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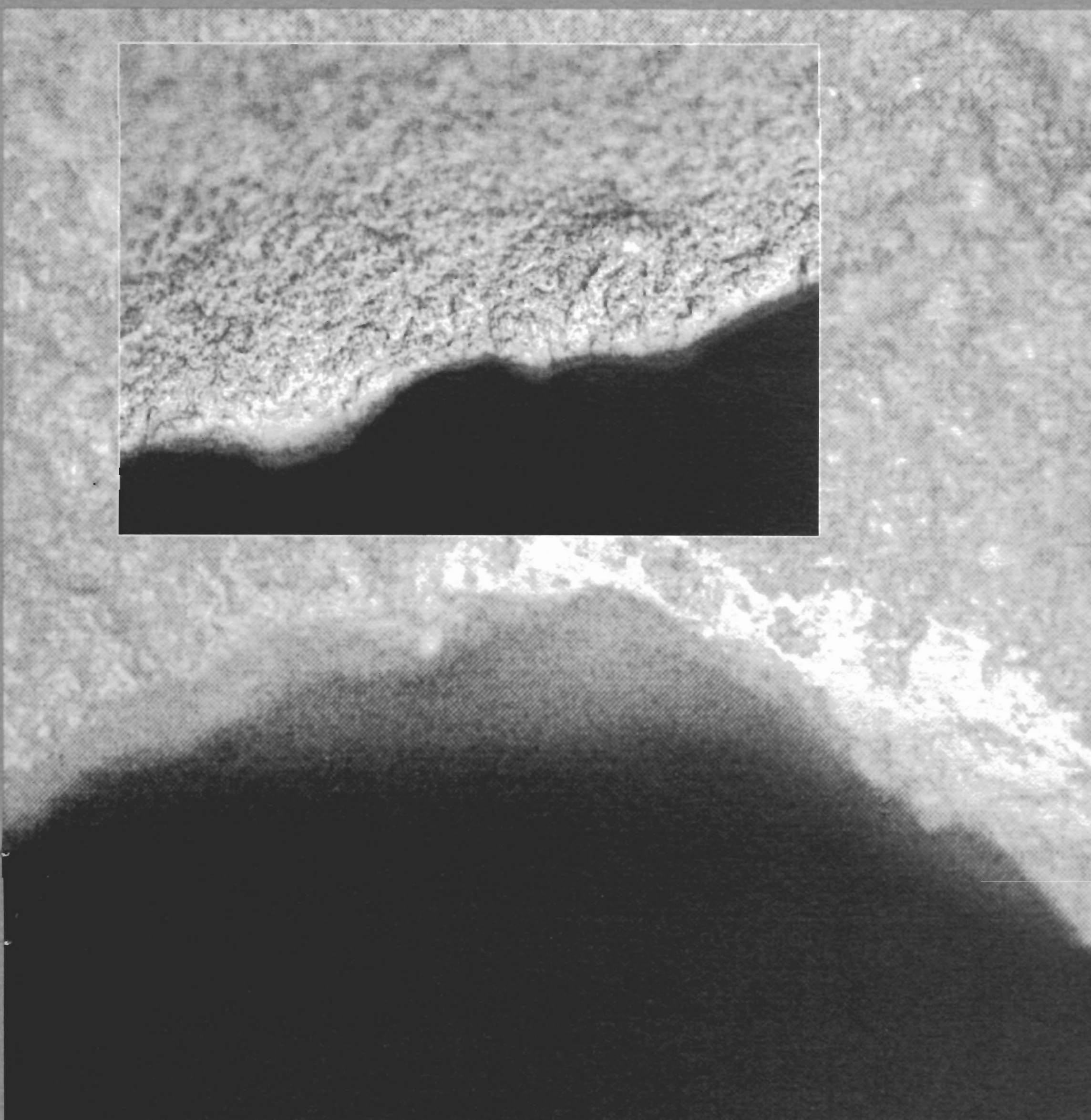

Obsidian Studies and the Archaeology of 19th-Century California

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Obsidian studies play an integral part in archaeology around the world, particularly in the Americas, but few archaeologists have employed obsidian studies to understand Native American life at historical archaeological sites. Yet, obsidian sourcing and hydration analysis can provide critical insights into site chronology and use, lithic recycling, and procurement and trade at contact and colonial sites. Obsidian geochemical sourcing and hydration analyses of a 19th-century rancho site in northern California have revealed new information on Native Americans who labored there in the second quarter of the 19th century. The obsidian data indicate a significant amount of lithic manufacture and use, a change in obsidian procurement in the 1800s, and an unprecedented number of obsidian sources represented on-site. The implications for general obsidian studies, as well as for regional archaeological issues, concern the problems with popular sourcing methods in northern California and the need to revisit current understandings of the first micron of hydration rim development.

