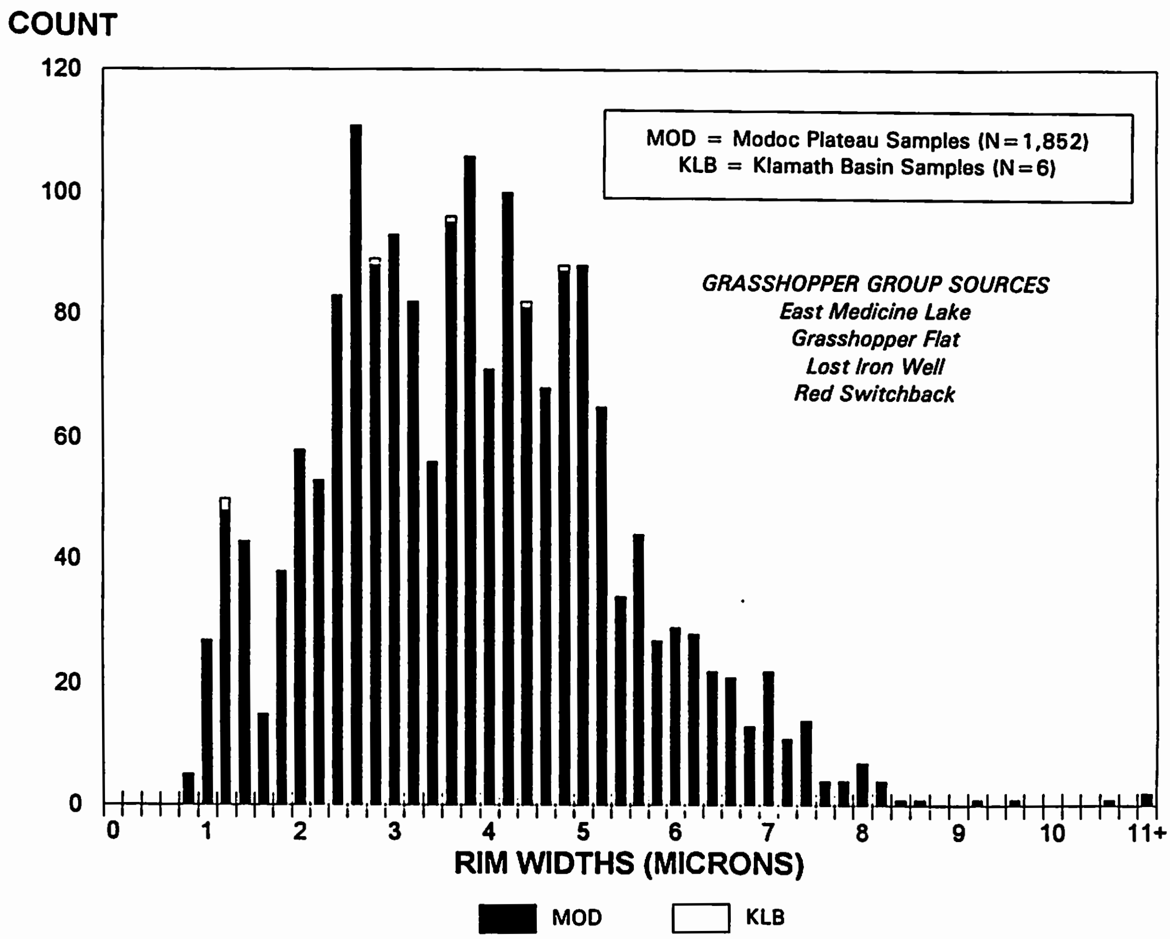

Figure 5-22 Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Grasshopper Group chemical source.

Napa Valley. All obsidian assigned to the Napa Valley source was recovered from PEP sites in the middle Central Valley, a pattern of prehistoric source use consistent with earlier obsidian characterization studies (Jackson 1986). The hydration band range is considerable, from 1.0 to 11.3 μm (with an outlier of 18.8 μm). Most of the rim values, however, were less than 6.0 μm, resulting in a skewed distribution curve (Figure 5-23). The apparent increased intensity of Napa Valley source use is due in part to bias towards younger site components. The late intensity reflected in Figure 5-23, however, also may reflect increasing use of North Coast Range obsidian sources by the prehistoric inhabitants of the Central Valley.

