4.0 OBSIDIAN CHARACTERIZATION STUDIES

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4.1 INTRODUCTION

Over the past three decades, obsidian characterization studies incorporated into archaeological research have drawn increasing interest, and source identification investigations have rapidly progressed from the exotic to the commonplace. In the Far West and many other regions, obsidian studies are now considered a routine and essential component of any well-developed archaeological research design. In this chapter, the results of the extensive obsidian characterization studies carried out in conjunction with the Project are presented and briefly examined.

4.1.1 PEP Sites and Samples Selected for Characterization Studies

During the PGT-PG&E Pipeline Expansion Project, more than 9,900 obsidian artifacts from 141 Oregon, California, and Idaho archaeological sites were selected for obsidian characterization studies (Tables 4-1, 4-2, and 4-3). The trace element composition of 9,543 of these items was determined by x-ray fluorescence spectrometry (XRF), and the resultant elemental abundances were used to identify the geochemical sources of the samples. A much smaller number of California artifacts were characterized visually prior to preparation for obsidian hydration measurements and are discussed later in this section. Forty-nine pre-Mazama artifacts from Oregon Site 35-JE-49 were tentatively characterized on the basis of microscopic petrographic attributes during hydration measurements and also are discussed later in this section. After geologic source identification, the majority of the obsidian artifacts were then examined for the presence of obsidian hydration rims (see Chapter 5).

Table 4-1 PEP Samples Selected for Characterization Studies.

State	Number of Sites	Obsidian Debitage	Obsidian Tools	Other Obsidian	Basalt Artifacts	Total XRF	Total Visual	Total
Idaho	1	2	0	0	0	2	0	2
Washington	0	0	0	0	0	0	0	0
Oregon	83	5,537	1,100	5	0	6,595	49	6,644[a]
California	57	2,363	904	0	26	2,946	347	3,293[b]
Total	141	7,902	2,004	5	26	9,543	396	9,939

[a] Includes two nonobsidian artifacts.
[b] Does not include 68 items that were not sourced.

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Table 4-2 Summary of Northwest PEP Sites and All Samples Selected for Characterization Studies.

Site	Characterized Debitage	Characterized Tools	XRF Characterization	Visual Characterization	Total
IDAHO					
10-BY-444	2[a]	0	2	0	2
Total Idaho	2	0	2	0	2
OREGON					
35-CR-626	102	2	104	0	104
35-CR-627	2	2	4	0	4
35-DS-33	780	184	964	0	964
35-DS-116	36	8	44	0	44
35-DS-263	382	25	408	0	408[b]
35-DS-429	28	1	29	0	29
35-DS-554	22	1	23	0	23
35-DS-555	114	23	137	0	137
35-DS-557	532	120	652	0	652
35-DS-558	31	2	33	0	33
35-DS-559	28	25	53	0	53
35-DS-808	43	2	45	0	45
35-DS-809	10	1	11	0	11
35-DS-865	19	3	22	0	22
35-DS-866	25	0	25	0	25
35-DS-917	100	2	102	0	102
35-DS-983	21	17	38	0	38
35-DS-985	11	5	16	0	16
35-GM-25	173[a]	30	203	0	203
35-GM-101	9	0	9	0	9
35-GM-105	4	0	4	0	4
35-GM-110	0	1	1	0	1
35-JE-49	409[a]	108	468	49	517
35-JE-50	30	13	43	0	43
35-JE-51B	460[a]	68	528	0	528
35-JE-281	2	4	6	0	6
35-JE-282	11	1	13	0	13[b]
35-JE-283	98	4	102	0	102
35-JE-284	12	0	12	0	12
35-JE-285	17	1	18	0	18
35-JE-286	0	1	1	0	1
35-JE-287	1	3	4	0	4
35-JE-288	5	5	10	0	10
35-JE-289	1	0	1	0	1

Table 4-2 (continued)

Site	Characterized Debitage	Characterized Tools	XRF Characterization	Visual Characterization	Total
35-JE-290	1	1	2	0	2
35-JE-291	13	3	16	0	16
35-JE-292	0	1	1	0	1
35-JE-293	24	21	45	0	45
35-JE-296	86	14	100	0	100
35-JE-297	41	11	52	0	52
35-JE-298	34	24	58	0	58
35-JE-300	0	1	1	0	1
35-JE-301	5	0	5	0	5
35-JE-302	83	4	87	0	87
35-JE-304	2	2	4	0	4
35-JE-305	1	1	2	0	2
35-KL-810	309	68	377	0	377
35-KL-811	13	1	14	0	14
35-KL-812	123	31	154	0	154
35-KL-813	85	25	110	0	110
35-KL-814	193	66	259	0	259
35-KL-815	16	6	22	0	22
35-KL-816	0	1	1	0	1
35-KL-817	1	0	1	0	1
35-KL-818	29	24	53	0	53
35-KL-832	4	7	14	0	14[b]
35-KL-834	8	1	9	0	9
35-KL-835	26	3	29	0	29
35-KL-865	2	0	2	0	2
35-SH-135	7[a]	3	10	0	10
35-SH-136	2[a]	3	5	0	5
35-SH-137	2[a]	4	6	0	6
35-SH-140	4[a]	1	5	0	5
35-SH-145	38[a]	3	41	0	41
35-SH-149	0[a]	1	1	0	1
35-SH-150	3[a]	0	3	0	3
35-SH-151	2	0	2	0	2
35-UM-154	3[a]	1	4	0	4
35-WS-120	35	5	40	0	40
35-WS-223	1	0	1	0	1
35-WS-224	9	2	11	0	11
35-WS-225	309[a]	52	361	0	361
35-WS-226	16	1	17	0	17
35-WS-227	40	4	44	0	44

Table 4-2 (continued)

Site	Characterized Debitage	Characterized Tools	XRF Characterization	Visual Characterization	Total
35-WS-230	7	2	9	0	9
35-WS-231	432[a]	34	466	0	466
35-WS-232	2	1	3	0	3
35-WS-233	4	3	7	0	7
35-WS-239	0	1	1	0	1
OR-JE-5	1	0	1	0	1
PEP 5-76	2	0	2	0	2
PEP 6-23	2	0	2	0	2
PEP 7-3	1	1	2	0	2
Total Oregon	5,537	1,100	6,595[b]	49	6,644[b]
TOTAL NORTHWEST	5,539	1,100	6,597	49	6,646

[a]Represents a 100 percent sample of analyzable obsidian debitage.
[b]Total includes unmodified obsidian nodules.

Table 4-3 Summary of California PEP Sites and All Samples Selected for Characterization Studies.

Site	Characterized Debitage	Characterized Tools	XRF Characterization	Visual Characterization	Total
CA-CCO-129	6	0	6	0	6
CA-CCO-368	47	5	52	0	52
CA-COL-165	58	5	62	1	63
CA-COL-178	42	1	43	0	43
CA-MOD-77	57	16	58	15	73
CA-MOD-128	4	1	0	5	5
CA-MOD-129	80	17	62	35	97
CA-MOD-1205	30	16	37	9	46
CA-MOD-1206/07	179	76	217	38	255
CA-MOD-1461	87	72	144	15	159
CA-MOD-2555	86	13	92	7	99
CA-MOD-2556	15	11	19	7	26
CA-MOD-2557	30	1	31	0	31
CA-MOD-2558	5	2	7	0	7
CA-MOD-2559	111	35	141	5	146
CA-MOD-2560	146	82	197	31	228
CA-MOD-2561	44	0	38	6	44
CA-MOD-2562	110	69	160	19	179
CA-MOD-2563	85	62	117	30	147
CA-MOD-2564	25	12	37	0	37

Table 4-3 (continued)

Site	Characterized Debitage	Characterized Tools	XRF Characterization	Visual Characterization	Total
CA-MOD-2565	55	18	62	11	73
CA-MOD-2566/67	125	26	130	21	151
CA-MOD-2568	30	2	16	16	32
CA-MOD-2569	10	4	5	9	14
CA-MOD-2570	40	9	34	15	49
CA-MOD-2571	20	10	30	0	30
CA-MOD-2572	49	7	47	9	56
CA-MOD-2573	29	3	32	0	32
CA-MOD-2574	29	14	43	0	43
CA-MOD-2575	23	10	21	12	33
CA-MOD-2627	32	17	48	1	49
CA-MOD-2646	30	1	31	0	31
CA-MOD-2904	0	1	1	0	1
CA-SHA-68/H	122	56	153	25	178
CA-SHA-1474	27	0	27	0	27
CA-SHA-1836	0	3	3	0	3
CA-SHA-1837	21	3	24	0	24
CA-SHA-1838/H	115	13	128	0	128
CA-SHA-1839/H	27	8	35	0	35
CA-SHA-1840	0	1	1	0	1
CA-SHA-1841	44	19	63	0	63
CA-SHA-1842	33	97	130	0	130
CA-SHA-1843/H	15	6	21	0	21
CA-SHA-1891	6	10	16	0	16
CA-SHA-1966	18	8	26	0	26
CA-SHA-1975	0	20	20	0	20
CA-SHA-1976	0	13	13	0	13
CA-SIS-1552	70	14	84	0	84
CA-SIS-1553	18	2	15	5	20
CA-SOL-347	11	1	12	0	12
CA-SOL-348	4	2	6	0	6
CA-SOL-351	15	2	17	0	17
CA-TEH-1528	34	13	47	0	47
CA-TEH-1529/H	40	17	57	0	57
CA-TEH-1611	20	3	23	0	23
CA-YOL-161	4	0	4	0	4
CA-YOL-177	0	1	1	0	1
Total	2,363	930[a]	2,946	347	3,293

[a] Includes 26 basalt tools.

Oregon samples are represented by 6,644 items from 83 archaeological sites in the eight counties intersected by the pipeline (Figures 4-1 and 4-2). Sample sizes ranged by county from four items in Umatilla County to 2,602 items in Deschutes County. Fifty-seven sites from eight California counties also were selected for characterization studies and 3,294 items were submitted for source identification. Two pieces of obsidian debitage from 10-BY-444, the only Idaho obsidian items of adequate size for XRF analysis, were also included in the trace element studies. This combined corpus of 9,939 specimens constitutes, to our knowledge, the largest sample of characterized obsidian artifacts associated with any single archaeological project in the world to date.

The sample selected for obsidian studies includes most of the Oregon and many of the California obsidian tools suitable for XRF analysis (greater than 10 mm minimum dimension). The selection of debitage samples at individual sites was made on the basis of site-specific strategies typically relating to obsidian procurement or chronologic objectives. Due to the problematic nature of obsidian characterization studies at north-central Oregon sites and the relatively small number of obsidian artifacts recovered during testing and data recovery, a 100 percent sample of obsidian debitage suitable for XRF analysis was selected from many of these sites. The results of obsidian-related site and sampling data are summarized in Tables 4-1, 4-2, and 4-3.

The results of all obsidian characterization studies associated with the Project are presented in this section. Interpretation of the prehistoric lithic procurement systems reflected by the spatial patterning of the characterized obsidian is discussed in Volume IV, *Synthesis of Findings*. Obsidian hydration studies of many of the characterized artifacts are detailed in Chapter 5 of this volume. The results of obsidian characterization and hydration studies from earlier periods of the Project are reported and discussed in the context of individual site descriptions in previous testing and evaluation reports (Atwell et al. 1994; Holson et al. 1991; Lebow et al. 1991; Romano et al. 1993; Speulda 1993; Speulda et al. 1993). Results of the 1991 obsidian studies are also summarized by Skinner (1993).

Several categories of artifacts did not fall into standard analytical groupings. Twenty-six basalt artifacts from CA-MOD-1461 were also characterized. Although the basalt items are not discussed further here, results of those analyses are reported in Appendix C.2. Twenty-four artifacts from CA-TEH-1528/H submitted for obsidian hydration measurements were neither geochemically nor visually characterized, although it is likely that all or most originated from the nearby Tuscan source. Hydration band measurements for these artifacts are reported in Chapter 5 and Appendix C.4.

Artifact provenience, classification, obsidian source assignments (determined from XRF analyses), 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 specimen an alphabetic item code in addition to the specimen number given to the lot group. All analyzed items represented were flaked stone artifacts or, occasionally, nodules of unmodified raw material.

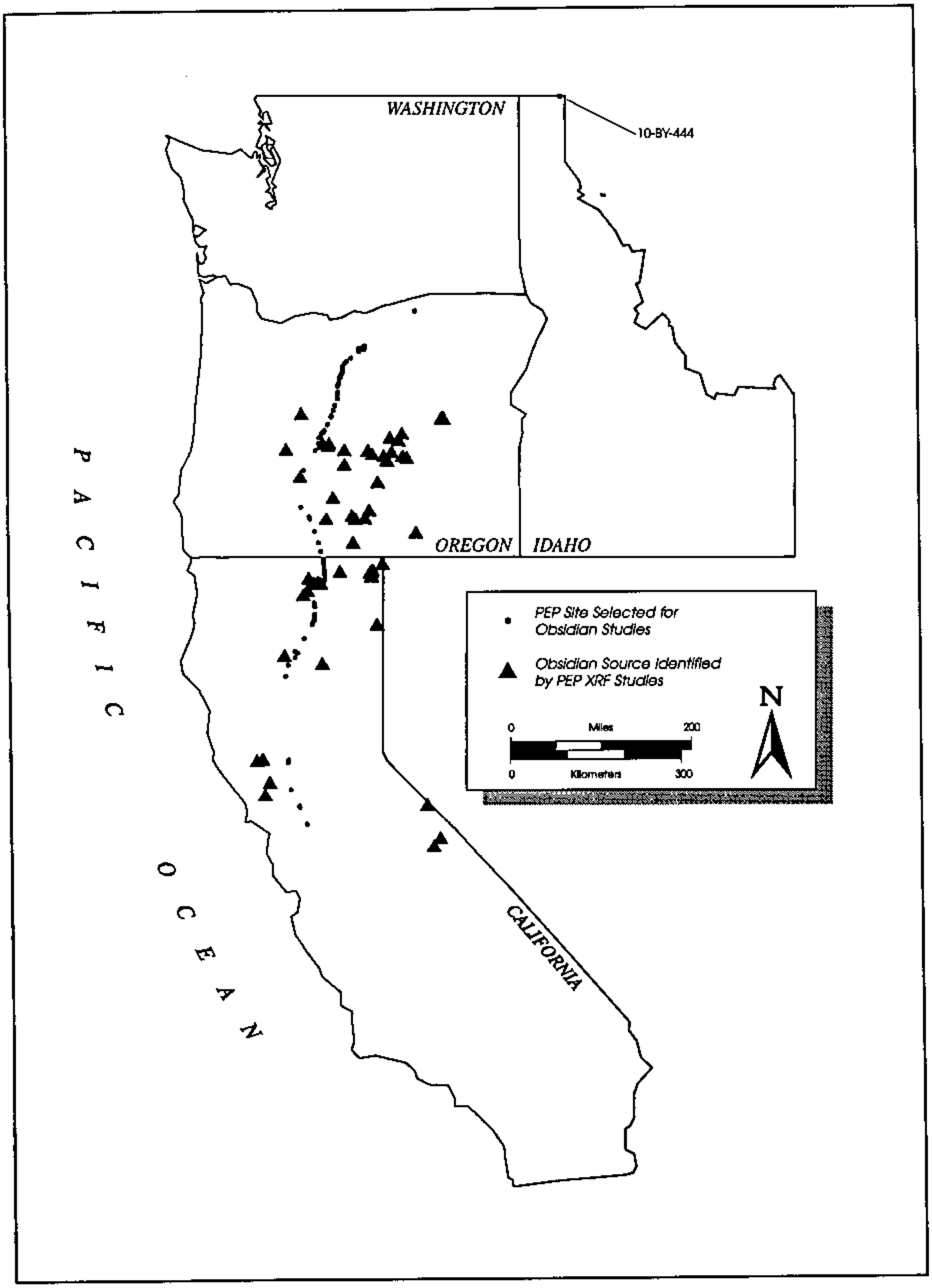

Figure 4-1 Distribution of PEP sites selected for obsidian characterization studies.

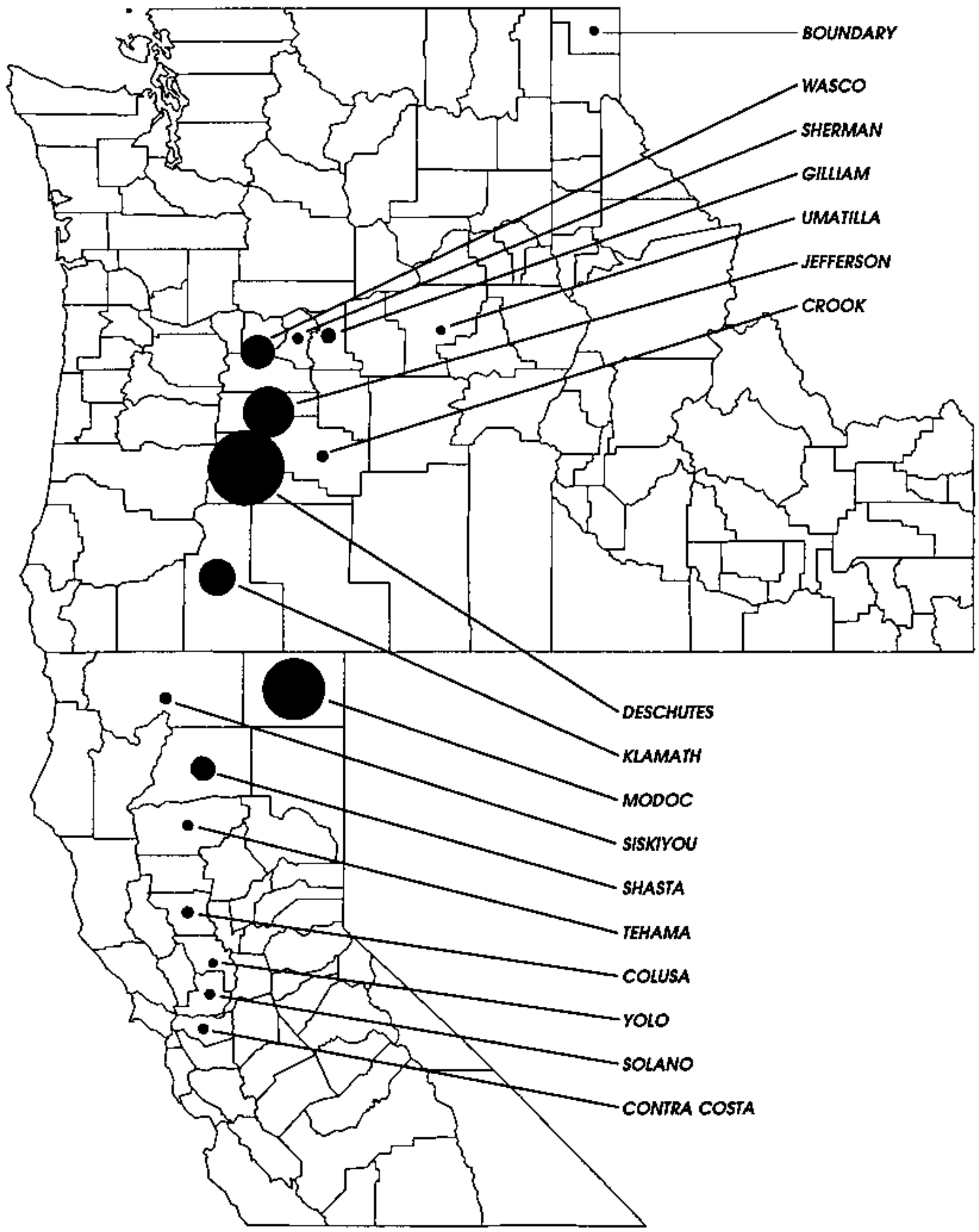

Figure 4-2 County distribution and number of characterized Project samples. The symbol size indicates the relative number of samples from each county.

4.1.2 Principles of Obsidian Characterization

Introduction. Although a variety of physical, optical, petrographic, and chemical attributes have been used to characterize volcanic glasses, the use of trace element abundances to "fingerprint" sources and artifacts has shown the greatest success. With the introduction of systematic obsidian trace element studies by Cann and Renfrew and their associates (e.g., Cann and Renfrew 1964; Renfrew et al. 1966; and Renfrew et al. 1968) and the widespread availability of hardware capable of nondestructive artifact analysis, the modern era of obsidian characterization studies has emerged. The basic analytical and interpretive path established by these early workers (Figure 4-3) has been followed by almost all subsequent researchers.