Introduction

The sourcing and dating of obsidian artifacts contribute greatly to archaeology in Mesoamerica, the Mediterranean, the Pacific, and North America. Although many archaeologists in North America, particularly those working in the Southwest, California, and the Great Basin, study obsidian artifacts for information about pre-contact chronology and sourcing, very few archaeologists working in historical periods have contributed to or made use of obsidian studies. This absence is noteworthy given the otherwise burgeoning contact and colonial-period research in obsidian-rich areas of the world. California is a case in point. Fifteen years ago, Thomas Origer claimed that his laboratory in California had, since 1978, "processed more than 10,000 obsidian artifacts from archaeological contexts in the United States and abroad, yet only a handful of specimens (a few dozen) have hydration bands measuring less than one micron" (Origer 1989: 70). Little has changed since then in our understanding of the one-micron range that frequently indicates a relatively recent age. The lack of data for these recent periods is not because obsidian artifacts do not exist at historical sites or because there is a dearth of such sites, but rather because archaeologists working on contact and colonial sites tend not to appreciate their potential usefulness.

The usefulness of obsidian studies for historical archaeology is outlined here. Obsidian studies do not offer a simple, straightforward set of data, particularly since controversy surrounds the effectiveness and utility of obsidian-hydration dating (e.g., Anovitz et al. 1999; Ridings 1996), but they do provide data useful for refining archaeological interpretations of post-contact and colonial sites. My argument is that obsidian sourcing and hydration can provide information on site chronology, stone tool recycling, and lithic procurement and trade for historical sites with Native American residents. Although prehistorians routinely use obsidian artifacts for the same issues, historical archaeologists have engaged only minimally with obsidian studies.

I begin with a brief outline of methodological issues in obsidian studies at historical sites and follow with a case study of a 19th-century site in northern California, known as CA-Son-2294/H in the Petaluma Adobe State Historic Park north of San Francisco, which illustrates the effectiveness of obsidian studies using a combination of original energy-dispersive x-ray fluorescence (EDXRF) and obsidian-hydration analyses. In addition to demonstrating the usefulness of obsidian studies for unraveling some details of indigenous involvement in colonial worlds, the results are also significant for analytical methods in American west coast archaeology and for archaeological obsidian studies as a whole. A final section takes up these implications and offers a challenge to sourcing methods in California.

Obsidian Studies and Historical Archaeology

Virtually all obsidian studies involve either the sourcing of obsidian artifacts and raw material to a geographical or geological source using analytical chemistry or macroscopic visual inspection, or the dating of obsidian artifacts in relative or absolute terms by measuring the width of the hydration rim that forms on an exposed surface over time. Frequently, archaeologists pursue these efforts simultaneously to increase the reliability of archaeological interpretation and archaeometric results. In place of detailed technical summaries of obsidian sourcing and dating, I turn instead to a general outline of the applicability of obsidian studies to contact and colonial sites. I do not offer obsidian studies as unproblematic and unambiguous for historical sites, but I do show how obsidian data can provide complementary results for historical archaeology and, simultaneously, how the application of obsidian analyses in historical contexts can benefit broader archaeological obsidian studies.

Site Chronology

The obsidian-hydration technique entails measurement of the water absorption band that forms on an exposed obsidian surface and grows as a function of time and environmental factors (Freter 1993; Friedman and Smith 1960; Michels and Tsong 1980). Although many have grave concerns about obsidian-hydration as a reliable dating technique (Anovitz et al. 1999; Ridings 1996), recent applications in Mesoamerica (Evans and Freter 1996; Freter 1992, 1993; Webster, Freter, and Rue 1993), the western United States (Hull 2001), and the Pacific (Ambrose 1998; Stevenson et al. 1996) demonstrate the continued viability of obsidian-hydration analysis for tackling archaeological problems, if used carefully. Significant strides have also been made in the last 20 years in deriving source-specific rates from empirical studies of independently-dated archaeological materials (Bettinger 1989; Hall and Jackson 1989) and in studying hydration rate formulas and source comparisons from experimental studies of induced hydration (Mazer et al. 1991; Stevenson and Scheetz 1989; Stevenson, Carpenter, and Scheetz 1989; Stevenson, Mazer, and Scheetz 1998; Tremaine 1989).

Prehistorians regularly use obsidian-hydration dating, particularly in western North America, to refine site and regional chronologies and, when coupled with obsidian sourcing, to investigate changes in site use, mobility patterns, and trade relations (e.g., Byram 1995). In California, obsidian-hydration dating has proven to be a useful archaeometric tool (Ericson 1989; Hall and Jackson 1989; Hull 2001; Origer 1987; Origer and Wickstrom 1982). These studies frequently occur separately from, but draw on, efforts to geochemically characterize obsidian sources and artifacts. Archaeologists rarely use obsidian-hydration dating in the American Southwest because more precise chronological methods are available, but obsidian sourcing is common (Glascock, Kunselman, and Wolfman 1999; Shackley 1988, 1995; Stevenson and Klimkiewicz 1990).