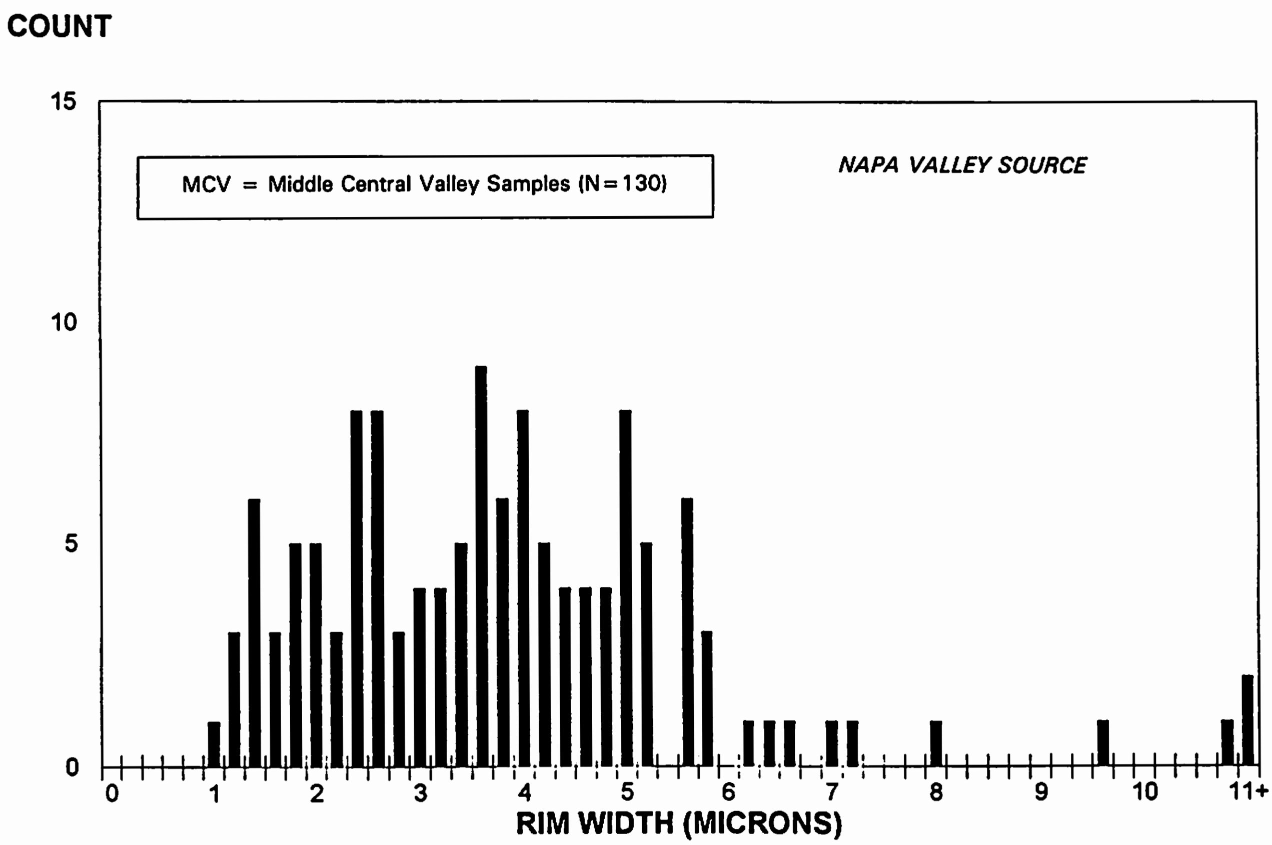

Figure 5-23 Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Napa Valley chemical source.

Tuscan. Obsidian from the Tuscan chemical group is found at many different source locations along the upper margin of the Central Valley. In the current investigation, glass from this chemical source is common in Tehama and Shasta county sites, but rare to the north and south. Tuscan glass is replaced in the Central Valley by obsidian from North Coast Range sources and in Modoc County by obsidian from many northern California sources, particularly from the East Medicine Lake and Grasshopper Flat/Lost Iron Well/Red Switchback sources.

Hydration readings from the Tuscan obsidian sample (Figure 5-24) indicate use predominately in the Late Period, possibly indicating more restricted access to better quality obsidians to the north and south during this period.