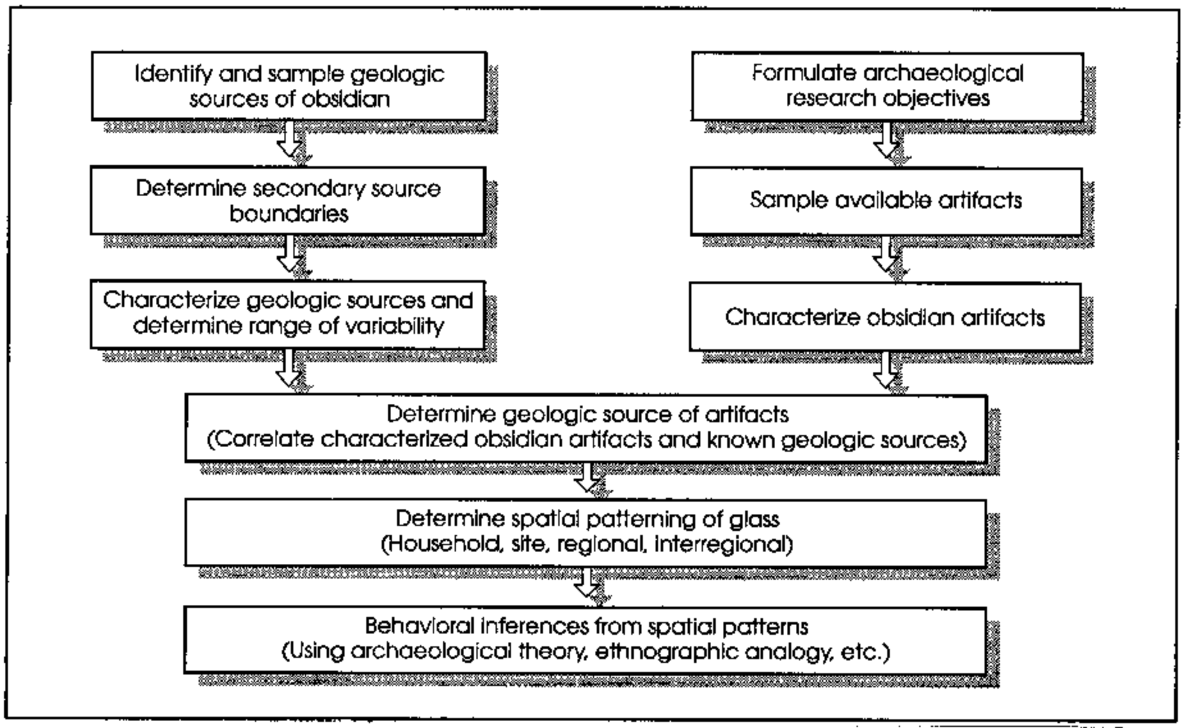

Figure 4-3 Steps in the process of obsidian characterization studies.

Obsidian characterization is based upon the fact that most geologic sources are quite homogeneous for selected trace elements, yet demonstrate adequate intersource variability; thus, individual sources of volcanic glass can be distinguished. Because obsidian can be widely dispersed from its primary geologic source through a variety of natural processes, specimens of chemically identical glass sometimes are recovered from outcrops spread over large areas. Obsidian nodules associated with extensive ashflow sheets in the Great Basin, for example, sometimes are spread over hundreds of square kilometers (Hughes and Smith 1993). Hughes (1986a) points out that these chemically identical obsidian outcrops must be considered as a single chemical group or chemical type and his terminology is followed here.

The petrogenesis and transport of obsidian is potentially complex. Consequently, the range of trace element chemical variation in sources of glass, although often remarkably small, can only reliably be determined through systematic trace element studies of source materials. Magma mixing, the eruption of ashflow sheets containing obsidian from progressively fractionating magma chambers, the physical mixing of secondary deposits from different chemically distinguishable primary sources, and incomplete or inadequate sample sizes are all factors that affect trace element variability at a given source (Bowman et al. 1973; Shackley 1992; Skinner 1983; Hughes and Smith 1993). Rigorous geochemical studies of obsidian sources often have demonstrated the existence of additional chemically identifiable sources (Hamusek 1993; Hughes 1989, 1992; Skinner 1983, 1986).

From small-scale (household and site) to large-scale (regional and interregional) analysis, the spatial patterning of characterized obsidian artifacts is affected by many environmental and cultural influences. Studying artifact distribution in relation to geologic sources provides valuable information about prehistoric behavioral and environmental procurement variables. At the site level, patterns of source use may indicate specific activity areas, single tool manufacturing events, or, in special cases, may point to differential access of goods and the existence of nonegalitarian social structures. At the intersite or regional level, the geographic patterning of artifacts can provide information about seasonal procurement ranges, territorial and ethnic boundaries, the trails and travel routes, the curational value of particular sources or formal artifact types, cultural preferences regarding glass quality and colors, trade and exchange systems, group interaction, and the exchange of prestige items between elites of different groups (Ericson 1981; Hughes 1978, 1990b; Hughes and Bettinger 1984; Skinner 1983:87–91). The effects of environmental influences such as the distance to source, the location of alternative or competing sources of lithic materials, the distribution of raw materials in secondary deposits, or the presence of potential barriers such as mountain ranges, must be considered. In particular, distance to source has been a well-studied environmental influence (Renfrew 1977). Bias introduced during sampling by certain recovery methods, analytical size selection, and the use of small sample sizes also may significantly affect reconstruction of the spatial patterning of analyzed artifacts.

Diachronic studies of obsidian use patterns can add a temporal dimension to our understanding of prehistoric source use. Evidence for shifting land-use patterns, changes in social alliances and territorial boundaries, influxes of new populations, fluctuations in population density, the depletion of geologic sources, variations in social organization and complexity, and changes in exchange systems have all been inferred from the changes in observed patterns of source utilization over time.

4.1.3 Research Objectives

The Project runs through some of the most obsidian-rich regions of the world. Well over 100 geochemically identifiable sources of rhyolitic volcanic glass have been identified in Oregon; dozens of other sources have been found in California, particularly in the northern part of the state (Ericson et al. 1976; Hughes 1986a; Skinner 1983). Because of the importance of obsidian, both in its role as a prehistoric lithic resource and its value as a source of chronologic and lithic procurement information, considerable emphasis was placed on obsidian studies during the course of the PEP.

Obsidian-related investigations fall into two major categories: obsidian hydration studies and obsidian characterization studies. Obsidian hydration studies, discussed in Chapter 5, provide chronologic information that may be of considerable importance in carbon-poor archaeological sites, such as many of those encountered during the PEP. The chemical composition of obsidian is an important variable influencing the hydration rate of the glass, and obsidian source identification studies were used to control for that variable during the Project.

In addition to providing a chemical control for use with obsidian hydration analyses, obsidian characterization studies were used to explore prehistoric procurement and interactional systems. Patterns of source use provide crucial information about seasonal subsistence ranges, territorial boundaries, and direct and indirect procurement. Given the previous dearth of knowledge about prehistoric lithic procurement patterns in northern California and Oregon, particularly in central and north-central Oregon, trace element studies of PEP obsidian provide essential baseline information for both current and future investigations. These characterization data, used in conjunction with obsidian hydration measurements and the presence of well-dated Mazama tephra at several sites, provide information about obsidian use against which Project research objectives and subsequent hypotheses can be tested and a foundation upon which further archaeological research will be built.

4.2 METHODS

4.2.1 Sample Preparation and Problems

Obsidian samples selected by IRI and FWARG laboratory personnel typically were restricted to those artifacts with a relatively flat surface at least 10 mm in diameter and at least 1 mm thick. Occasionally, artifacts as small as 8 mm in diameter were analyzed. Because of the increased counting times and potentially large analytical uncertainties experienced with very small sample size, the analysis of these small artifacts was limited to exceptional circumstances.

Deschutes Region Patina. Many of the obsidian artifacts from Deschutes County, Oregon, are covered with a light gray patina that often made identification difficult. The patina, initially suspected to be composed of calcium carbonate, proved resistant to a vinegar wash and a 30 percent solution of HCl and is probably a silica-based encrustation. Silica is weakly soluble in water and the artifact crust may have originated from the tephra-rich soils of the Deschutes County sites. Opaline silica deposits are often found in the surface horizons of soils derived from volcanic ash (Jenny 1980:105; Rieger 1983:136-137). The presence of the patina presented problems for both chemical characterization and obsidian hydration rim measurements. During initial XRF analysis, the encrustation was found to contain elevated levels of titanium (Ti), a diagnostic element used to distinguish between the regionally widespread McKay Butte and Quartz Mountain sources. This problem led to initial indeterminate source assignments for many of the obsidian artifacts identified as originating from one of these two geologic sources.

All samples initially identified as originating from the Quartz Mountain/McKay Butte source were cleaned by IRI laboratory personnel prior to reanalysis. The patina-like encrustation on each of these artifacts was removed from at least a 10 mm diameter, flat to slightly convex portion of the surface. The patina was first scraped free with an X-ACTO knife; any remaining encrustation was removed with steel wool. After the removal of the patina, the artifact was washed in tap water to remove any traces of contamination resulting from the cleaning process. In practice, the clean area sometimes proved to be too small and during reanalysis both the patina and the cleaned area were sampled, resulting in greater than expected reported elemental abundances for some samples. In several cases, it was not possible to distinguish between separate sources, and artifacts with these characteristics remain classified in the Quartz Mountain/McKay Butte group.

Because of the problems associated with surficial post-depositional deposits on artifacts, all obsidian samples submitted for analysis during later stages of the Project were cleaned prior to further analyses. When surface patina was found on an artifact, traces of the encrustation were scraped from a target area approximately 20 mm in diameter.

Surface Zinc Contamination. Several samples from 35-DS-33 produced elevated zinc (Zn) values. Although Zn is not a particularly significant diagnostic trace element, anomalous abundances detected on a few obsidian artifacts were of concern. However, when it was discovered that these same samples had been subjected to a patina removal experiment with a high-speed Dremel tool equipped with a small wire brush, it was determined that the surface of the artifacts likely was contaminated by the alloy brush used during the preparation process.

4.2.2 X-ray Fluorescence Analysis

Analytical Methods. All nondestructive XRF analyses and obsidian source determinations were carried out by Dr. Richard E. Hughes of Geochemical Research (Rancho Cordova, California) and BioSystems Analysis (Santa Cruz, California).

Geochemical Research (Richard Hughes). XRF analyses were performed on a Spectrace 5000 (Tracor X-ray) energy dispersive x-ray fluorescence (EDXRF) spectrometer equipped with a Rh x-ray tube, a 50 kV x-ray generator, 1251 pulse processor (amplifier), 1236 bias/protection module, a 100 mHz analog-to-digital converter (ADC) with automated energy calibration, and a Si(Li) solid state detector with 150 eV resolution (FWHM) at 5.9 keV in a 30 mm^2 area. The x-ray tube was operated at 35.0 kV, 0.28 mA, using a 0.127 mm Rh primary beam filter in an air path for 200 seconds livetime to generate x-ray intensity data for zinc (Zn), gallium (Ga), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), and niobium (Nb). X-ray intensities were converted to concentration estimates (parts per million [ppm]) employing a least-squares calibration line established for each element through analysis of rock standards certified by the U.S. Geological Survey, the U.S. National Institute of Standards and Technology, the Geological Survey of Japan, and the Centre de Recherches Petrographiques et Geochimiques (France). Further details pertaining to x-ray tube operating conditions and calibration are presented by Hughes (1988). XRF analytical methods are reviewed in detail by Norrish and Chappell (1967) and Potts and Webb (1992).

Trace element abundances were determined to the nearest ppm to reflect the resolution capabilities of nondestructive EDXRF spectrometry. Resolution limits of the present x-ray fluorescence instrument for the determination of the reported trace elements are: Zn, about 3 ppm; Ga, about 2 ppm; Rb, about 4 ppm; Sr, about 3 ppm; Y, about 2 ppm; Zr, about 5 ppm, and Nb, about 3 ppm. When error uncertainty estimates (e.g., $\pm$ 3 ppm) for a sample are greater than calibration-imposed limits of resolution, the larger number is preferred as a more conservative, robust reflection of elemental composition and measurement error due to variations in the size of the samples and the surface and x-ray reflection geometry (see Hughes [1988] for further details).

BioSystems Analysis. BioSystems XRF studies were conducted using analytical hardware and operating conditions similar to those employed by Hughes. All analyses were completed using a Spectrace 5000 EDXRF system equipped with a Si(Li) detector with a resolution of 155 eV FHWM for 5.9 keV x-rays (at 1000 cps) in an area 30 mm^2. The x-ray tube employed is a Bremsstrahlung type with an Rh target and 5 mil Be window. For analysis of Th, Rb, Y, Sr, Zr, and Nb, the Rh x-ray tube is operated at 30–40 kV, .30–.45 mA (pulsed), with a 0.127 Pd filter. A counting period of 200–300 seconds live-time was used. Lead (Pb) and thorium (Th) abundances, although determined for most specimens, are not reported in Appendices C.1 and C.2. Pb and Th values and their analytical uncertainties appear in an early testing and evaluation report (Holson et al. 1991).

Nondestructive XRF Analysis of Obsidian Artifacts. In traditional XRF trace element studies, samples are typically powdered and pelletized prior to analysis (Norrish and Chappell 1967; Potts and Webb 1992); however, all XRF studies reported here were performed nondestructively. In theory, the irregular surfaces characteristic of most obsidian artifacts should introduce measurement problems because of shifts in artifact-to-detector reflection geometry (Hughes 1986a:35). Early experiments with intact obsidian flakes by Robert N. Jack, and later by Hughes, however, indicate that analytical results from lenticular or biconvex obsidian surfaces are comparable to those from flat surfaces and pressed powder pellets, paving the way for the nondestructive characterization of glass artifacts (Hughes 1986a:35–37; Jack 1976). The minimum optimal sample size for analysis was found to be approximately 10 mm in diameter and 1.0–1.5 mm thick. Later experiments conducted by Shackley and Hampel (1993) using samples with flat and slightly irregular surface geometries have corroborated Hughes' initial observations. In a similar experiment, Jackson and Hampel (1993) determined that for accurate results the minimum sample size of an artifact appears to be about 10 mm in diameter and about 3 mm thick.

4.2.3 Correlation of Artifacts and Geologic Sources

All trace element values used to characterize the artifacts were compared directly to values for known obsidian sources reported by Hughes (1986), Jack (1976), and Skinner (1983, 1986). Artifacts were assigned to a parent obsidian source or chemical source group (two or more chemically indistinguishable obsidian occurrences) if diagnostic trace element abundances (Rb, Sr, Y, and Zr) corresponded at the 2-sigma level, that is, if the diagnostic mean measurements for the artifacts fell within two standard deviations of mean values for the source standards. Diagnostic trace elements, as the term is used here, refer to trace elements that are measured by XRF with high precision and low analytical uncertainty and whose abundances show low intrasource variability along with marked intersource variability. In short, these diagnostic elements are those that allow the clearest geochemical distinctions between sources (Hughes 1990a; Skinner 1983). Geologic source designations of the characterized obsidian artifacts are reported in Appendices C.1, C.2, C.3, and C.4.

When initial diagnostic trace elements (Rb, Sr, Y, Zr) failed to provide sufficient resolution to distinguish between sources (as was the case with the Quartz Mountain and McKay Butte sources, for example), additional analyses were often carried out. In these instances, the determination of titanium (Ti), manganese (Mn), barium (Ba), and iron (Fe_2O_3) abundances were usually sufficient to identify specific sources or chemical source groups. In cases where diagnostic elements could not be used to discriminate between different chemical sources, the identified possible sources are separated by a slash (e.g., Quartz Mountain/ McKay Butte). It should be noted that, in many cases, indeterminate and ambiguous source assignments currently reported for PEP samples could be resolved with further geochemical studies.

At the close of PEP investigations, the final geochemical data set was compiled and examined. New chemical data resulting from later fieldwork and additional source analyses by Richard Hughes, particularly for sources in north-central Oregon, were integrated into the earlier results reported in Lebow et al. (1991). This resulted in the resolution or partial resolution of many of the unknown sources identified in the early stages of the Project. Whenever possible, sources previously designated as unknown were reassigned to the preliminary chemical source groups identified by Hughes in later characterization studies.

Although the reliability of source assignments in most areas of the Project appears to be high, any examples of anomalous sources or unexpected long-distance procurement should be interpreted with caution. Anomalies in characterization may result from long-distance procurement, or alternatively, may signal the presence of previously uncharacterized sources or analytical problems. The presence of many north-central Oregon artifacts with uncertain source assignments or undifferentiated chemical groups reflects our still incomplete knowledge of the distribution and geochemistry of obsidian in that region.

Unknown Sources. When obsidian source assignments are not possible, that is, when no known geologic obsidian source is available for comparison and correlation, the source of the artifact is designated as "Unknown." Probable major chemical source groups are designated by letter suffixes; however, the letters following the Unknown prefix have no significance other than to temporarily differentiate, at the site level, among unknown obsidian sources and are assigned simply on the basis of the order of the catalog number of the artifact (e.g., Unknown D, Unknown G). These unknown group designations are **site specific**, that is, Unknown A at one site has no genetic relationship with an Unknown A source at any other site.

Assignments of artifacts to unknown sources can result from one of three conditions:

1. The artifact originated from a geologic source that has not been located or for which geochemical data are not yet available.

2. The composition of the artifact falls outside the known range of chemical variability of a known parent geologic source.

3. Analytic problems led to anomalous results, for example, inadequate size, unsuitable surface geometry, surface contamination, or the presence of non-obsidian materials (spherulite, phenocryst, accidental inclusion, etc.) in the target area.

Designations of samples from unknown sources provisionally classified into discrete chemical source groups must always be considered tentative. Without geochemical source data with which to determine the true range of geochemical variability, it is often difficult to ascertain whether the variation in trace element data represents the presence of more than one source or simply reflects the chemical range of variation of a single obsidian source.

Unknown Sources in North-Central Oregon. Obsidian characterization studies of archaeological sites in north-central Oregon, including those sites investigated during the early stages of the Project, often yielded large proportions of unknown artifact source assignments (Erlandson et al. 1991; Hughes 1987, 1993a, 1993b, 1993c). Archaeological and geological information regarding obsidian in this area is very sparse and lacking in detail, often limited only to a mention or very brief description of obsidian sources (Bransford and Mead 1975; Brown 1982; Crowley 1960:26; Ericson 1977:316; Hughes 1986b). During the course of PEP obsidian studies, many new sources of glass in the Ochoco and Malheur National Forests of north-central Oregon were located, sampled, and analyzed by Richard Hughes. Currently, however, trace element studies of these sources are still in the very early stages. The number of analyzed samples is low, the geochemical range of variability of the sources is incompletely known, and field studies are still in progress. It is likely that many of the samples assigned here to unknown sources originated from as yet unsampled sources in the Ochoco-Malheur National Forest region, or simply fall outside the chemical range of variability that has so far been determined for known sources.

The Grasshopper and GF/LIW/RS Chemical Groups. The Grasshopper Flat, Lost Iron Well, and Red Switchback (GF/LIW/RS) sources, located on the northern and southern edges of Medicine Lake Highlands, are chemically inseparable and are considered a single group for characterization purposes. The nearby East Medicine Lake (EML) group consists of two contiguous source localities along the eastern edge of the Highland (see Appendix C.5). Hughes (1986a) has maintained that these two chemical groups can be differentiated from GF/LIW/RS based on zirconium (Zr) concentration values. However, "the separation is not statistically valid at the 95 percent confidence interval," as noted by Jackson (in Holson et al. 1991), and distinguishing among obsidian sources based on a single trace-element abundance has been shown to be statistically invalid. To correct for this situation, Hughes (1986a, personal communication 1993) has identified the ratio of iron (Fe) to manganese (Mn) as an additional distinguishing factor between the two sources. Hughes' 1986 sample of 20 items indicates a very narrow separation, with EML sources showing an Fe/Mn ratio >55. Using source specimens plotted against the PEP sample from site CA-SHA-1474, the separation point distinguishing EML is a Fe/Mn ratio ≥ 48, with Zr at >176 ppm (Hughes, personal communication 1993).