Applications of obsidian-hydration dating at colonial and post-contact sites are few, however. Only a handful of studies in California have used it to refine issues of site chronology in historical periods (Layton 1990; Lightfoot and Silliman 1997; Lightfoot, Wake, and Schiff 1991). One reason for its infrequency in archaeological studies of post-contact sites can be attributed to the assumption that obsidian-hydration dating is too imprecise when compared to dating based on historical archives and colonial mass-produced artifacts. Few would disagree with this assessment, but archaeologists are making headway in tightening the resolution of obsidian-hydration dating (Ambrose 1998; Stevenson, Gottesman, and Macko 2000).

Although obsidian-hydration analysis does not offer a methodological panacea, obsidian-hydration dating can address chronological issues in the historic period in three ways. First, obsidian-hydration data can aid in the dating of lithic artifacts at colonial and contact sites with potentially mixed stratigraphic deposits, which is particularly important in open-air sites in the American West affected by bioturbation, deflation, agricultural activities, and other post-depositional processes. Second, obsidian-hydration can address questions of lithic recycling and the attendant impacts on chronological and behavioral interpretation. Insightful applications of obsidian-hydration dating to the recycling question have been offered in the literature on pre-contact sites (Michels 1969; Rondeau 1997; Waechter and Origer 1993), but few have considered it in historical cases. One exception is Lightfoot and Silliman's (1997) case of the 19th-century Russian settlement of Ross on California's north coast, where the predominantly pre-contact dates of obsidian artifacts within 19th-century layers are as much, if not more, due to lithic scavenging as to bioturbation or mixed stratigraphic deposits. Obsidian-hydration analysis indicated that indigenous residents lost some trade relations necessary for acquiring fresh obsidian raw material (Lightfoot, Wake, and Schiff 1991: 116) and turned to the site's earlier deposits as a lithic resource (Lightfoot and Silliman 1997: 352). Third, some historical sites associated with Native Americans may have few documents or mass-produced colonial goods useful for dating. Without obsidian-hydration dates, archaeologists