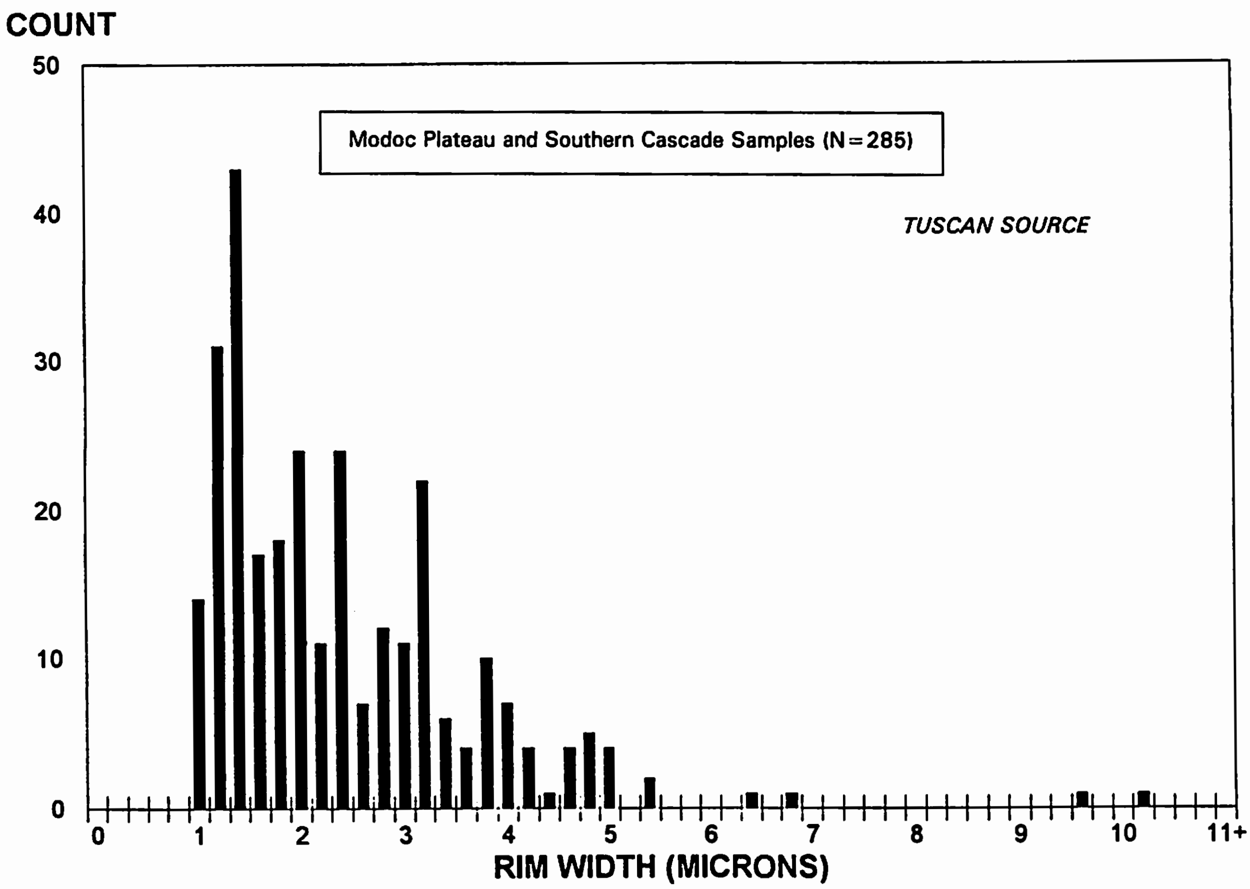

Figure 5-24 Frequency distribution of obsidian hydration rim measurements from artifacts correlated with the Tuscan source.

5.7 CONCLUSIONS AND RECOMMENDATIONS

5.7.1 Conclusions

In many areas of central Oregon, northern California, and central California, carbon suitable for radiocarbon determinations often are absent, while artifacts of natural glass are common. Obsidian hydration measurements provide a critical source of chronologic information in these regions. During the PEP, 9,210 obsidian samples from 131 Idaho, Oregon, and California archaeological sites were selected for obsidian hydration studies. The geologic sources of the ensuing 7,910 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 originate 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. Major California obsidian sources with large hydration databases are Blue Mountain, Borax Lake, Buck Mountain, Cougar Butte, Glass Mountain, the Grasshopper Group sources of the Medicine Lake Highlands, Napa Valley, and the Tuscan source.

Anomalous hydration rim values were recorded from artifacts correlated with the Big Obsidian Flow, Newberry Volcano, and Glass Mountain, Medicine Lake Highlands. The discovery of a previously unrecognized older member of the Big Obsidian Flow chemical group provided an explanation for the Newberry source. The anomalous distribution of Glass Mountain rims remains unexplained. 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. 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 roughly similar rate.

Source production 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, which may have been caused by population changes, historical pressures, and/or differential use of sources in different geographic areas.

5.7.2 Recommendations for Further Research

Obsidian hydration studies in areas bisected by the Project corridor are still in their infancy, particularly for sites and sources in Oregon. The hydration investigations undertaken during the analyses of PEP artifacts, while they go a long way toward filling the gap in obsidian hydration data that formerly existed in central Oregon and northern California, also suggest improvements and directions for 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 can analyze very small-sized 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; also see Chapter 7). 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 rims 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 insufficient 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 in sampling strategies?

- *Coordination of lithic technology and obsidian hydration studies.* Obsidian artifacts, particularly tools in areas where glass is 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 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 will 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 will 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 PGT-PG&E 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 on almost every continent on earth.