It is Jackson's contention (Jackson, personal communication 1994) that the Fe/Mn ratio is no more useful than Zr concentration values for discriminating between the two source groups. There is a statistically significant overlap in the data, particularly between LIW and EML. Four points regarding this problem need to be recognized: (1) there is always more variability in artifact obsidian trace elements than source obsidian elements, primarily because of the influence of artifact dimensions and surface characteristics during analyses; (2) a confidence level of at least 95 percent should be obtained; (3) error factors that should be taken into consideration include the $\pm$ value of each element, reflecting an estimate of x-ray counting uncertainty and regression fitting error, and machine error (commonly 3–3.5%); and (4) given a 95 percent level of confidence, only those specimens within that level should be used for comparative analysis, all other things being equal. The latter point indicates the need for the determination of statistically valid trace element concentrations for each group.

As a first step in assessing the feasibility of distinguishing between these sources for PEP artifacts, Hughes' determinations of trace element concentrations and source attributions (see Appendix C.2) for projectile points (GIF/LIW/RS and EML only; n=237) were compared. The results of this review were surprising because although the Zr values suggested that distinguishing between EML and GF/LIW/RS is possible, the Fe/Mn ratios did not (Figure 4-4). Zirconium data from the debitage sample (n=501) were subsequently plotted in anticipation of a comparable pattern, but the single-distribution nature of Zr values (Figure 4-5), previously noted by Jackson, was immediately apparent. Based on the assumption that Fe/Mn ratios might clarify the issue, the debitage sample was submitted for additional analyses by Dr. Paul Bouey (Appendix C.2). The results of these analyses failed to segregate the sources as expected (note that the range of values reflects machine and sample size variation between the different analyses). In fact, the debitage Fe/Mn data signaled an equally problematic distribution of values between the two source clusters (Figure 4-6). The initial response to these data was to treat the entire assemblage as an undifferentiated Grasshopper Group (GG) collection. Reservations have been expressed regarding that strategy—although the data warrant such an approach—so an alternative methodology was applied. Based on Hughes' projectile point data and his source ascriptions, cut-off points were chosen to distinguish GF/LIW/RS, GG, and EML. Since neither study

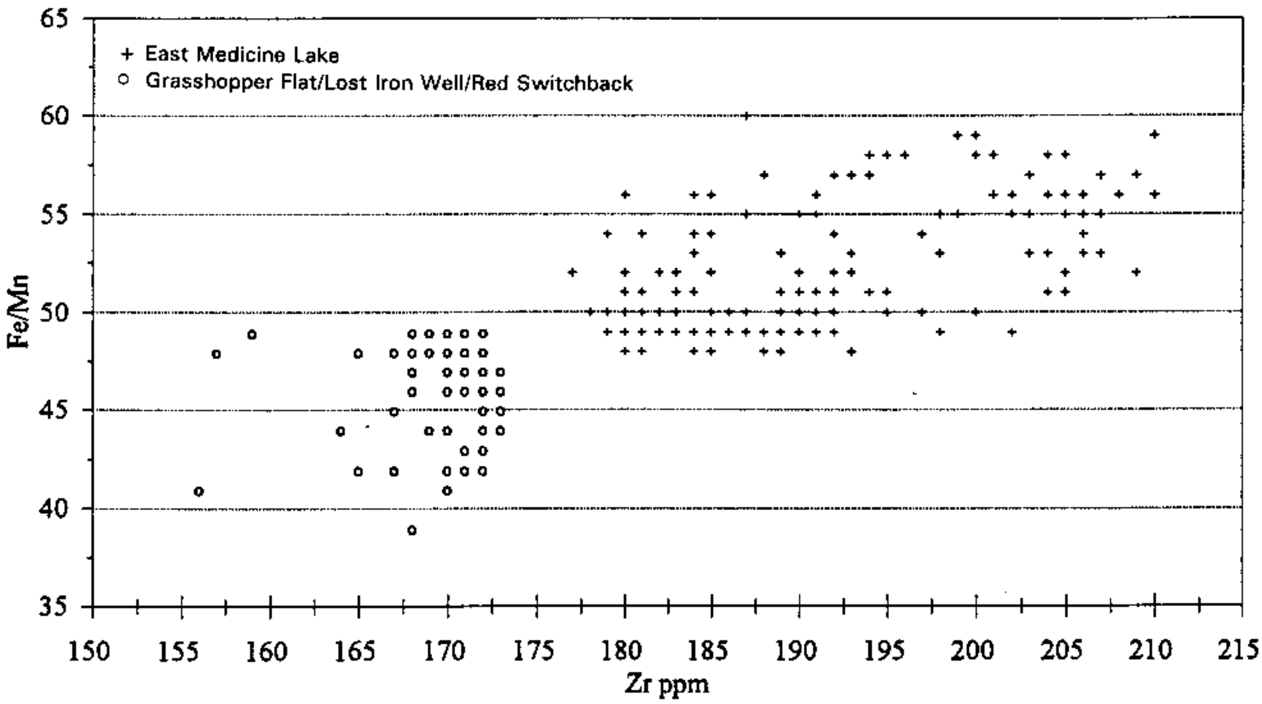

Figure 4-4 Plot of zirconium values and iron-manganese ratios for Grasshopper Flat/Lost Iron Well/Red Switchback and East Medicine Lake projectile points.

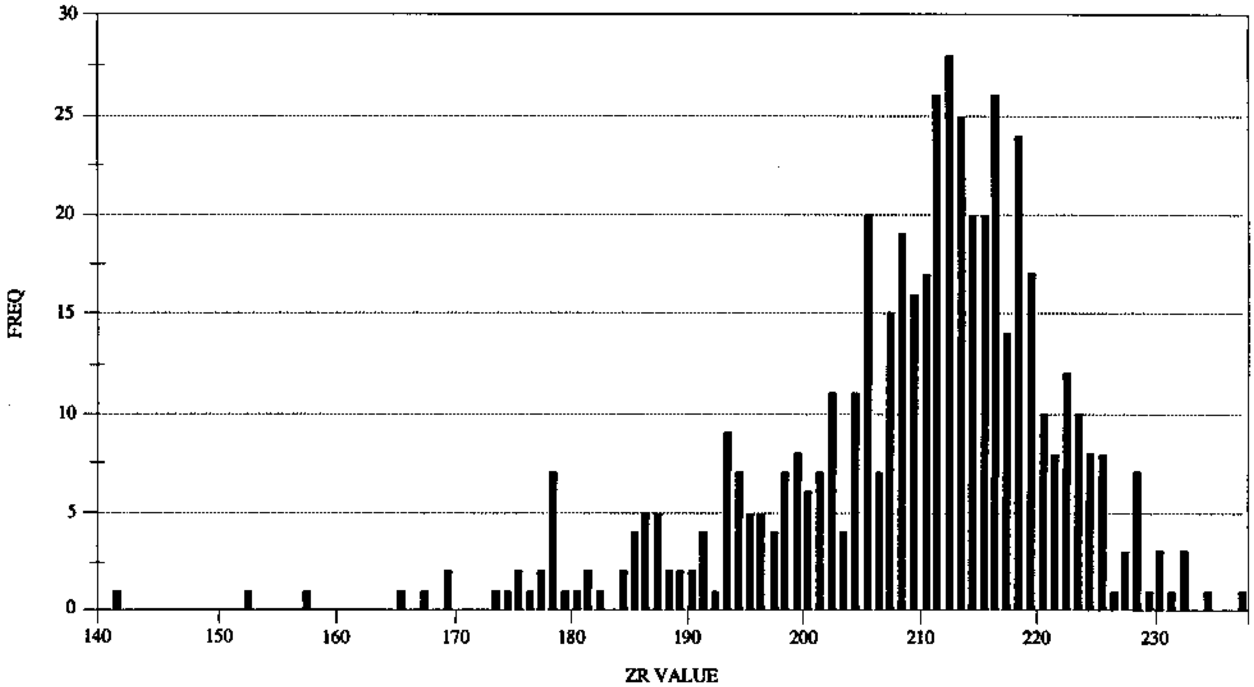

Figure 4-5 Distribution of frequencies of zirconium values for Grasshopper Flat/Lost Iron Well/Red Switchback, East Medicine Lake, and Grasshopper Group debitage.

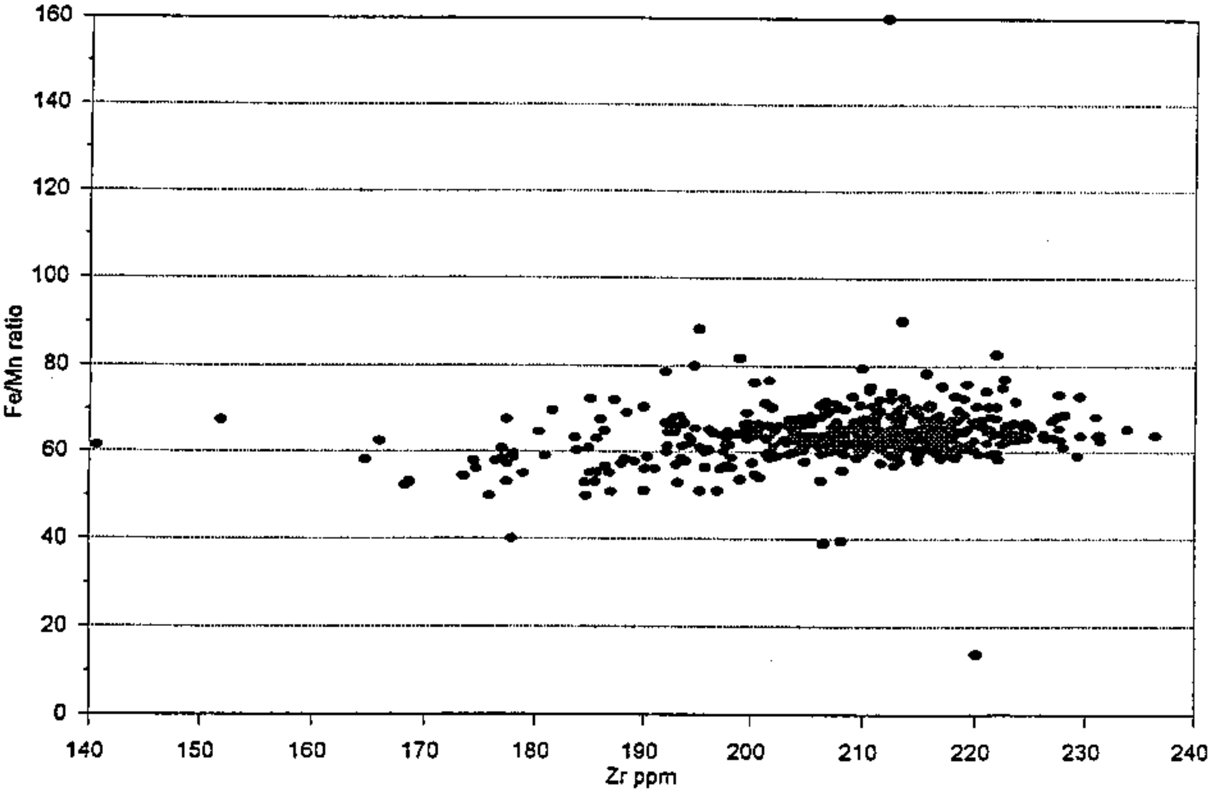

Figure 4-6 Plot of zirconium values and iron-manganese ratios for Grasshopper Flat/Lost Iron Well/Red Switchback, East Medicine Lake, and Grasshopper Group debitage.

yielded useful Fe/Mn figures, only the Zr values were employed. Specimens assigned to GF/LIW/RS have ppm determinations of <173, and EML have quantities >179; GG attributions were given to those pieces with Zr values between or equal to 173 and 179. These splits are estimates based on a visual inspection of data from archaeological specimens, allowing for a slightly greater overlap range than suggested by Hughes. Resulting conversions generated an assemblage dominated by EML, with relatively few examples of GF/LIW/RS or GG present.

Microscopic Visual Characterization—35-JE-49, North-Central Oregon. Although 35-JE-49 contained a significant pre-Mazama component, very few samples of obsidian large enough for XRF analysis were recovered from the pre-Mazama units. Because of the potential importance of the Mazama temporal horizon in establishing obsidian hydration rates, a limited sample (n=49) of small pre-Mazama flakes were examined for hydration rims. Previous trace element studies indicated that glass from Obsidian Cliffs in the central High Cascades was likely to be found in significant proportions in the pre-Mazama samples at 35-JE-49. Petrographic studies of obsidian from the Obsidian Cliffs source have also suggested that this source can sometimes be distinguished from other major regional sources by the presence of specific distinctive microscopic subcrystalline structures (acicular prismatic microlites) (Skinner 1983, 1986). Using petrographic criteria during hydration rim measurements of these small flakes, Tom Origer tentatively identified Obsidian Cliffs as the source of several of the samples. All other sample sources were designated as unknown, although several petrographically-distinguishable sources were identified. Without geochemical studies to chemically establish the sources, these source determinations should be considered tentative. However, the data may provide useful supporting evidence in regional obsidian hydration rate studies.

All samples characterized in this manner are presented in Appendices C.1 and C.3 and are designated by the MV abbreviation enclosed in parentheses following the source designation and by "microscopic visual characterization" in the comments column.

Megascopic Visual Characterization—Medicine Lake Highlands, Northern California. Obsidian from Grasshopper Group sources in the Medicine Lake Highlands can be distinguished from other regional sources with a high degree of certainty by either visual or geochemical means. A sample of 267 obsidian artifacts was randomly selected by BioSystems to test the accuracy of the visual identification of the Grasshopper Group source. This is noted in the comments column of Appendix C.4 by the "Grasshopper Group visual source" notation. Grasshopper Group obsidian was correctly recognized for 253 samples for a successful identification rate of 94.8 percent (Holson et al. 1991).

Based on visual characteristics observed prior to obsidian hydration measurements, 340 additional artifacts were visually assigned to the Grasshopper Group source. Six more artifacts from CA-MOD-129 and CA-MOD-2566/67 were visually assigned to the Blue Mountain source and a single item from CA-COL-165 was attributed to the Napa Valley source. All samples with visually identified sources are designated in the comments column of Appendix C.2 as "visually assigned source." The results of the visual characterization of California artifacts are reported in Table 4-9.

4.2.5 Data Management and Analysis

Due to the scope of the obsidian studies project, data management considerations were both crucial and unique. Artifact data were initially recorded and stored in Lotus-compatible worksheets using Quattro Pro (Windows and DOS versions). The results of each year's obsidian studies were compiled on a separate worksheet with obsidian data associated with BioSystems and FWARG investigations stored in separate spreadsheet files. All trace element (and obsidian hydration) data collected during the latter part of the Project were acquired on disk and were incrementally integrated with the annual artifact spreadsheets. Provenience and classification information was integrated into the worksheets from subsets of site catalogs created with dBASE IV. Other data fields deemed useful during the management or analysis of the data were developed as needed.

When artifact analysis was complete, the spreadsheets were exported for curation purposes as dBASE IV databases. Most data analysis was carried out with dBASE IV and FileMaker Pro, a Windows database. This latter database was used because of its ease of operation and ability to produce publication-quality tables. At the end of the Project, the reassignment of unknown to known obsidian sources using newly available trace element data was accomplished using multi-element queries of the completed databases. Although statistical and graphical methods are often used for the correlation of characterized artifacts and geologic sources, database-assisted source assignments are very effectively used here to initially assign sources. This method is particularly useful when examining large numbers of characterized artifacts, as with this project. Final data analysis was carried out on an 80486 50-MHz IBM-compatible microcomputer with eight megabytes of RAM and a 600-megabyte hard disk drive.

4.3 RESULTS OF X-RAY FLUORESCENCE ANALYSES

Fifty-seven chemically discrete parent geologic sources of obsidian were identified from the 9,543 obsidian artifacts characterized with XRF methods. Thirty-three of the sources are in Oregon, 22 are in California, one is in Nevada, and one, Obsidian Cliff, is within the boundaries of Yellowstone National Park, Wyoming. All obsidian sources identified during characterization studies are described in Appendix C.5. In addition, several unknown chemical source groups were delineated after known source assignments were completed. These unidentified sources were particularly prevalent in the John Day and Lower Deschutes River drainages of north-central Oregon and it is likely that several obsidian sources are yet to be identified by obsidian researchers. Trace element abundances and analytical uncertainties for all analyzed samples are listed in Appendices C.1 and C.2. Additional provenience information and obsidian hydration measurements for many of the analyzed artifacts are found in Chapter 5.

4.3.1 Idaho Obsidian Characterization Studies

Two items of obsidian debitage from 10-BY-444, near the United States-Canada border in Idaho, were characterized. These were the only obsidian artifacts from any Idaho site of suitable size for XRF analysis. The source of one of the flakes could not be identified. The second piece of debitage was found to originate from Obsidian Cliff in Yellowstone National Park, Wyoming, a major source of obsidian over 650 km (400 mi) southeast of 10-BY-444.

This diminutive 15.0 x 10.7 mm flake holds the distinction among PEP artifacts of prehistorically having been transported farthest from its known geologic source.

Glass from the Obsidian Cliff source was utilized extensively during the prehistoric period and has been identified at sites in Montana, Idaho, Wyoming, Ohio, Illinois, Wisconsin, Michigan, Alberta, Saskatchewan, and Ontario. Obsidian from this source was used in the manufacture of many Hopewellian ceremonial artifacts and was an important raw material in the extensive Middle Woodland procurement systems (Davis 1972; Frison 1974; Griffin et al. 1969; Hatch et al. 1990).

4.3.2 Oregon Obsidian Characterization Studies

The trace element composition of 6,595 specimens from 83 Oregon archaeological sites was determined during the course of the Project (Figures 4-7 and 4-8). Based on their chemical composition, 56 of the items are not of obsidian. Of the remaining specimens, geologic sources or tentative sources were assigned to 6,002 items. The composition of the remaining 537 artifacts could not be correlated with any currently known source. About 350 of these artifacts, however, fall into a single tentative source group designated here as the Unknown X source. Sample sizes at investigated sites ranged from one item each for several sites to 964 tools and flakes from 35-DS-33. Summary results for Oregon PEP sites are presented in Tables 4-4, 4-5, 4-6, and 4-8.

John Day River Basin. Obsidian tools and debitage were relatively uncommon at sites in the John Day Basin, typically composing only 5–10 percent of the lithic materials. Of the 296 analyzed artifacts from 13 Sherman, Gilliam, and Umatilla county sites, 249 were obsidian debitage; the remaining 47 items were tools. Identified sources are presented in Table 4-4. Fourteen known obsidian sources and multiple unknown sources were represented in the collection.

Conspicuous in the lithic assemblage from the John Day sites is a uniformly black material with a glassy to resinous luster (classified as CCS) that closely resembles obsidian. In 1-mm thick flakes, the material is opaque; the surface texture is smooth and no inclusions are visible in the glassy matrix. In larger specimens, the obsidian-like material can be distinguished from true obsidian by its apparent lower density, its resinous luster, and the presence of pitted planar surfaces resembling cortex. These pits are clearly visible with a hand lens but may be difficult to distinguish with the naked eye. This glassy substance is easily confused with obsidian; two items from 35-SH-150 analyzed for trace element abundances were found to be of this nonobsidian lithic material. The relatively higher abundances of Zn and Sr in the obsidian-like samples make this material clearly distinguishable from other regionally available types of true volcanic glass.

A large percentage of the characterized artifacts from the John Day River Basin PEP sites were initially assigned to several unknown source groups (Lebow et al. 1991; Speulda 1993; Speulda et al. 1993). Based on the early results of ongoing trace element studies of obsidian from the Seneca area, however, it was possible to reassign many of these artifacts to known sources. More than half of the characterized samples originated from the Whitewater Ridge and Little Bear Creek sources, located in the Bear Creek Valley near Seneca. Items from many unknown sources, 18.6 percent of the 296 characterized artifacts, still await

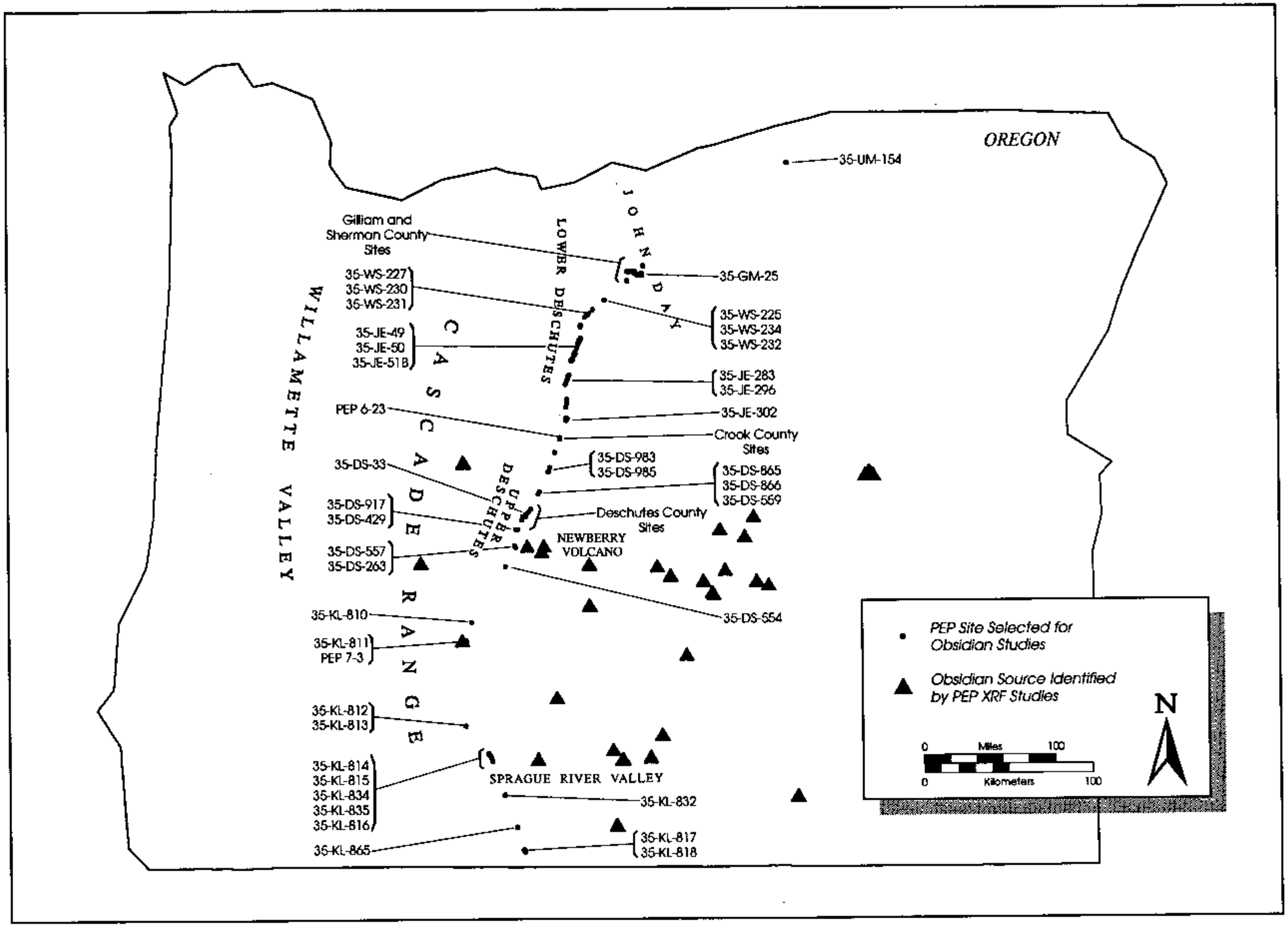

Figure 4-7 Location of characterized Oregon PEP archaeological sites and obsidian sources identified during trace element studies.

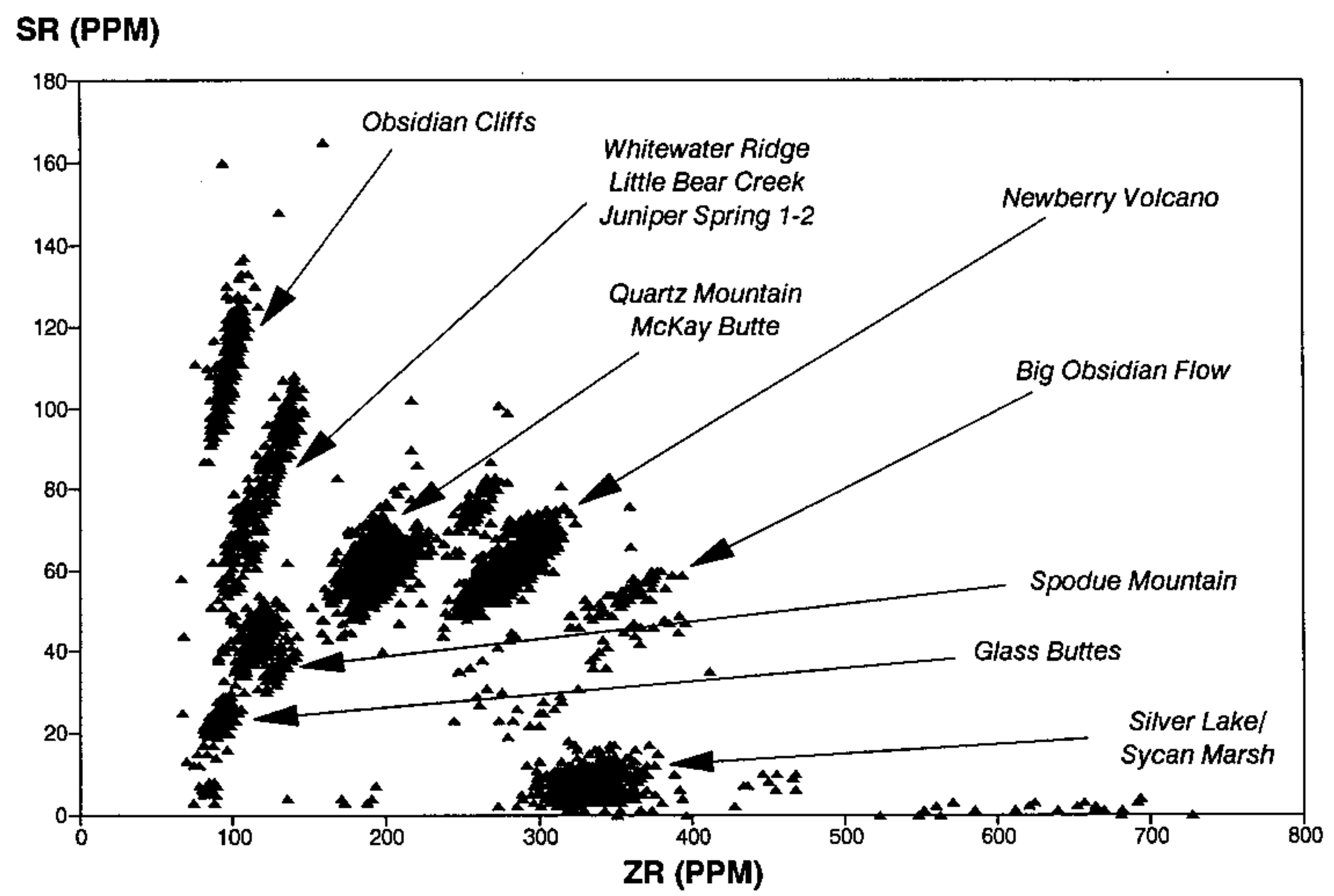

Figure 4-8 Scatterplot of Sr plotted versus Zr for all Oregon artifacts correlated with known geologic sources.

Table 4-4 Results of Trace Element Studies of Artifacts from John Day River Basin Sites.

Obsidian Source/ Chemical Type	Archaeological Sites															
	35-GM-25	35-GM-101	35-GM-105	35-GM-110	35-SH-135	35-SH-136	35-SH-137	35-SH-140	35-SH-145	35-SH-149	35-SH-150	35-SH-151	35-UM-154	PEP 5-76	Total	(%)
Chickahominy? [a]	4	0	0	0	0	0	0	0	0	0	0	0	0	0	4	(1.4)
Cougar Mountain	1	2	1	0	0	0	1	0	0	0	0	0	0	0	5	(1.7)
Delintment Creek? [a]	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	(0.7)
Glass Buttes	6	0	0	0	0	0	0	0	1	0	0	0	0	0	7	(2.4)
Horse Mountain? [a]	2	0	1	0	0	2	0	0	0	0	0	0	0	0	5	(1.7)
Juniper Spring 2/Whitewater Ridge	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	(0.3)
Little Bear Creek (?) [b]	9	0	0	0	0	0	0	0	0	0	0	0	0	0	9	(3.0)
Little Bear Creek/Whitewater Ridge	17	2	0	0	0	1	0	0	1	0	0	0	0	0	21	(7.1)
Little Bear Creek/Whitewater Ridge/ Juniper Spring 2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	(0.3)
McKay Butte	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	(0.3)
Newberry Volcano (?) [b]	3	0	0	0	0	0	3	0	4	0	0	0	0	0	10	(3.4)
Obsidian Cliffs	2	0	0	0	0	0	0	0	1	1	0	0	0	0	4	(1.4)
Quartz Mountain (?) [b]	4	0	0	0	2	0	0	0	0	0	0	0	0	0	6	(2.0)
Quartz Mountain/McKay Butte	2	2	0	0	5	0	0	0	1	0	0	0	0	0	10	(3.4)
Whitewater Ridge (?) [b]	95	2	1	0	1	1	0	3	23	0	3	0	0	1	130	(43.9)
Wolf Creek (?) [b]	11	0	0	0	0	0	0	0	0	0	0	0	0	0	11	(3.7)
Unknown	35	1	1	0	1	0	2	1	10	0	0	0	4	0	55	(18.6)
Not Obsidian	8	0	0	1	0	1	0	1	0	0	0	2	0	1	14	(4.7)
Total	203	9	4	1	10	5	6	5	41	1	3	2	4	2	296	

[a] ? = Provisional source assignment.
[b] (?) = Final and provisional source assignments combined in one category.

identification. As trace element studies of obsidian geologic sources in this region progress, it is probable that many of these artifacts will be found to originate from already known sources whose range of geochemical variability is currently inadequately described. It is a virtual certainty, however, that other new sources of glass used by the prehistoric inhabitants of the John Day area sites remain to be rediscovered by modern archaeologists. The large proportion of unknown sources combined with the relatively small percentage of obsidian debitage from these sites (often less then 5%) suggests distant parent obsidian sources, most likely east or southeast of the investigated sites.

Lower Deschutes River Basin. A collection of 2,589 items from 36 archaeological sites in the Lower Deschutes River Basin was chosen for characterization studies. This total includes 396 obsidian tools, 2,192 pieces of debitage, and 1 nodule of unmodified glass. Of this sample, 2,540 were sourced using XRF and 49 were sourced visually. The results of the XRF studies are summarized in Table 4-5.

Twenty-six different obsidian types, an unusually large number of sources from this relatively restricted geographic region, were found in the characterized assemblage. The locations of these sources are distributed from the High Cascades to the west, Newberry Volcano and the Klamath Basin to the south, and to the Seneca area and the northwestern Great Basin to the southeast. This large source diversity is due, in part, to an absence of obsidian sources in the Lower Deschutes Basin; all natural glass was imported, either through long-distance direct procurement or through exchange.

Similar to the initial John Day Drainage characterization results, compositions of many artifacts from Jefferson and Wasco county sites could not initially be correlated with known geologic sources (Lebow et al. 1991). Many of these unknown source assignments were resolved at the completion of the XRF studies. The Whitewater Ridge chemical group and other newly analyzed locales in the northwestern Great Basin and Ochoco and Malheur National Forests proved to be sources of many of the unknowns. Still, the geologic origins of 15 percent of the artifacts remain unidentified. Like the John Day region specimens, many of the Lower Deschutes unassigned artifacts may eventually be correlated with the already identified but incompletely investigated sources southeast of the Lower Deschutes River region. The large number of items ascribed to chemically distinct unknown sources points, however, to the likely existence of several sources currently unrecognized by archaeologists.

Evidence for long-distance procurement of obsidian is plentiful at these sites. Many, if not most, of the sources are more than 100 km (62 mi) from these Lower Deschutes River Basin sites. Long-distance procurement from the Newberry Volcano region is especially prevalent—over 50 percent of the glass originated from sources in the caldera or on the flanks of Newberry Volcano.

Whether the wide ranging Lower Deschutes River Basin procurement sphere included exchange with groups in adjoining areas or resulted from long-distance direct access procurement is unresolved at this time.

Table 4-5 Results of XRF Studies of Lower Deschutes River Artifacts.

Obsidian Source/ Chemical Type	Archaeological Sites									
	35-JE-49	35-JE-50	35-JE-51B	35-JE-281	35-JE-282	35-JE-283	35-JE-284	35-JE-285	35-JE-286	35-JE-287
Bald Butte	0	0	1	0	0	0	0	0	0	0
Big Obsidian Flow (?) [a]	4	0	33	0	0	0	0	0	0	0
Brooks Canyon (?) [a]	2	0	0	0	0	0	2	0	0	0
Chickahominy (?) [a]	3	0	1	0	1	0	0	0	0	0
Cougar Mountain	6	0	2	1	0	1	0	0	0	0
Delintment Creek	0	0	0	0	0	0	0	0	0	0
Glass Buttes (?) [a]	16	5	48	0	2	0	1	0	1	0
Horse Mountain (?) [a]	0	0	2	0	0	0	0	0	0	0
Inman Creek/Salt Creek A (?) [a]	0	0	0	0	0	0	0	0	0	0
Juniper Spring 1	1	0	0	0	0	0	0	0	0	0
Juniper Spring 2	1	0	6	0	0	0	0	0	0	0
Juniper Spring 2/Whitewater Ridge (?) [a]	0	1	5	0	0	0	0	0	0	0
Little Bear Creek (?) [a]	4	0	2	0	0	1	0	0	0	0
Little Bear Creek/Juniper Spring 1	0	0	0	0	0	0	0	0	0	0
Little Bear Creek/Juniper Spring 2	0	0	0	0	0	0	0	0	0	0
Little Bear Creek/Whitewater Ridge (?) [a]	2	0	25	0	0	0	1	0	0	0
Little Bear Cr./Whitewater R./Juniper Sp. 1	0	0	4	0	0	0	0	0	0	0
Little Bear Cr./Whitewater R./Juniper Sp. 2	0	0	0	0	0	0	0	0	0	0
McKay Butte	6	2	19	0	0	0	0	0	0	0
Newberry Volcano (?) [a]	243	17	187	0	0	79	3	14	0	1
Newberry Volcano/Unknown X (?) [a]	0	0	1	0	0	0	0	0	0	0
Obsidian Cliffs (?) [a]	51	3	102	3	1	9	2	1	0	1
Potato Hills (?) [a]	7	0	4	0	0	0	0	0	0	0
Quartz Mountain (?) [a]	56	9	23	0	0	0	0	0	0	1
Quartz Mountain/McKay Butte	25	1	6	1	2	0	0	0	0	0
Riley (?) [a]	1	1	0	0	0	0	1	1	0	0
Round Top Butte	1	0	0	0	0	0	0	0	0	0
Sawmill Creek	0	0	0	0	0	0	0	0	0	0
Silver Lake/Sycan Marsh (?) [a]	1	0	3	0	0	0	0	0	0	0
Spodue Mountain (?) [a]	1	0	4	0	0	0	0	0	0	0
Whitewater Ridge (?) [a]	4	2	29	0	1	1	0	1	0	1
Wolf Creek	0	0	0	0	0	0	0	0	0	0
Yreka Butte (?) [a]	0	0	1	0	0	0	1	0	0	0
Unknown	27	1	18	0	6	8	0	0	0	0
Not Obsidian	6	1	2	1	0	3	0	1	0	0
Total	468	43	528	6	13	102	12	18	1	4

[a] (?) = Final and provisional source assignments combined in one category.

Table 4-5 (continued)

Obsidian Source/ Chemical Type	Archaeological Sites									
	35-JE-288	35-JE-289	35-JE-290	35-JE-291	35-JE-292	35-JE-293	35-JE-296	35-JE-297	35-JE-298	35-JE-300
Bald Butte	0	0	0	0	0	0	0	0	0	0
Big Obsidian Flow (?) [a]	0	0	0	0	0	0	0	0	0	0
Brooks Canyon (?) [a]	0	0	0	0	0	0	0	0	0	0
Chickahominy (?) [a]	0	0	0	0	0	1	1	0	2	0
Cougar Mountain	0	0	0	0	0	1	0	0	1	0
Delintment Creek	0	0	0	0	0	0	1	0	1	0
Glass Buttes (?) [a]	4	0	0	1	0	3	20	0	1	0
Horse Mountain (?) [a]	1	0	0	0	0	1	0	0	0	0
Inman Creek/Salt Creek A (?) [a]	0	0	0	1	0	0	0	1	1	0
Juniper Spring 1	0	0	0	0	0	0	0	0	0	0
Juniper Spring 2	0	0	0	0	0	0	0	0	0	0
Juniper Spring 2/Whitewater Ridge (?) [a]	0	0	0	0	0	0	0	0	0	0
Little Bear Creek (?) [a]	1	0	0	0	0	0	0	0	0	0
Little Bear Creek/Juniper Spring 1	0	0	0	0	0	0	0	0	0	0
Little Bear Creek/Juniper Spring 2	0	0	0	0	0	0	0	0	0	0
Little Bear Creek/Whitewater Ridge (?) [a]	0	0	0	0	0	1	2	1	1	0
Little Bear Cr./Whitewater R./Juniper Sp. 1	0	0	0	0	0	0	0	0	0	0
Little Bear Cr./Whitewater R./Juniper Sp. 2	0	0	0	0	0	0	0	0	0	0
McKay Butte	0	0	0	0	0	0	0	0	0	0
Newberry Volcano (?) [a]	2	0	1	5	0	15	15	22	24	0
Newberry Volcano/Unknown X (?) [a]	0	0	0	0	0	0	0	0	0	0
Obsidian Cliffs (?) [a]	0	0	1	7	0	4	22	23	8	1
Potato Hills (?) [a]	0	0	0	0	0	0	0	0	0	0
Quartz Mountain (?) [a]	0	0	0	0	0	4	6	0	0	0
Quartz Mountain/McKay Butte	1	0	0	1	1	7	2	1	12	0
Riley (?) [a]	0	0	0	0	0	0	0	0	0	0
Round Top Butte	0	0	0	0	0	0	0	0	0	0
Sawmill Creek	0	0	0	0	0	0	1	0	0	0
Silver Lake/Sycan Marsh (?) [a]	0	0	0	0	0	1	0	0	1	0
Spodue Mountain (?) [a]	0	0	0	0	0	0	0	0	0	0
Whitewater Ridge (?) [a]	1	0	0	0	0	0	13	0	1	0
Wolf Creek	0	0	0	0	0	1	0	0	0	0
Yreka Butte (?) [a]	0	0	0	0	0	0	0	0	0	0
Unknown	0	1	0	0	0	3	17	4	3	0
Not Obsidian	0	0	0	1	0	3	0	0	2	0
Total	10	1	2	16	1	45	100	52	58	1

[a] (?) = Final and provisional source assignments combined in one category.

Table 4-5 (continued)

Obsidian Source/ Chemical Type	Archaeological Sites									
	35-JE-301	35-JE-302	35-JE-304	35-JE-305	35-WS-120	35-WS-223	35-WS-224	35-WS-225	35-WS-226	35-WS-227
Bald Butte	0	0	0	0	0	0	0	0	0	0
Big Obsidian Flow (?) [a]	0	0	0	0	0	0	0	18	0	0
Brooks Canyon (?) [a]	0	0	0	0	0	0	0	0	0	0
Chickahominy (?) [a]	0	0	3	0	1	0	0	0	0	1
Cougar Mountain	0	0	0	0	1	0	0	11	1	1
Delintment Creek	0	0	0	0	0	0	0	0	0	0
Glass Buttes (?) [a]	0	0	0	0	1	1	0	14	0	2
Horse Mountain (?) [a]	0	0	0	0	1	0	1	2	0	0
Inman Creek/Salt Creek A (?) [a]	0	0	0	0	0	0	0	0	0	0
Juniper Spring 1	0	0	0	0	0	0	0	0	0	0
Juniper Spring 2	0	0	0	0	0	0	0	0	0	0
Juniper Spring 2/Whitewater Ridge (?) [a]	0	0	0	0	0	0	0	4	0	0
Little Bear Creek (?) [a]	0	1	0	0	0	0	0	1	0	1
Little Bear Creek/Juniper Spring 1	0	0	0	0	0	0	0	0	0	0
Little Bear Creek/Juniper Spring 2	0	0	0	0	0	0	0	0	0	0
Little Bear Creek/Whitewater Ridge (?) [a]	0	0	0	0	2	0	0	8	0	2
Little Bear Cr./Whitewater R./Juniper Sp. 1	0	0	0	0	0	0	0	2	0	0
Little Bear Cr./Whitewater R./Juniper Sp. 2	0	0	0	0	0	0	0	0	0	0
McKay Butte	0	0	0	0	0	0	0	110	0	0
Newberry Volcano (?) [a]	0	1	0	1	17	0	6	140	6	9
Newberry Volcano/Unknown X (?) [a]	0	0	0	0	0	0	0	1	0	0
Obsidian Cliffs (?) [a]	4	77	0	0	3	0	1	11	9	6
Potato Hills (?) [a]	0	0	0	0	0	0	0	1	0	0
Quartz Mountain (?) [a]	0	1	0	0	0	0	0	9	0	0
Quartz Mountain/McKay Butte	1	0	0	0	11	0	1	3	1	13
Riley (?) [a]	0	0	0	0	0	0	0	0	0	0
Round Top Butte	0	0	0	0	0	0	0	0	0	0
Sawmill Creek	0	0	0	0	0	0	0	0	0	0
Silver Lake/Sycan Marsh (?) [a]	0	0	0	0	1	0	0	4	0	0
Spodue Mountain (?) [a]	0	0	0	0	0	0	0	0	0	0
Whitewater Ridge (?) [a]	0	3	0	0	1	0	0	7	0	2
Wolf Creek	0	0	0	0	0	0	0	1	0	0
Yreka Butte (?) [a]	0	0	0	0	0	0	1	1	0	0
Unknown	0	0	1	0	1	0	2	4	0	4
Not Obsidian	0	4	0	1	0	0	0	9	0	3
Total	5	87	4	2	40	1	11	361	17	44

[a] (?) = Final and provisional source assignments combined in one category.

Table 4-5 (continued)

Obsidian Source/ Chemical Type	Archaeological Sites 35-WS-230	35-WS-231	35-WS-232	35-WS-233	35-WS-239	OR-JE-5	Total	(%)
Bald Butte	0	0	0	0	0	0	1	(0.1)
Big Obsidian Flow (?) [a]	0	0	0	0	0	0	55	(2.2)
Brooks Canyon (?) [a]	0	0	0	0	0	0	4	(0.2)
Chickahominy (?) [a]	0	4	1	0	0	0	19	(0.7)
Cougar Mountain	2	5	0	0	0	0	33	(1.3)
Delintment Creek	0	2	0	0	0	0	4	(0.2)
Glass Buttes (?) [a]	1	52	0	0	0	0	173	(6.8)
Horse Mountain (?) [a]	0	4	0	0	0	0	12	(0.5)
Inman Creek/Salt Creek A (?) [a]	0	1	0	0	0	0	4	(0.2)
Juniper Spring 1	0	2	0	0	0	0	3	(0.1)
Juniper Spring 2	0	12	0	0	0	0	19	(0.7)
Juniper Spring 2/Whitewater Ridge (?) [a]	0	2	0	0	0	0	12	(0.5)
Little Bear Creek (?) [a]	0	6	0	0	0	0	17	(0.7)
Little Bear Creek/Juniper Spring 1	0	1	0	0	0	0	1	(0.1)
Little Bear Creek/Juniper Spring 2	0	0	1	0	0	0	1	(0.1)
Little Bear Creek/Whitewater Ridge (?) [a]	1	15	0	0	0	0	61	(2.4)
Little Bear Cr./Whitewater R./Juniper Sp. 1	0	5	0	0	0	0	11	(0.4)
Little Bear Cr./Whitewater R./Juniper Sp. 2	0	2	0	0	0	0	2	(0.1)
McKay Butte	0	4	0	0	0	0	141	(5.5)
Newberry Volcano (?) [a]	2	87	1	3	0	0	901	(35.4)
Newberry Volcano/Unknown X (?) [a]	0	0	0	0	0	0	2	(0.1)
Obsidian Cliffs (?) [a]	0	43	0	1	0	0	394	(15.5)
Potato Hills (?) [a]	0	3	0	0	0	0	15	(0.6)
Quartz Mountain (?) [a]	0	123	0	0	0	0	232	(9.1)
Quartz Mountain/McKay Butte	3	11	0	1	0	1	106	(4.2)
Riley (?) [a]	0	4	0	1	0	0	9	(0.3)
Round Top Butte	0	1	0	0	0	0	2	(0.1)
Sawmill Creek	0	0	0	0	0	0	1	(0.1)
Silver Lake/Sycan Marsh (?) [a]	0	3	0	0	0	0	14	(0.5)
Spodue Mountain (?) [a]	0	0	0	0	0	0	5	(0.2)
Whitewater Ridge (?) [a]	0	40	0	0	1	0	109	(4.3)
Wolf Creek	0	0	0	0	0	0	2	(0.1)
Yreka Butte (?) [a]	0	0	0	0	0	0	3	(0.1)
Unknown	0	32	0	1	0	0	133	(5.2)
Not Obsidian	0	2	0	0	0	0	39	(0.2)
Total	9	466	3	7	1	1	2,540	

[a] (?) = Final and provisional source assignments combined in one category.

Glass from Obsidian Cliffs also appears in significant quantities at the Jefferson and Wasco county sites. The presence of obsidian from the central High Cascades is consistent with a model of stone resources acquired during seasonal resource forays into the High Cascades and Western Cascades. The summer trans-Cascade travel by Lower Deschutes River Basin groups into the Western Cascades for seasonally available foods is a well-documented ethnographic pattern (Minor 1987:23–35; Murdock 1980).

Upper Deschutes River Basin. Fourteen known sources of glass were distinguished among the 2,710 characterized artifacts recovered from 18 Crook and Deschutes county archaeological sites (Table 4-6). Although artifact obsidian from sources in the High Cascades, Klamath Basin, and northwestern Great Basin are found in Upper Deschutes River Basin sites, the overwhelming proportion of glass is from local sources—over 95 percent of the obsidian came from flows and domes located on the flanks or within the summit caldera of Newberry Volcano.

Numerous sources of obsidian were available locally to the prehistoric inhabitants of the examined Deschutes and southern Crook county sites. Many glass sources are found in the caldera and on the lower flanks of Newberry Volcano, a large composite volcano centered about 35 km (20 mi) southeast of Bend. With several late Pleistocene to late Holocene obsidian flows (Figure 4-9), the 6 to 8 km (4–5 mi) wide summit caldera of Newberry Volcano was a major regional focal point for prehistoric obsidian procurement, initial lithic reduction, and biface manufacture (Connolly 1991:93–94; Flenniken and Ozbun 1988:140; Ozbun 1991).

The Newberry Caldera obsidian flows have been described in the geologic literature by many researchers, including Friedman (1977), Friedman and Obradovich (1981), Higgins (1968 and 1973), MacLeod et al. (1981, 1982), and Williams (1935). Within the caldera, two chemically distinguishable groups of obsidian are identified. The first of these, the Newberry Volcano chemical group, consists of the Interlake, Game Hut, Central Pumice Cone, and East Lake flows. The flows of the Newberry Volcano chemical type were all extruded after the climatic eruptions of Mount Mazama and vary in age from about 6,400 to 3,400 obsidian hydration years (Friedman 1977; Friedman and Obradovich 1981). The second source group, the Big Obsidian Flow chemical type, consists of the late Holocene Big Obsidian Flow and the early Holocene to late Pleistocene Buried Obsidian Flow. This chemical group is discussed in more detail in the next part of this chapter. On the flanks of the volcano, major sources include McKay Butte, Quartz Mountain, and Unknown X (this latter source is examined later in this section). An unnamed flank source near the nonartifact quality Little Obsidian Flow (Higgins 1968:273–274) has not yet been characterized. At this time, we are unsure whether this source falls within an already identified chemical group or presents its own unique trace element signature.

<u>The Big Obsidian Flow Chemical Group</u>. The Big Obsidian Flow, the most recent of the caldera obsidian sources, erupted about 1,300 radiocarbon years ago (MacLeod et al. 1982; Figure 4-9). The extrusion of this flow was immediately preceded by an explosive eruption of tephra that now provides an important chronostratigraphic horizon in the Newberry Caldera area and the region east of the vent. The prominent Big Obsidian Flow is geochemically distinguishable from the geographically proximate Newberry Caldera

Table 4-6 Results of XRF Studies of Artifacts from Upper Deschutes Basin Sites.

Obsidian Sources/Chemical Type	Archaeological Sites											
	35-CR-626	35-CR-627	35-DS-33	35-DS-116	35-DS-263	35-DS-429	35-DS-554	35-DS-555	35-DS-557	35-DS-558	35-DS-559	35-DS-808
Big Obsidian Flow	0	0	6	0	7	0	5	0	5	0	0	1
Brooks Canyon? [a]	0	0	1	0	0	0	0	0	0	0	0	0
Cougar Mountain	0	0	0	0	1	0	0	0	0	0	1	0
Glass Buttes	0	0	0	0	0	0	0	0	1	0	1	0
Inman Creek/Salt Creek A	0	0	0	0	0	0	0	1	0	0	0	0
Juniper Spring 1	0	0	1	0	0	0	0	0	0	0	0	0
Little Bear Creek	0	0	0	0	0	0	0	0	0	0	0	0
McKay Butte (?) [b]	5	1	27	0	77	21	1	0	353	2	2	2
McKay Butte/Unknown X (?) [b]	0	0	0	0	0	0	0	0	9	1	0	0
Newberry Volcano (?) [b]	88	1	865	40	148	0	16	114	104	1	17	40
Newberry Volcano/Unknown X (?) [b]	0	0	16	0	0	0	0	2	16	0	0	0
Obsidian Cliffs	3	1	23	2	1	0	0	3	1	0	17	0
Quartz Mountain	2	0	6	1	0	0	0	0	4	17	7	0
Quartz Mountain/McKay Butte	6	0	2	0	0	8	0	0	0	13	3	0
Silver Lake/Sycan Marsh (?) [b]	0	0	7	0	0	0	0	17	4	0	0	2
Spodue Mountain	0	0	2	1	0	0	0	0	0	0	0	0
Unknown X (?) [b]	0	0	6	0	172	0	1	0	152	0	0	0
Unknown	0	1	2	0	1	0	0	0	3	0	5	0
Not Obsidian	0	0	0	0	1	0	0	0	0	0	0	0
Total	104	4	964	44	408	29	23	137	652	33	53	45

[a] ? = Provisional source assignment; [b] (?) = Final and provisional source assignments combined in one category.

Table 4-6 (continued)

Obsidian Sources/ Chemical Type	Archaeological Sites							
	35-DS-809	35-DS-865	35-DS-866	35-DS-917	35-DS-983	35-DS-985	Total	(%)
Big Obsidian Flow	0	1	2	0	0	0	27	(1.0)
Brooks Canyon? [a]	0	0	0	0	0	0	1	(0.1)
Cougar Mountain	0	2	6	0	0	1	11	(0.4)
Glass Buttes	0	0	0	0	1	0	3	(0.1)
Inman Creek/Salt Creek A	0	0	0	0	0	0	1	(0.1)
Juniper Spring 1	0	0	0	0	0	0	1	(0.1)
Little Bear Creek	0	0	0	0	1	0	1	(0.1)
McKay Butte (?) [b]	1	8	10	83	10	2	605	(22.3)
McKay Butte/Unknown X (?) [b]	0	0	0	0	0	0	9	(0.3)
Newberry Volcano (?) [b]	10	1	0	2	15	6	1,468	(54.2)
Newberry Volcano/Unknown X (?) [b]	0	0	0	1	0	0	35	(1.3)
Obsidian Cliffs	0	1	0	0	5	1	58	(2.1)
Quartz Mountain	0	2	1	0	0	0	40	(1.5)
Quartz Mountain/McKay Butte	0	2	3	1	3	0	41	(1.5)
Silver Lake/Sycan Marsh (?) [b]	0	0	0	0	0	2	32	(1.2)
Spodue Mountain	0	0	0	0	0	1	4	(0.1)
Unknown X (?) [b]	0	1	0	14	1	0	347	(9.1)
Unknown	0	4	3	0	1	3	23	(0.8)
Not Obsidian	0	0	0	1	1	0	3	(0.1)
Total	11	22	25	102	38	16	2,710	

[a] ? = Provisional source assignment; [b] (?) = Final and provisional source assignments combined in one category.

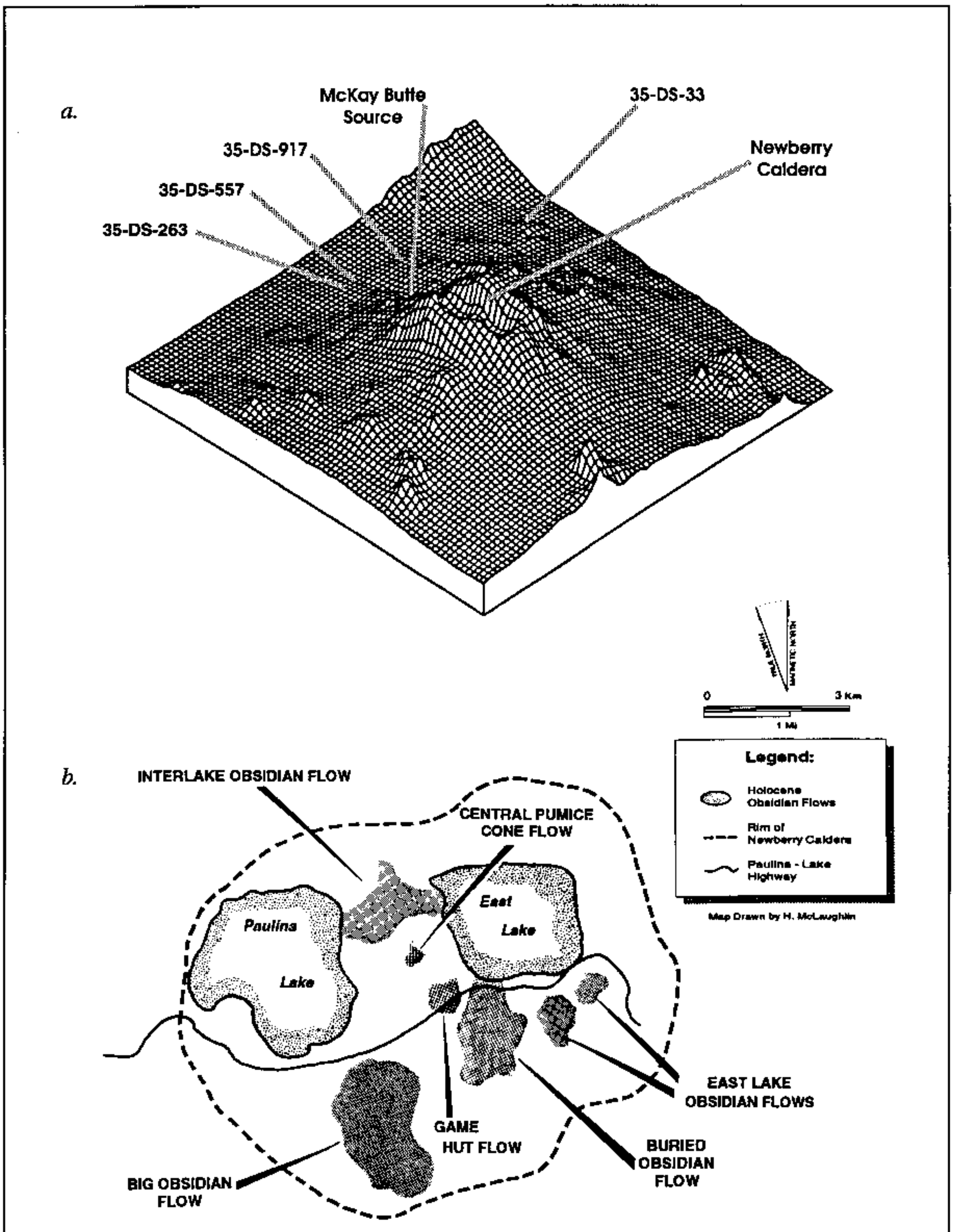

Figure 4-9 Geologic sketch map of Newberry Caldera region showing the location of major obsidian sources (map is adapted from McLeod et al. 1982). Top of Newberry Volcano digital elevation model above is oriented towards the northwest.

geochemical group flows on the basis of its relatively high Zr content. Until recently, it appeared that this provided archaeologists with a chemically unique source of known age, one that could establish a maximum procurement age for artifact obsidian correlated with the source. New evidence suggests, however, that another caldera obsidian source, the pre-Mazama Buried Obsidian Flow (Figure 4-9), is compositionally similar to the Big Obsidian Flow. Limited geochemical analyses by Linneman (1990:277) indicate that the glass of the Buried Obsidian Flow (called the Southeastern Obsidian Flow by Linneman) and Big Obsidian Flow are geochemically comparable. Both flows are similarly rich in Zr, the element most commonly used to differentiate between the Newberry and Big Obsidian Flow sources; the diagnostic trace elements generally used to differentiate among the caldera sources (Rb, Sr, Zr) would fail to distinguish between the Big Obsidian Flow and Buried Obsidian Flow. The age of the pre-Mazama Buried Obsidian Flow is estimated to be about 10,000 years B.P. (Linneman 1990:87), and any chronological inferences for artifacts previously correlated with the Big Obsidian Flow should.be carefully reexamined. The Buried Obsidian Flow was not among the reference samples used for artifact comparison during the present trace element study. Any Big Obsidian Flow source assignments reported here should, therefore, be considered in the context of the Big Obsidian Flow chemical group and may not originate from the 1,300-year-old caldera flow.

Eighty-one artifacts from five sites in central and north-central Oregon were firmly or provisionally assigned to the Big Obsidian Flow. Obsidian hydration rim values from these artifacts range from 1.1–5.1 μm and exhibit a modal value of 2.4 μm. Hydration rims from the Big Obsidian Flow geologic sources were measured by Friedman (1977) at about 1.0 $\pm$ 0.2 μm. This disparity between expected and observed rim values provides corroborating evidence of the prehistoric use of a pre-Big Obsidian Flow source (see Chapter 5, this volume).

<u>McKay Butte Obsidian</u>. Prominent in the lithic assemblage of the Deschutes County sites is a distinctive medium dark gray (5YR 4/1) to medium bluish gray (5B 5/1) obsidian originating from McKay Butte, an alignment of three Pleistocene rhyolite domes on the lower western flank of Newberry Volcano (MacLeod et al. 1981; Skinner 1983:261–262). Nodules of grayish glass up to 20 cm in diameter are common on the lower eastern slopes of the central dome; small nodules of black glass to about 4 cm in diameter also are found. The glass at the source contains abundant spherulites ranging from several centimeters in diameter to sub-millimeter size; small spherulites were also noted in many of the artifacts chemically correlated with McKay Butte. The presence of spherulites is unique among the Newberry sources and may prove valuable in the macroscopic identification of the glass. The bluish-gray color of McKay Butte glass also appears to be unique among the Newberry sources. Most other glasses from the Newberry Caldera sources that were examined range from black to dark greenish gray, although obsidian tentatively correlated with the Unknown X group ranges from black to gray and could be confused with McKay Butte obsidian.

Although obsidian color alone has rarely proved useful in the macroscopic identification and characterization of obsidian sources, the regionally distinctive hue of obsidian from McKay Butte and the appearance of spherulites in the glass may prove valuable in regional obsidian procurement studies. Three of the Deschutes County sites (35-DS-263, 35-DS-557, and 35-DS-917) within 10 km (6 mi) of the McKay Butte source yielded concomitantly large proportions of McKay Butte glass (Table 4-7). The gray to bluish-gray glass in collections from these sites suggests that McKay Butte was the primary source for many of the characterized artifacts. Geochemical characterization of the artifacts partially bore this out—most artifacts did originate from McKay Butte, although a significant proportion of the visually similar Unknown X glass was found among the darker gray samples.

Table 4-7 Sites with Identified Unknown X Obsidian.

Site	Unknown X		McKay Butte		Newberry Volcano	Other	Subtotal
35-DS-33	6	0.6%	27	2.8%	881	50	964
35-DS-263	172	42.2%	77	18.9%	148	11	408
35-DS-554	1	4.3%	1	4.3%	16	5	23
35-DS-557	152	23.3%	362	55.5%	120	18	652
35-DS-865	1	4.5%	8	36.4%	1	12	22
35-DS-917	14	13.7%	83	81.4%	3	2	102
35-DS-983	1	2.6%	10	26.3%	15	12	38
Total	347		568		1,184	110	2,209

The obsidian hydration rim distribution frequency of McKay Butte artifacts decreases significantly at values of less than about 5 μm (Figure 4-11). This rim width corresponds very approximately to the period of the Mazama ashfall; over 1 m of volcanic tephra fell in this region, significantly altering the original landscape. Why the dramatic decrease of McKay Butte glass from the archaeological record at this time? The sudden appearance of competing sources resulting from the eruption of several post-Mazama obsidian flows in nearby Newberry Caldera provides one possible answer. It does not, however, adequately explain the near disappearance of high-quality obsidian from a source considerably closer than those in the caldera. We suggest here that the drop in McKay source utilization at this time may have been due to the burial of the McKay Butte source by Mazama ash. Today, this source is poorly exposed, with glass apparent mainly in areas disturbed by recent road-building and logging. The appearance of McKay Butte glass in periods following the ashfall may be largely due to recycling of existing materials. If this is true, many post-Mazama artifacts should exhibit evidence of reuse, an observation confirmable through technological and obsidian hydration studies of the original and reused surfaces.

Unknown X Obsidian. Of considerable interest at several Deschutes County sites is the identification of relatively large quantities of glass from an as yet unidentified geologic source, termed here the Unknown X source. Initially encountered during trace element studies of artifacts recovered during the 1991 testing of Deschutes County sites, this source was suspected to reflect only unrecorded chemical variability of the McKay Butte or Newberry Volcano chemical groups. Later characterization studies using larger sample sizes from pre-Mazama contexts almost certainly indicated a new, distinct source. Clear trace element grouping and very different obsidian hydration distribution characteristics (see Chapter 5) indicate that Unknown X obsidian is from a distinct source (Figure 4-10).

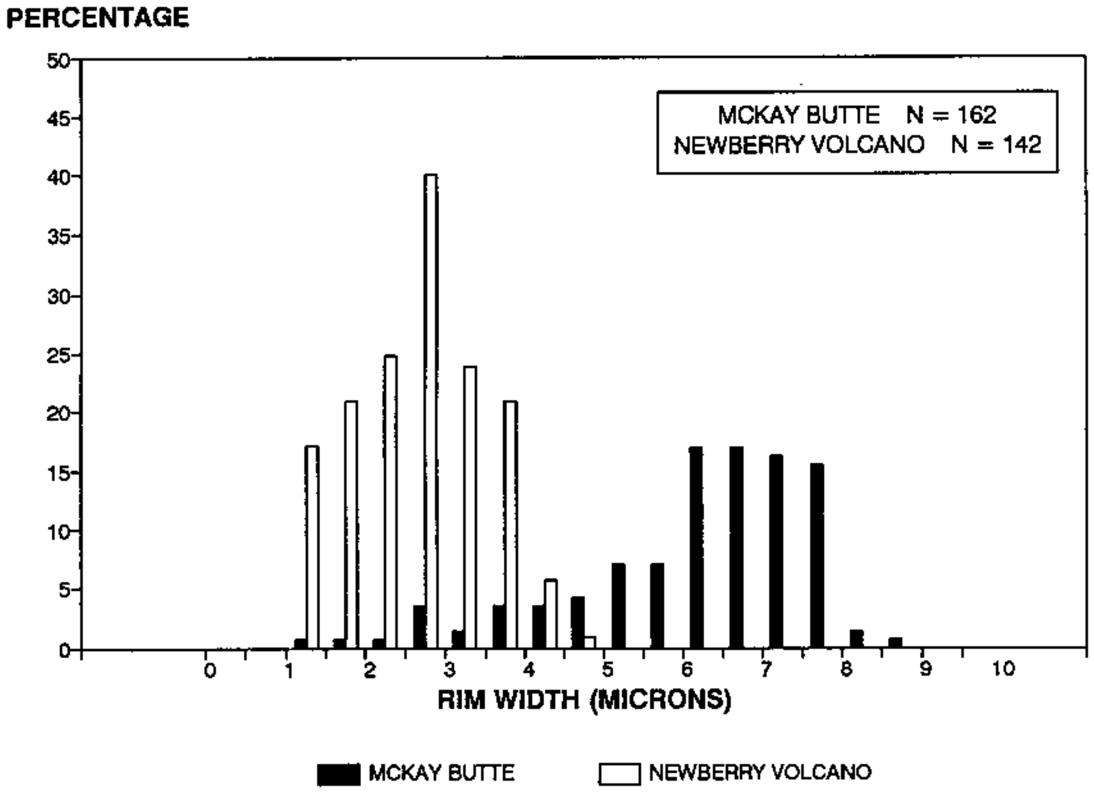

Figure 4-10 Relative frequency over time of McKay Butte and Newberry Volcano obsidian at 35-DS-263 and 35-DS-429 based on hydration rim width.

Much of the Unknown X obsidian was recovered at two sites on stream terraces along Paulina Creek, 35-DS-263 and 35-DS-557. The sites are separated by less than 1 km and are only a few kilometers from the McKay Butte source. Prehistoric use of glass from the Unknown X group decreases very rapidly to the north and south of the two sites and almost disappears from the archaeological record a short distance to the north at 35-DS-33.

As with McKay Butte obsidian, the use of Unknown X glass declined significantly during the post-Mazama period. We hypothesize here that, like McKay Butte, the Unknown X source may have been covered by Mazama tephra and that use of new glass from the source was discontinued. This hypothesis can be tested through technological and obsidian hydration analyses of reused surfaces in the same manner suggested for the McKay Butte source.

The rapid disappearance of glass from the Unknown X source from artifact collections north and south of Paulina Creek, the co-occurrence of the material with McKay Butte obsidian, the relative frequencies of glass, and the technological similarities of debitage from the two sources suggest that both sources are in the same vicinity. Geologic mapping of the area around 35-DS-557 and 35-DS-263 indicates the presence of several rhyolite and rhyodacite domes and flows, one of which may prove to be the primary source for the Unknown X material (MacLeod et al. 1982).

Diachronic Shifts in Obsidian Use at Newberry Volcano. Nowhere during the course of PEP obsidian studies was a temporal shift in obsidian source use as striking as at the Deschutes County sites, particularly at 35-DS-263 and 35-DS-557 (Figure 4-10). Both of these sites contained clearly defined pre- and post-Mazama components and both sites contained large quantities of glass from McKay Butte, Unknown X, and Newberry Volcano.

While the pre-Mazama units were dominated by McKay Butte and Unknown X glass, post-Mazama units contain obsidian almost exclusively from the Newberry Caldera (Figure 4-11). Obsidian from McKay Butte and Unknown X sources nearly disappears from the archaeological record. The eruption of several obsidian flows within Newberry Caldera closely following the Mazama ashfall, combined with the possible burial of the McKay Butte and Unknown X sources, provides a possible explanation for this dramatic shift in obsidian source utilization in the Newberry Volcano region. The relative obsidian hydration chronologies of these three obsidian sources is discussed in more detail in Chapter 5.

Klamath Lake Basin. The characterized lithic assemblage from most of the Oregon Klamath Basin sites is distinguished primarily by its lack of source diversity. With the exception of a few sites in the southern and northern margins of the Basin, the Spodue Mountain and Silver Lake/Sycan Marsh chemical groups dominate the identified sources. Together, these two sources account for nearly 90 percent of the PEP obsidian identified in the Klamath Basin (Table 4-8).

The Silver Lake/Sycan Marsh chemical group, composed of several scattered sources south of Silver Lake in the northeast margin of the Klamath Basin (Hughes and Mikkelsen 1985; Hughes 1986a:313–314), accounted for 455 artifacts from all Klamath Basin sites and made up 43.5 percent of the artifacts from the central Klamath Basin sites. Nodules of obsidian from Spodue Mountain, another major source of glass on the eastern margin of the Klamath Basin, are widely distributed throughout the Sprague River Valley in secondary alluvial deposits (Hughes and Mikkelsen 1985; Hughes 1986a:311–312). Spodue Mountain glass made up 46 percent (n=482) of the characterized Klamath Basin artifacts. The crenulated weathered exterior cortex typical of these nodules was found on many pieces of debitage from sites in the Basin and it is likely that the glass was procured locally from alluvial deposits. Obsidian artifacts from the Klamath Basin sources, including large ceremonial bifaces, have also been found in the Rogue River drainage of western Oregon and at sites in western central Oregon, the central Western Cascades, the Willamette Valley, and northern California (Hughes 1990b; Holson et al. 1991; LaLande 1989; Skinner and Winkler 1991).

Site 35-KL-810, located near Chemult, yielded obsidian characterization results atypical of sites from the Klamath Basin (Atwell et al. 1994). The presence of obsidian from Newberry Volcano, the Klamath Basin, and sources to the east in the northwestern Great Basin indicates an unusual occupational history. A single projectile point was correlated with the GF/LIW/RS chemical group in the Medicine Lake Highlands of northern California, the northernmost appearance of glass from this source. Also found at this site was a bifacial tool from Beatys Butte, a major source of glass situated along the southern margin of the Catlow Basin in southeastern Oregon. This particular artifact, found over 200 km (125 mi) from the source, was one of the best examples of long distance procurement noted during the project.

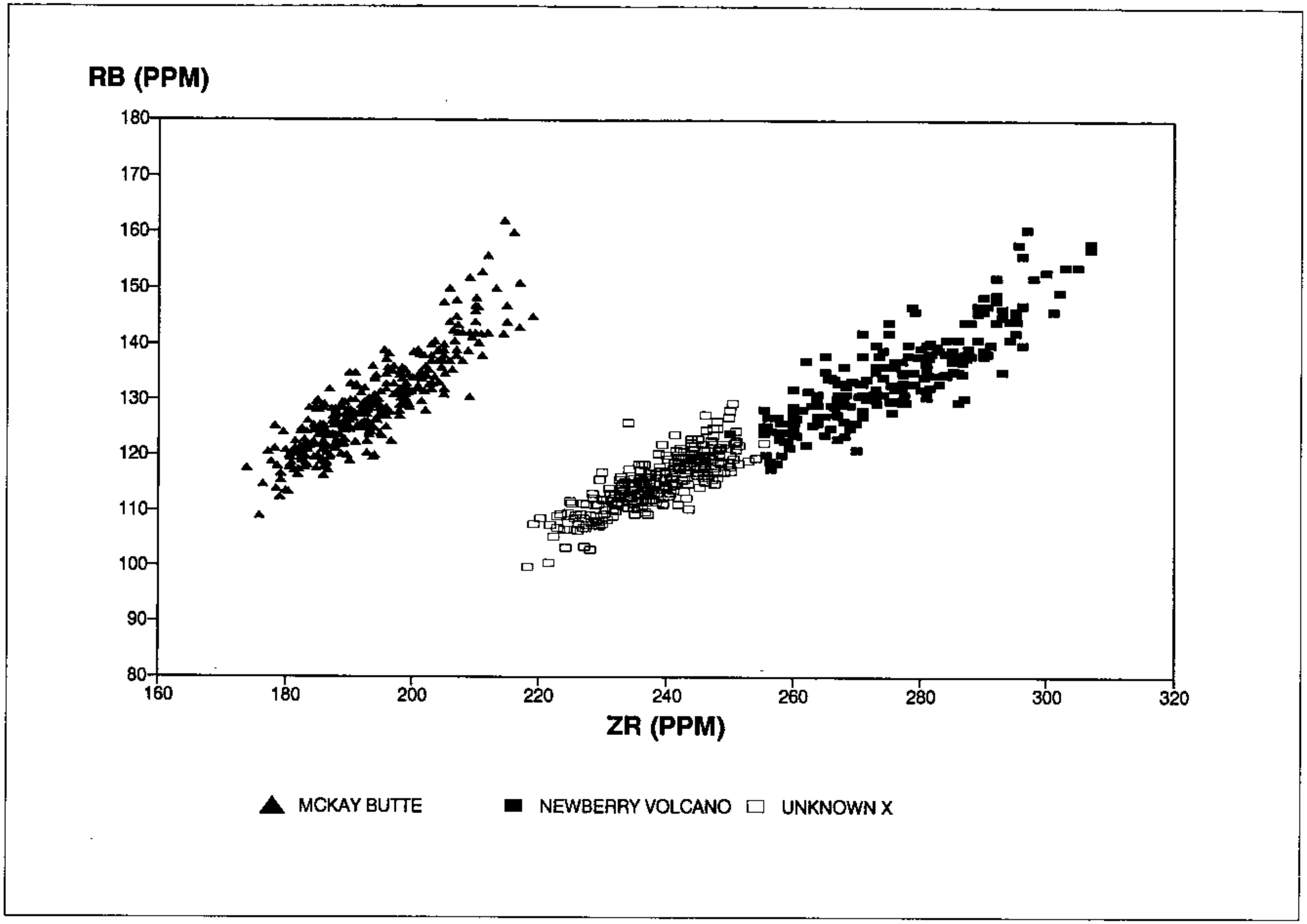

Figure 4-11 Scatterplot of Rb versus Zr for obsidian artifacts from 35-DS-263 and 35-DS-557.

Table 4-8 Results of Trace Element Studies of Artifacts from Klamath Basin Sites.

Obsidian Source/ Chemical Type	Archaeological Sites														Total	
	35-KL-810	35-KL-811	35-KL-812	35-KL-813	35-KL-814	35-KL-815	35-KL-816	35-KL-817	35-KL-818	35-KL-832	35-KL-834	35-KL-835	35-KL-865	PEP 7-3		
Beatys Butte	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.1%
Blue Mountain (?) [a]	0	0	0	0	0	0	0	0	8	0	0	0	0	0	8	0.8%
Cougar Butte (?) [a]	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0.1%
Cougar Mountain (?) [a]	13	1	0	0	0	0	0	0	0	0	0	0	0	0	14	1.3%
Deer Creek/Burn Butte (?) [a]	2	13	0	1	0	0	0	0	0	0	0	0	0	2	18	1.7%
Drews Creek/Butcher Flat	0	0	0	0	0	0	0	0	11	0	0	0	0	0	11	1.1%
East Medicine Lake?	0	0	0	0	0	0	0	0	7	0	0	0	0	0	7	0.7%
GF/LIW/RS	1	0	0	0	1	0	0	0	3	0	0	0	0	0	5	0.5%
GF/LIW/RS/East Medicine Lake	0	0	0	0	0	0	0	0	5	0	0	0	0	0	5	0.5%
Glass Mountain? [b]	0	0	0	0	1	0	0	0	1	0	0	0	0	0	2	0.2%
McComb Butte/Tucker Hill? [b]	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0.1%
Newberry Volcano	19	0	0	0	0	0	0	0	0	0	0	0	0	0	19	1.8%
Obsidian Cliffs	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.3%
Silver Lake/Sycan Marsh	283	0	76	45	42	2	1	0	1	0	2	3	0	0	455	43.5%
Spodue Mountain	49	0	75	63	215	20	0	1	14	13	7	23	2	0	482	46.0%
Witham Creek	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0.1%
Unknown	6	0	2	0	0	0	0	0	2	1	0	2	0	0	13	1.2%
Not Obsidian	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0.1%
Total	377	14	154	110	259	22	1	1	53	14	9	29	2	2	1,047	

[a] (?) = Final and provisional source assignments combined in one category; [b] ? = Provisional source assignment;

The distance to geologic source is exceeded only by a single piece of debitage found at 10-BY-444 in Idaho. Nineteen artifacts at 35-KL-810 were found to originate from Newberry Volcano and it is likely that this site marks the approximate southern boundary of the Newberry Volcano procurement sphere.

4.3.3 California Obsidian Characterization Studies

Forty-eight California PEP sites, the majority located on the northern California Modoc Plateau, were selected for obsidian characterization studies (Figures 4-12 and 4-13; Tables 4-9, 4-10, and 4-11). The analyzed California PEP collection included 930 tools and 2,363 pieces of debitage. Most of the samples were characterized using XRF analytical methods; an additional 347 were identified on the basis of visual characteristics. Twenty-four potential California geologic sources were identified after characterization of the 2,946 items analyzed for trace element concentrations (Figure 4-13). Artifacts from five southern Oregon sources were also found. A single item may have originated from the Mosquito Lake source in northwestern Nevada.

Visually Characterized California Artifacts. In addition to the large body of artifacts from California Project sites studied with trace element methods, 347 items from 24 California archaeological sites were assigned sources based solely on their megascopic appearance. The Grasshopper Group (Grasshopper Flat, Lost Iron Well, Red Switchback, and Medicine Lake sources) accounted for 340 of these artifacts. The remainder were assigned to the Blue Mountain and Napa Valley sources. The results of the visual characterization of artifacts from California sites are presented in Table 4-9 and have appeared previously in Holson et al. (1991). These data are not considered further in the discussion of California artifacts characterized with trace element methods.

Modoc Plateau and Adjoining Areas. The 20,000 km^2 (13,000 mi^2) Modoc Plateau in the northeastern corner of California consists of a thick accumulation of geologically young volcanic rocks. Because of the shared obsidian procurement patterns, PEP sites and samples from the Modoc Plateau, the California portion of the Klamath Lake Basin, the extreme southern end of the Cascade Range, and the very upper end of the Great Valley are all discussed together under the category of Modoc Plateau.

Medicine Lake Volcano is a large Pleistocene and Holocene shield volcano centered immediately south of the Klamath Basin in northern California. Topped by a summit caldera housing Medicine Lake, the highlands associated with the volcano are collectively known as the Medicine Lake Highlands. Like the geologically similar Newberry Volcano, numerous Pleistocene to late-Holocene flows of volcanic glass are scattered over the caldera and flanks of the Medicine Lake Highlands (Anderson 1933; Donnelly-Nolan et al. 1990; Hughes 1986a). Of particular chronological significance is the Glass Mountain obsidian flow, a spectacular late-Holocene flow that erupted near the east Medicine Lake Caldera rim. The obsidian flow shows abundant evidence of prehistoric quarrying activities; hundreds of archaeological sites have been recorded around the margins of the flow (Hardesty and Fox 1974). This glass flow overlies 1,050-year-old tephra from the nearby Glass Mountain obsidian flow vent and is thought, based on an associated radiocarbon date, to be no more than 885 $\pm$ 40 years old (Donnelly-Nolan et al. 1990). Any artifacts correlated with the Glass Mountain flow are constrained to the maximum age of the eruption.

Table 4-9 Results of Visual Characterization of California Obsidian Artifacts.

Site	Blue Mountain	Grasshopper Group	Napa Valley?	Total
CA-COL-165	0	0	1	1
CA-MOD-77	0	15	0	15
CA-MOD-128	0	5	0	5
CA-MOD-129	5	30	0	35
CA-MOD-1205	0	9	0	9
CA-MOD-1206/07	0	38	0	38
CA-MOD-1461	0	15	0	15
CA-MOD-2555	0	7	0	7
CA-MOD-2556	0	7	0	7
CA-MOD-2559	0	5	0	5
CA-MOD-2560	0	31	0	31
CA-MOD-2561	0	6	0	6
CA-MOD-2562	0	19	0	19
CA-MOD-2563	0	30	0	30
CA-MOD-2565	0	11	0	11
CA-MOD-2566/67	1	20	0	21
CA-MOD-2568	0	16	0	16
CA-MOD-2569	0	9	0	9
CA-MOD-2570	0	15	0	15
CA-MOD-2572	0	9	0	9
CA-MOD-2575	0	12	0	12
CA-MOD-2627	0	1	0	1
CA-SHA-68/H	0	25	0	25
CA-SIS-1553	0	5	0	5
Total	6	340	1	347

The Project corridor runs along the eastern base of the Medicine Lake Volcano and, not surprisingly, artifact obsidian from the Modoc Plateau sites is dominated by glass from the Medicine Lake Highlands (Grasshopper Flat, Lost Iron Well, Red Switchback, East Medicine Lake, Cougar Butte, and Glass Mountain). With 2,833 total characterized Modoc and Shasta county items, approximately 83 percent originated from sources on the flanks of Medicine Lake Volcano. Much of the remainder of the artifact obsidian originates from a variety of different sources to the east, including several in the Warner Mountains southeast of Goose Lake.

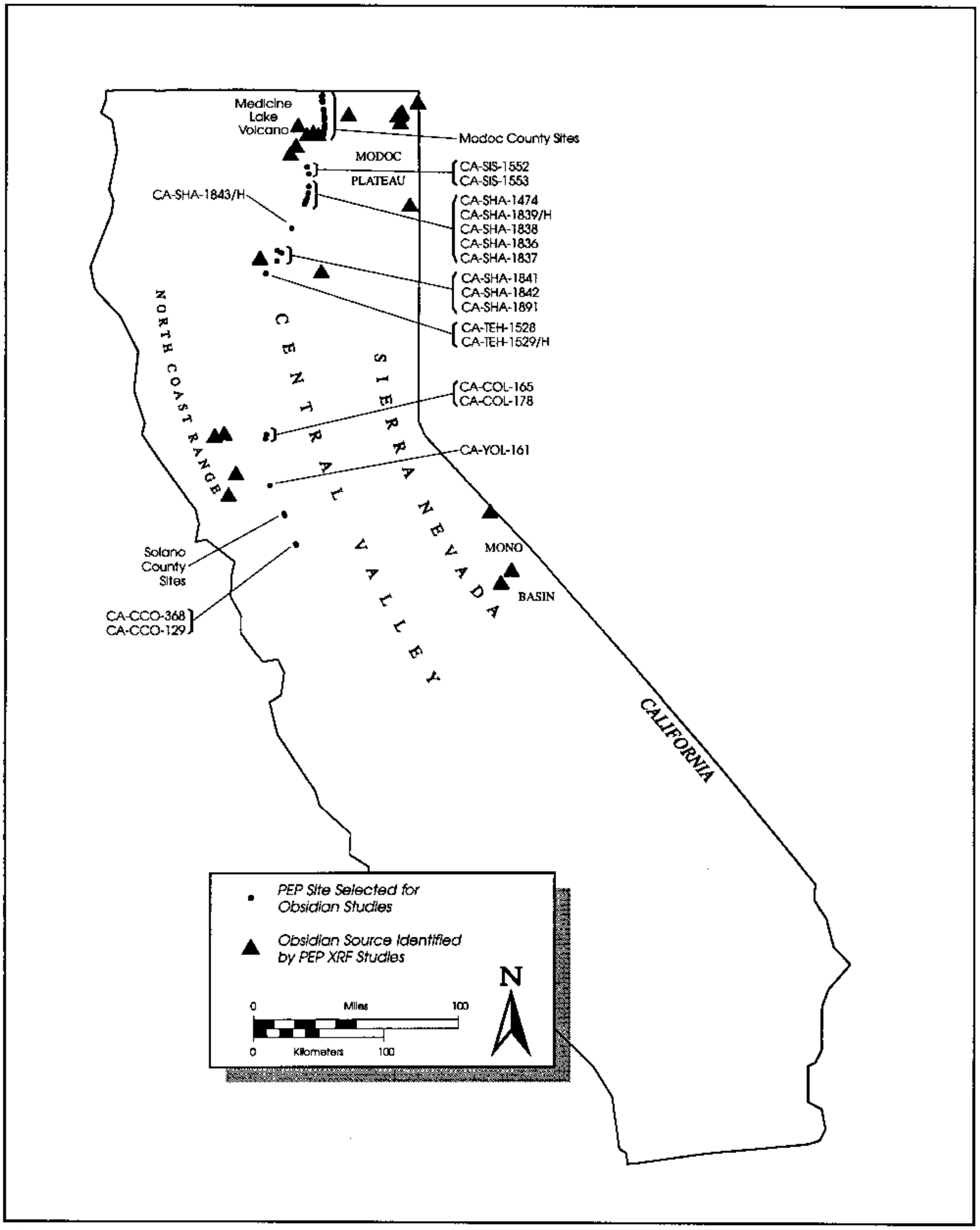

Figure 4-12 Distribution of characterized California PEP archaeological sites and identified sources.

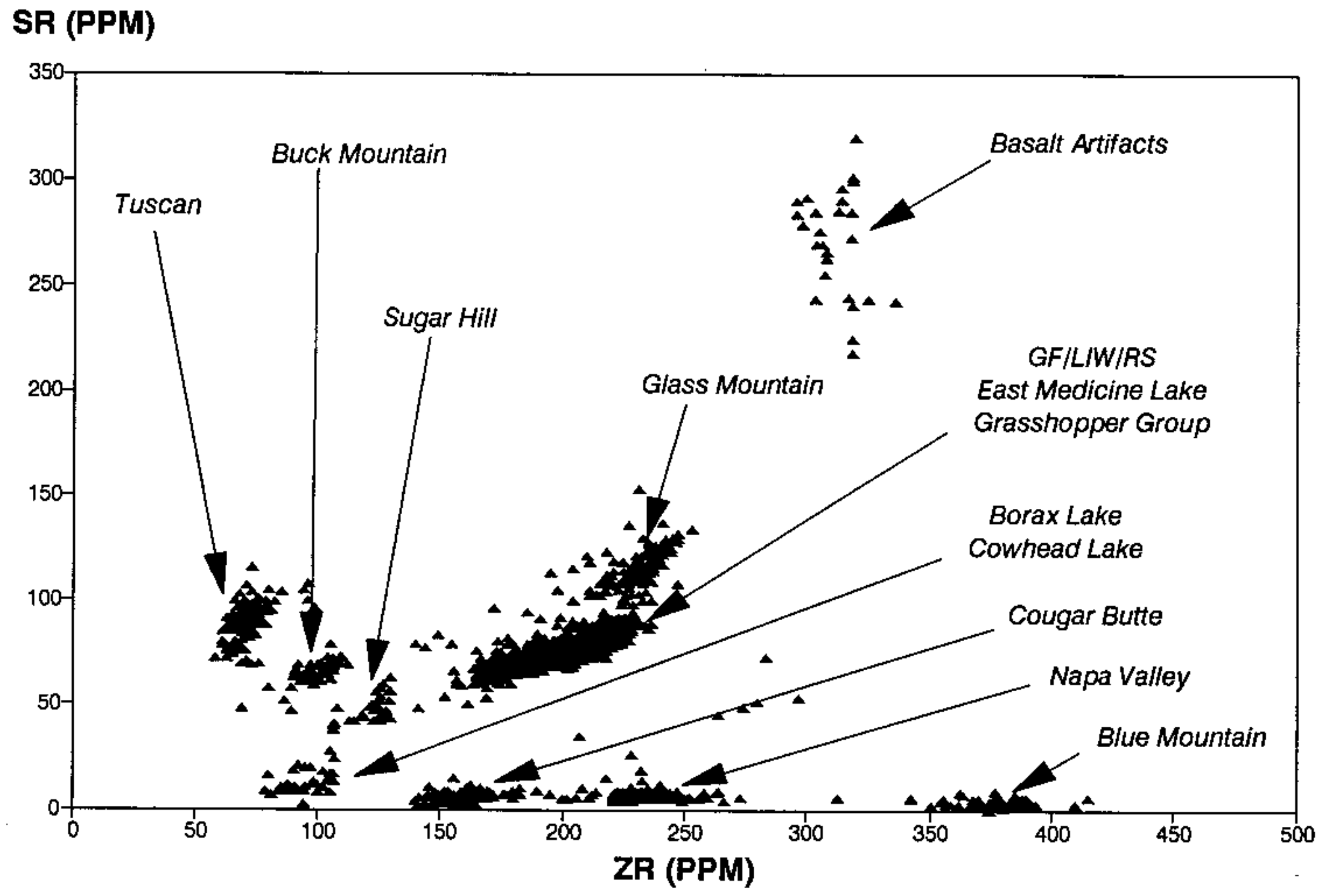

Figure 4-13 Scatterplot of Sr versus Zr for all California artifacts with known sources; major sources of prehistorically utilized obsidian are indicated.

Table 4-10 Results of XRF Studies of Modoc Plateau Obsidian Artifacts.

Obsidian Source/ Chemical Type	Archaeological Sites								
	CA-MOD-77	CA-MOD-128	CA-MOD-129	CA-MOD-1205	CA-MOD-1206/07	CA-MOD-1461	CA-MOD-2555	CA-MOD-2556	CA-MOD-2557
Blue Mountain	12	0	12	3	10	0	1	0	1
Blue Spring/Mosquito Lake	0	0	0	0	0	0	0	0	0
Blue Spring	0	0	0	0	0	0	0	0	0
Borax Lake	0	0	0	0	0	0	0	0	0
Bordwell Springs	0	0	0	0	0	0	0	0	0
Buck Mountain	1	0	3	1	3	6	1	0	0
Buck Mountain/Coglan Buttes	0	0	1	0	0	0	0	0	0
Callahan Flow	0	0	0	0	0	0	0	0	0
Cougar Butte	3	0	4	1	35	19	55	0	0
Cougar Butte/East Glass Mountain	0	0	0	0	0	1	0	0	0
Cowhead Lake	2	0	0	1	1	0	0	0	0
Cowhead Lake-Drews Creek/Butcher Flat	1	0	1	0	1	0	0	0	0
Drews Creek/Butcher Flat	1	0	1	0	0	0	0	0	0
East Glass Mountain	0	0	0	0	0	0	0	0	0
East Medicine Lake	24	0	30	30	128	35	33	18	30
Fox Mountain	0	0	0	0	0	0	0	0	0
Glass Mountain	4	0	3	0	30	37	0	0	0
GF/LIW/RS	1	0	1	0	0	0	1	0	0
Grasshopper Group (?) [a]	19	5	32	9	40	16	7	7	0
Kelly Mountain	0	0	0	0	0	0	0	0	0
McComb Butte	0	0	1	0	0	0	0	0	0
Rainbow Mines	0	0	0	0	0	0	0	0	0
Silver Lake/Sycan Marsh	0	0	0	0	0	0	0	0	0
South Warners	0	0	0	0	1	1	0	0	0
Spodue Mountain (?) [a]	4	0	1	0	0	0	0	0	0
Sugar Hill (?) [a]	0	0	2	0	2	2	0	0	0
Tucker Hill	0	0	0	0	0	0	0	0	0
Tuscan	0	0	0	0	0	0	0	0	0
Warner Mts. Rhyodacite	0	0	1	0	0	0	0	0	0
Witham Creek	0	0	0	0	0	0	0	0	0
Unknown	1	0	4	1	4	16	1	1	0
Total	73	5	97	46	255	133	99	26	31

[a] (?) = Final and provisional source assignments combined in one category.

Table 4-10 (continued)

Obsidian Source/ Chemical Type	Archaeological Sites									
	CA-MOD-2558	CA-MOD-2559	CA-MOD-2560	CA-MOD-2561	CA-MOD-2562	CA-MOD-2563	CA-MOD-2564	CA-MOD-2565	CA-MOD-2566/67	CA-MOD-2568
Blue Mountain	1	4	0	0	0	1	1	5	3	1
Blue Spring/Mosquito Lake	0	0	0	0	0	0	0	0	1	0
Blue Spring	0	0	0	0	0	0	0	0	0	0
Borax Lake	0	0	0	0	0	0	0	0	0	0
Bordwell Springs	0	0	0	0	0	0	0	0	0	0
Buck Mountain	0	1	7	0	6	5	1	0	5	0
Buck Mountain/Coglan Buttes	0	0	0	0	0	0	0	0	0	0
Callahan Flow	0	0	0	0	0	0	1	0	0	0
Cougar Butte	0	13	16	0	4	4	0	4	8	0
Cougar Butte/East Glass Mountain	0	0	0	0	0	0	0	0	0	0
Cowhead Lake	0	0	1	0	0	0	0	1	2	0
Cowhead Lake-Drews Creek/Butcher Flat	0	0	0	0	0	0	0	0	0	0
Drews Creek/Butcher Flat	0	0	0	0	0	0	0	1	1	0
East Glass Mountain	0	0	0	0	0	0	0	0	1	0
East Medicine Lake	6	120	135	38	143	99	32	50	94	15
Fox Mountain	0	0	0	0	0	0	0	0	0	0
Glass Mountain	0	0	26	0	1	0	0	0	3	0
GF/LIW/RS	0	1	1	0	0	2	0	0	2	0
Grasshopper Group (?) [a]	0	5	33	6	21	30	0	11	21	16
Kelly Mountain	0	0	0	0	0	0	0	0	0	0
McComb Butte	0	0	0	0	0	0	0	0	1	0
Rainbow Mines	0	0	0	0	1	0	0	0	1	0
Silver Lake/Sycan Marsh	0	0	0	0	0	0	0	0	0	0
South Warners	0	0	0	0	0	0	0	0	0	0
Spodue Mountain (?) [a]	0	1	2	0	0	0	0	0	1	0
Sugar Hill (?) [a]	0	0	1	0	0	1	0	0	2	0
Tucker Hill	0	0	0	0	1	0	1	0	0	0
Tuscan	0	0	0	0	0	0	0	0	0	0
Warner Mts. Rhyodacite	0	0	0	0	0	0	0	0	0	0
Witham Creek	0	0	0	0	0	0	0	0	1	0
Unknown	0	1	6	0	2	5	1	1	4	0
Total	7	146	228	44	179	147	37	73	151	32

[a] (?) = Final and provisional source assignments combined in one category.

Table 4-10 (continued)

Obsidian Source/ Chemical Type	Archaeological Sites									
	CA-MOD-2569	CA-MOD-2570	CA-MOD-2571	CA-MOD-2572	CA-MOD-2573	CA-MOD-2574	CA-MOD-2575	CA-MOD-2627	CA-MOD-2646	CA-MOD-2904
Blue Mountain	0	0	2	1	1	1	3	4	0	0
Blue Spring/Mosquito Lake	0	0	0	0	0	0	0	0	0	0
Blue Spring	0	0	0	0	0	0	0	0	0	0
Borax Lake	0	0	0	0	0	0	0	0	0	0
Bordwell Springs	0	0	0	0	0	0	0	0	0	0
Buck Mountain	0	1	1	1	0	1	1	1	0	0
Buck Mountain/Coglan Buttes	0	0	0	0	0	0	0	0	0	0
Callahan Flow	0	0	0	0	0	0	0	0	0	0
Cougar Butte	0	2	4	0	1	2	3	3	0	0
Cougar Butte/East Glass Mountain	0	0	0	0	0	0	0	0	0	0
Cowhead Lake	0	0	0	0	0	2	0	1	0	0
Cowhead Lake-Drews Creek/Butcher Flat	0	1	0	0	0	0	0	3	0	0
Drews Creek/Butcher Flat	0	0	0	0	1	1	0	0	0	0
East Glass Mountain	0	0	0	0	0	0	0	0	0	0
East Medicine Lake	4	26	22	43	25	13	13	21	31	1
Fox Mountain	0	0	0	0	0	0	0	0	0	0
Glass Mountain	0	0	0	0	1	18	3	4	0	0
GF/LIW/RS	0	1	0	0	2	0	0	0	0	0
Grasshopper Group (?) [a]	9	16	0	10	0	0	9	8	0	0
Kelly Mountain	0	0	0	0	0	0	0	0	0	0
McComb Butte	0	0	0	0	0	0	0	0	0	0
Rainbow Mines	0	0	0	1	0	0	0	0	0	0
Silver Lake/Sycan Marsh	0	0	0	0	0	1	0	0	0	0
South Warners	0	0	0	0	0	0	0	0	0	0
Spodue Mountain (?) [a]	1	0	0	0	1	1	1	4	0	0
Sugar Hill (?) [a]	0	0	1	0	0	1	0	0	0	0
Tucker Hill	0	0	0	0	0	0	0	0	0	0
Tuscan	0	0	0	0	0	0	0	0	0	0
Warner Mts. Rhyodacite	0	0	0	0	0	0	0	0	0	0
Witham Creek	0	0	0	0	0	0	0	0	0	0
Unknown	0	2	0	0	0	2	0	0	0	0
Total	14	49	30	56	32	43	33	49	31	1

[a] (?) = Final and provisional source assignments combined in one category.

Table 4-10 (continued)

Obsidian Source/ Chemical Type	Archaeological Sites CA-SHA-68/H	CA-SHA-1474	CA-SHA-1836	CA-SHA-1837	CA-SHA-1838/H	CA-SHA-1839/H	CA-SHA-1840	CA-SHA-1841	CA-SHA-1842	CA-SHA-1843/H
Blue Mountain	0	0	0	0	0	0	0	0	0	0
Blue Spring/Mosquito Lake	0	0	0	0	0	0	0	0	0	0
Blue Spring	0	0	0	0	1	0	0	0	0	0
Borax Lake	0	0	0	0	0	0	0	0	0	0
Bordwell Springs	0	0	0	0	1	0	0	0	0	0
Buck Mountain	8	1	0	0	3	1	0	0	2	0
Buck Mountain/Coglan Buttes	0	0	0	0	0	0	0	0	0	0
Callahan Flow	0	0	0	0	0	0	0	0	0	0
Cougar Butte	0	0	0	1	0	0	0	0	0	0
Cougar Butte/East Glass Mountain	0	0	0	0	0	0	0	0	0	0
Cowhead Lake	0	0	0	0	0	0	0	0	0	0
Cowhead Lake-Drews Creek/Butcher Flat	0	0	0	0	0	0	0	0	0	0
Drews Creek/Butcher Flat	0	0	0	0	0	0	0	0	0	0
East Glass Mountain	0	0	0	0	0	0	0	0	0	0
East Medicine Lake	82	23	3	23	80	0	0	21	15	6
Fox Mountain	0	0	0	0	0	0	0	0	0	0
Glass Mountain	1	0	0	0	0	0	0	0	0	0
GF/LIW/RS	48	1	0	0	16	0	0	3	6	0
Grasshopper Group (?) [a]	33	1	0	0	27	34	0	2	5	0
Kelly Mountain	0	0	0	0	0	0	0	1	0	0
McComb Butte	0	0	0	0	0	0	0	0	0	0
Rainbow Mines	0	0	0	0	0	0	0	0	0	0
Silver Lake/Sycan Marsh	0	0	0	0	0	0	0	0	0	0
South Warners	0	0	0	0	0	0	0	2	0	0
Spodue Mountain (?) [a]	0	0	0	0	0	0	0	0	0	0
Sugar Hill (?) [a]	0	0	0	0	0	0	0	0	0	0
Tucker Hill	0	0	0	0	0	0	0	0	0	0
Tuscan	5	1	0	0	0	0	1	34	102	15
Warner Mts. Rhyodacite	0	0	0	0	0	0	0	0	0	0
Witham Creek	0	0	0	0	0	0	0	0	0	0
Unknown	2	0	0	0	0	0	0	0	0	0
Total	179	27	3	24	128	35	1	63	130	21

[a] (?) = Final and provisional source assignments combined in one category.

Table 4-10 (continued)

Obsidian Source/ Chemical Type	Archaeological Sites										
	CA-SHA-1891	CA-SHA-1966	CA-SHA-1975	CA-SHA-1976	CA-SIS-1552	CA-SIS-1553	CA-TEH-1528	CA-TEH-1529/H	CA-TEH-1611	Total	(%)
Blue Mountain	0	0	0	0	0	0	0	0	0	67	(2.2)
Blue Spring/Mosquito Lake	0	0	0	0	0	0	0	0	0	1	(0.0)
Blue Spring	0	0	0	0	0	0	0	0	0	1	(0.0)
Borax Lake	0	0	0	0	0	0	0	1	0	1	(0.0)
Bordwell Spring	0	0	0	0	0	0	0	0	0	1	(0.0)
Buck Mountain	0	0	0	0	4	1	0	0	1	67	(2.2)
Buck Mountain/Coglan Buttes	0	0	0	0	0	0	0	0	0	1	(0.0)
Callahan Flow	0	0	0	0	0	0	0	0	0	1	(0.0)
Cougar Butte	0	0	0	0	0	0	0	0	0	182	(5.9)
Cougar Butte/East Glass Mountain	0	0	0	0	0	0	0	0	0	1	(0.0)
Cowhead Lake	0	0	0	0	0	0	0	0	0	11	(0.4)
Cowhead Lake-Drews Creek/Butcher Flat	0	0	0	0	0	0	0	0	0	7	(0.2)
Drews Creek/Butcher Flat	0	0	0	0	0	0	0	0	0	6	(0.2)
East Glass Mountain	0	0	0	0	0	0	0	0	0	1	(0.0)
East Medicine Lake	2	5	0	3	55	14	3	8	1	1,603	(52.3)
Fox Mountain	0	0	0	0	0	0	1	0	0	1	(0.0)
Glass Mountain	0	0	0	0	0	0	0	0	0	131	(4.3)
GF/LIW/RS	0	1	0	0	18	0	1	0	0	106	(3.5)
Grasshopper Group (?) [a]	0	3	0	0	7	5	4	0	2	453	(15.8)
Kelly Mountain	0	0	0	0	0	0	1	2	0	4	(0.1)
McComb Butte	0	0	0	0	0	0	0	0	0	2	(0.1)
Rainbow Mines	0	0	0	0	0	0	0	0	0	3	(0.1)
South Warners	0	2	0	0	0	0	0	0	0	6	(0.2)
Silver Lake/Sycan Marsh	0	0	0	0	0	0	0	0	0	1	(0.0)
Spodue Mountain (?) [a]	0	0	0	0	0	0	0	0	0	17	(0.6)
Sugar Hill (?) [a]	0	0	0	0	0	0	1	0	0	13	(0.4)
Tucker Hill	0	0	0	0	0	0	0	0	0	2	(0.1)
Tuscan	14	15	20	10	0	0	36	46	19	318	(10.4)
Warner Mts. Rhyodacite	0	0	0	0	0	0	0	0	0	1	(0.0)
Witham Creek	0	0	0	0	0	0	0	0	0	1	(0.0)
Unknown	0	0	0	0	0	0	0	0	0	54	(1.8)
Total	16	26	20	13	84	20	47	57	23	3,064	

[a] (?) = Final and provisional source assignments combined in one category.

The Medicine Lake Highlands prehistoric obsidian procurement sphere appears to have been wide-ranging. PEP artifacts from Medicine Lake sources were found as far north in Oregon as the northern margin of the Klamath Basin (35-KL-810) and as far south as CA-TEH-1528/H at the northern end of the Central Valley (Table 4-11). Hughes (1978, 1985, 1986a, 1990b) and Hughes and Bettinger (1984) also document the presence of glass from the Medicine Lake Highlands at sites in southwestern Oregon, in the Klamath Basin of Oregon and California, in Surprise Valley, and along the northern California coast. As the fringe of the Central Valley is reached, use of Medicine Lake sources rapidly gives way to dependence on Tuscan glass. Farther south in the Central Valley, the Tuscan material is replaced by obsidian from sources in the North Coast Range.

Central Valley. Identified obsidian specimens from the nine Central Valley Project sites were largely from sources in the North Coast Range of California (Table 4-11). Over 96 percent of all the artifact obsidian from the nine middle Central Valley sites originated from the Annadel, Borax Lake, Mt. Konocti, or Napa Valley sources—a typical middle Central Valley procurement pattern (Jackson 1986). Only five artifacts from these nine sites did not originate from sources in the the North Coast Range. Four items were identified with sources across the Sierra in eastern California, and obsidian from a single north Central Valley site, CA-TEH-1529/H, came from the Tuscan and East Medicine Lake sources to the north.

Table 4-11 Results of Trace Element Studies of California Central Valley Obsidian Artifacts.

	Archaeological Sites										
Obsidian Source/ Chemical Type	CA-CCO-129	CA-CCO-368	CA-COL-165	CA-COL-178	CA-SOL-347	CA-SOL-348	CA-SOL-351	CA-YOL-161	CA-YOL-177	Total	(%)
Annadel	0	4	0	0	0	1	0	0	0	5	(2.4)
Bodie Hills	0	2	0	0	0	0	0	0	0	2	(1.0)
Borax Lake	0	1	10	13	0	0	0	0	0	24	(11.6)
Casa Diablo	0	1	0	0	0	0	0	0	0	1	(0.5)
Mono Glass Mountain	0	1	0	0	0	0	0	0	0	1	(0.5)
Mt. Konocti	0	0	1	7	0	0	0	0	0	8	(3.9)
Napa Valley	6	41	52	22	12	5	17	4	1	160	(77.7)
Tuscan	0	0	0	1	0	0	0	0	0	1	(0.5)
Unknown	0	2	0	0	0	0	0	0	0	2	(1.0)
Not Obsidian	0	0	0	1	1	0	0	0	0	2	(1.0)
Total	6	52	63	44	13	6	17	4	1	206	

Trans-Sierran Obsidian Procurement. One of the best examples of long-distance obsidian procurement encountered during the Project is found in glass at CA-CCO-368 that was obtained through trans-Sierran procurement. Four obsidian flakes from three sources in the Mono Basin of eastern California were found at the site. The site also contained multiple burials, associated nonutilitarian burial artifacts (stone and *Haliotis* pendants and *Olivella* beads) and mica ornaments.

Eastern Sierran obsidian has been discovered at numerous archaeological sites in both the western Sierra and southern Great Central Valley (Bouey and Basgall 1984; Jackson 1974, 1986). Central Californian use of eastern Sierran obsidian, predominantly glass from Casa Diablo and Bodie Hills, appears to have peaked in the Early Horizon. During the Middle Horizon, Mono Basin glass began to be largely supplanted by Napa Valley obsidian, and by Late Horizon times Napa obsidian had virtually replaced the eastern obsidian (Bouey and Basgall 1984; Jackson 1986). Reported late prehistoric eastern Sierran obsidian found in central California consists only of formed tools, signalling a marked shift in the nature of procurement. Jackson (1986:41) states "I know of no finds of unmodified Sierra Nevada obsidian from northern San Joaquin Valley, Delta, or southern Sacramento Valley archaeological sites. This would imply that the artifacts of Sierra Nevada obsidian found there were imported as completed artifacts."

The trans-Sierran exchange of goods between western Sierran groups and eastern groups has also been documented during the ethnographic period (Davis 1961; Ericson 1981; Gayton 1948). This ethnographic evidence suggests that exchange systems were the principal process accounting for the movement of obsidian across the Sierra during the historic and proto-historic period. It is reasonable, then, to conclude that eastern obsidian at CA-CCO-368 probably found its way to the site through exchange. Different procurement systems may often account for utilitarian and high-value nonutilitarian goods, however, and the presence of the nonutilitarian materials found at CA-CCO-368 and the appearance of trans-Sierran glass may be related (Hughes 1978). The nature of artifactual materials recovered at the site (nonutilitarian burial goods and decorative materials), combined with an absence of eastern Sierran glass at nearby CA-CCO-129, also suggests that site function may have played an important role in the acquisition of imported obsidian.

4.3.4 Obsidian from Unknown Sources

Of the artifacts selected for obsidian studies during the Project, 309 could not be geochemically correlated with known geologic sources (Table 4-12). The Unknown X source potentially accounts for an additional 347 samples. The remainder of the items came from all regions along the Pipeline, although most are associated with north-central Oregon sites.

As discussed earlier in this section, unknown source assignments can result from several factors—analytical problems, unrecorded chemical source variability, and unknown sources. While analytical problems likely account for a small proportion of the unascribed sources, a scatterplot of diagnostic trace elements (Figure 4-14) reveals data clusters that strongly suggest distinct undiscovered sources. The visual examination of other trace element pairs also supports the pattern of distinct source clusters. It is clear that researchers looking for new sources of prehistorically used glass will find rich hunting in Oregon.

Table 4-12 Count and Percentage by County of Artifacts for which No Geologic Source Could Be Identified (Excluding the Unknown X in Central Oregon).

County and State	Unknown Sources	Total Characterized[a]	Percent Unknown
Boundary County, Idaho	1	2	50
Umatilla County, Oregon	4	4	100
Gilliam County, Oregon	37	217	17.1
Sherman County, Oregon	14	73	19.2
Wasco County, Oregon	44	960	4.6
Jefferson County, Oregon	116	1,629	7.1
Crook County, Oregon	2	110	1.8
Deschutes County, Oregon	22	2,602	0.8
Klamath County, Oregon	13	1,047	1.2
Modoc County, California	52	2,147	2.4
Shasta County, California	2	690	0.3
Tehama County, California	0	127	0.0
Colusa County, California	0	106	0.0
Yolo County, California	0	5	0.0
Solano County, California	0	35	0.0
Contra Costa County, California	2	58	0.0
Total	309	9,812	3.1

[a] Total number of samples characterized by true element and visual methods.

4.3.5 Nonobsidian Artifacts

Although the vast majority of artifacts selected for analysis proved to be obsidian, the trace element signatures of a few items clearly revealed a nonobsidian origin (Table 4-13). Most of the nonobsidian samples originated from sites in Gilliam, Sherman, Wasco, and Jefferson counties in north-central Oregon.

Table 4-13 Count and Percentage by County of Artifacts Geochemically Identified as Not Obsidian.

County and State	Not Obsidian	Total Characterized	Percent
Gilliam County, Oregon	9	217	4.1
Sherman County, Oregon	4	73	5.5
Wasco County, Oregon	14	960	1.5
Jefferson County, Oregon	25	1,629	1.6
Deschutes County, Oregon	3	2,602	0.1
Klamath County, Oregon	1	1,047	0.1
Modoc County, California	2	2,147	0.1
Solano County, California	1	35	2.9
Total	59	8,710	0.7

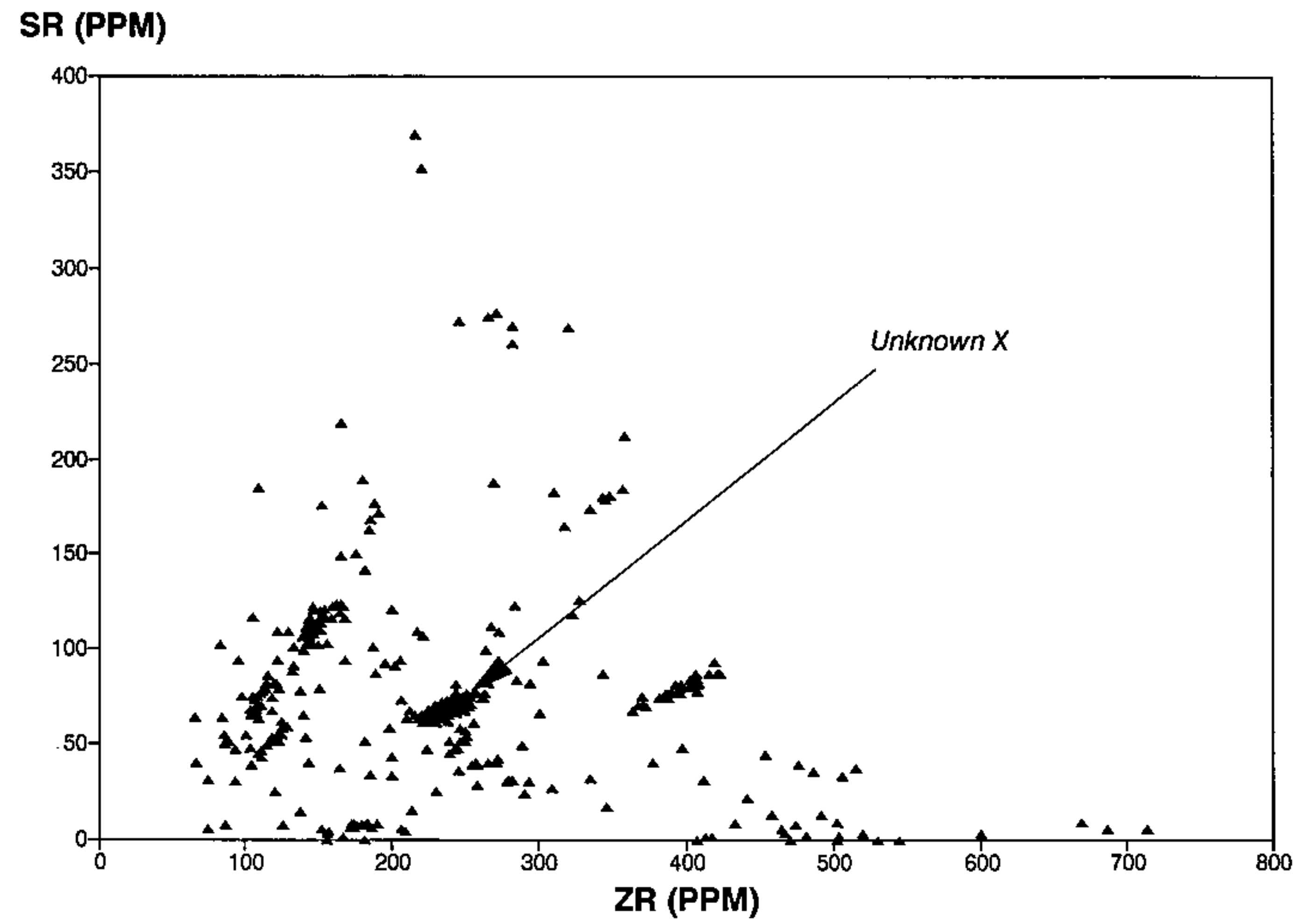

Figure 4-14 Scatterplot of Sr versus Zr for PEP artifacts with unknown sources.

Upon reexamination, many of these artifacts from the Oregon sites proved to be virtually indistinguishable visually from natural volcanic glass. This was particularly true for very small specimens. Attributes that provided clues about the nonobsidian nature of these samples most often included the opacity of even very thin items, a slightly waxy to resinous luster, and the unusual appearance of any remaining exterior cortex. A low magnification hand lens (x10) was used to identify these subtle distinctions. This clearly demonstrates that obsidian, a stone widely known to archaeologists and relatively easy to identify, can be mimicked by other materials. It also points out the need for the careful inspection of obsidian materials in regions where lithic materials with similar appearances are found.

4.4 CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

4.4.1 Conclusions

During the last 30 years, trace element studies of obsidian have become a commonplace and invaluable component of archaeological research programs in the Far West. Obsidian is frequently an important part of lithic assemblages, particularly in Oregon and California. The determination of the geologic sources of obsidian artifacts contributes valuable information about the prehistoric procurement patterns in these regions. The geographic patterning of characterized obsidian artifacts and sources provide archaeologists with uniquely convincing evidence of long-distance direct procurement and/or the presence of prehistoric exchange systems. These patterns also may yield clues about seasonal procurement ranges, the location of trade and travel routes, the presence of territorial or ethnic boundaries, differential access to goods, and the changes in these patterns through time. In addition, the determination of the chemical sources of artifacts provides essential information needed for obsidian hydration studies that often accompany artifact source investigations.

Over 9,900 obsidian artifacts from 141 Idaho, Oregon, and California archaeological sites were chemically and visually characterized as part of the PGT-PG&E Pipeline Expansion Project. Fifty-seven potential chemical sources in four states were identified among the greater than 9,000 artifacts subjected to trace element studies.

Overall, the pattern of obsidian procurement and use at most of the PEP sites is consistent with a model of local direct-access acquisition at nearby sources of glass combined with long-distance direct procurement of somewhat more distant obsidian. Probable procurement through exchange is suggested only at a few sites, most convincingly by the presence of eastern Sierran glass at CA-CCO-368 in the Central Valley of California. Most procurement was probably embedded within a matrix of normal seasonal subsistence activities (Binford 1979). The distribution of nonlocal obsidian may be cautiously used to reconstruct the boundaries of normal seasonal movements and subsistence ranges, as well as to explore the possibility of intergroup contact and exchange.

Prior to the research reported here, very few obsidian characterization studies had been undertaken in the regions bisected by the PEP corridor. While this was particularly true in north-central and central Oregon, knowledge of obsidian procurement patterns throughout the Project area was incomplete. The database of obsidian characterization information created as part of the PEP is unprecedented in scope in the short history of Far Western archaeological research. The potential of the data far outweighs the relatively brief treatment that it has been given in this section and elsewhere in this final report.

4.4.2 Recommendations for Further Research

Although many different obsidian flows, domes, and secondary deposits are known to exist in central Oregon and northern California, prior to this Project obsidian characterization studies have been few and far between. Sample sizes have been small and little was known about the prehistoric distribution and utilization of glass from the many major sources. The mechanisms of prehistoric glass procurement throughout the region transected by the pipeline were virtually unknown. Until now, theory and speculation about prehistoric obsidian procurement had far outstripped the hard evidence needed to test the substantive hypotheses that will prove of real value to archaeologists. Future obsidian-related archaeological research issues in California and Oregon might include:

- *Spatial investigations of specific prehistoric obsidian procurement systems or procurement spheres.* From these studies, we can begin to ascertain the significant characteristics of these systems, such as magnitude, directionality, and boundaries, and the natural and cultural influences that shaped them. When combined with obsidian hydration data, it also will be possible to chart these properties through time as well as through geographic space.

- *Geoarchaeological and geochemical investigations of prehistorically utilized sources of volcanic glass.* Systematic studies of the primary and secondary distribution boundaries and the range of chemical variability of sources are needed to take full advantage of artifact characterization information. The major sources identified by the Project provide a logical starting point for this research.

- *Evaluation of the efficacy of visual characterization methods in identifying sources of obsidian.* The McKay Butte source in central Oregon, as only one example, provides a potentially fertile source of information for exploring the promises and hazards of visual characterization methods. The availability of large numbers of artifacts of known source provenience provides archaeological researchers with ready-made visual source provenience experiments. Thin sections of these artifacts, already prepared during obsidian hydration studies, also provide researchers with an excellent opportunity to explore the use of microscopic petrographic attributes to identify sources.

- *Identification and geoarchaeological evaluation of unknown sources of obsidian.* The PEP studies presented here indicate that numerous sources of glass unknown to archaeologists remain to be found, particularly in north-central Oregon. The Unknown X source identified at Newberry Volcano sites is almost certain to lie within a few kilometers of the Project, although it is yet to be located.

- *Exploration of the value of lithic technological data in understanding lithic prehistoric procurement systems.* Technological attributes relating to tool manufacture have been collected for most of the characterized Oregon obsidian artifacts. These data may be used to investigate a variety of technological and procurement issues. What are the relationships of technological attributes to site function or source distance? How can source-specific technological attributes be used investigate prehistoric cultural behavior?

- *Obsidian source diversity issues.* Source diversity—the range of identified geologic sources—may be influenced by several natural and cultural variables. These include the size of the sample, the site function, distance and access to sources, seasonal subsistence activity and territorial boundaries, category and function of artifact, geographic region, and the proximity of competing sources. The database developed here offers a unique opportunity to explore the effects of some of these variables. For instance, geographically demonstrable differences in diversity may affect sampling strategies in future obsidian research, particularly in the allocation of typically limited obsidian characterization resources. Greater numbers of samples in high-diversity areas will be needed to adequately represent the range of source variability expected in these areas.

- *Artifact source diversity issues.* Recent Far Western obsidian studies point to a relationship between nonutilitarian and utilitarian artifact groupings and the preferential use of obsidian sources. Hughes (1986a, 1990b) and Hughes and Bettinger (1984), in examining the sources used in the manufacture of different classes of obsidian tools from southern Oregon and northern California sites, found distinctions in the use of local versus nonlocal sources. Andrefsky (1994) also points out that the relative availability of different lithic materials also affects their eventual manufacture into formal or informal tools. Given the local availability of a lithic material, ease of procurement tends to outweigh other factors and both formal and informal tools will usually be manufactured from local toolstone. What are the different cultural and noncultural variables affecting the choice of sources of raw material? The PEP, with its diverse geographic span, provides an excellent source of data with which to investigate these processes.

- *Relationship between distance to source and intensity of use.* The study of distance-decay or fall-off curves in relation to sources of raw material has been a favorite theoretical topic for many years. PEP obsidian studies can provide investigators with the hard evidence needed to further refine these investigations.

Although these and other possible inquiries regrettably lie beyond the scope of the current investigation, the geochemical artifact and source database created as part of the Project holds the promise of providing answers for many of these different research questions. In particular, when the Project data are integrated with existing obsidian characterization and hydration information, Oregon and California archaeologists will have a body of information currently unprecedented in the world for exploring these different regional research questions and processual issues.