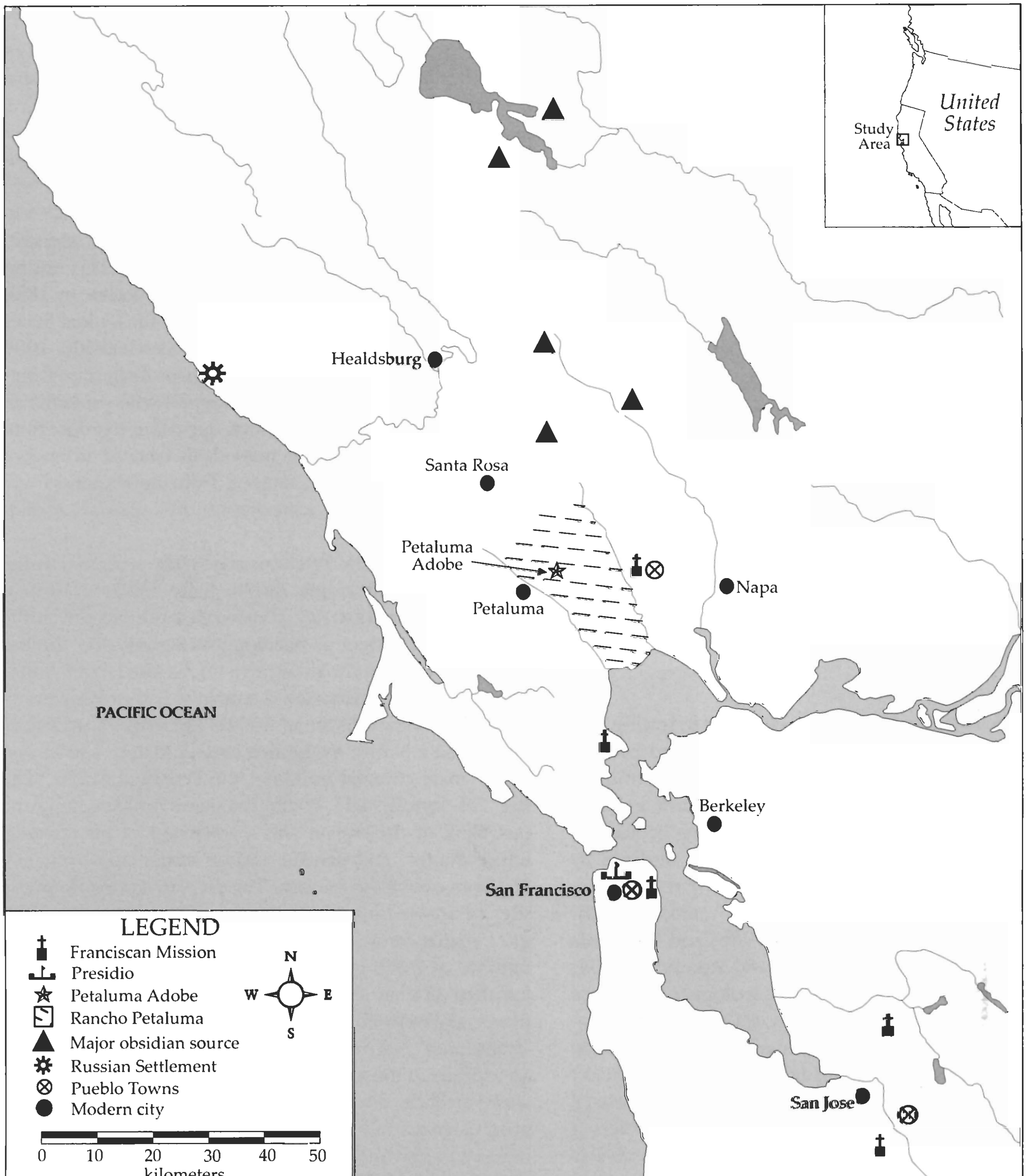

Figure 1. Map of northern California.

may wrongly label historical sites or obsidian artifacts in multi-component sites as "prehistoric." Since many archaeologists wrongly assume that contact with Europeans uniformly resulted in a loss of access to obsidian for Native Americans or a replacement of lithic materials with metal, it is likely that the simplistic attribution to prehistory of metal-, ceramic-, or glass-free sites in the American West is common. In California, farming out lithic artifacts on

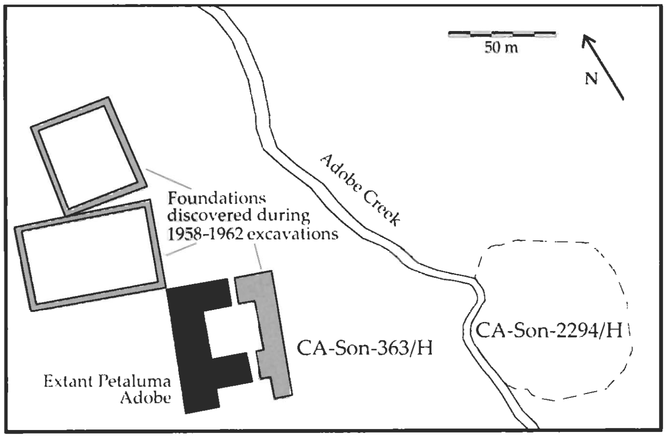

Figure 2. Plan of CA-Son-363/H (extant structures) and the Native American living area (CA-Son-2294/H) in Petaluma Adobe State Historic Park.

clearly colonial sites to pre-contact specialists exacerbates the problem. Obsidian-hydration dating can help replace assumptions with empirical assessments, especially since it is clear that Native groups were highly variable in whether or not and how they altered their lithic practices (e.g., Cobb 2003).

Procurement and Trade

Obsidian sourcing studies are well suited to tracing patterns of lithic procurement, trade, mobility, and population migration, particularly when coupled with obsidian-hydration or other dating methods. Care must be exercised, however, to avoid uncritically conflating geological, geochemical, and archaeological "sources," as outlined by Hughes (1998). Good examples of sourcing research derive from pre-contact archaeology in the American Southwest (Roth 2000; Shackley 1992, 1998b) and California (Bouey and Basgall 1984; Eerkens and Rosenthal 2004; Jackson 1986, 1989). The few archaeologists who trace similar changes in historical periods in California have focused on indigenous workers at Russian Fort Ross on the north coast (Farris 1989: 492; Lightfoot, Wake, and Schiff 1991: 116), on Native American sites in the near-coastal northwestern region (Layton 1990), on Native workers at a Mexican-Californian rancho north of San Francisco Bay (Silliman 2003, 2004), and on California Indian residents at the Spanish Mission Santa Cruz near Monterey (Allen 1998: 82). Tracing changes in obsidian procurement and trade from pre-contact to colonial times reveals how exchange relations shifted, how procurement diminished or intensified, and how people altered or held to mobility patterns across changing landscapes of colonial western North America.

Obsidian Use in 19th-Century California

To illustrate the usefulness of obsidian studies for contact and colonial studies, I turn to a case study in northern California. Since my purpose is not to relate the historical and archaeological specifics that have been detailed elsewhere (Silliman 2000a, 2004), the background presentation is brief. The site of interest is associated with the 19th-century Rancho Petaluma, a 270 sq km Mexican-Californian rancho owned by Mariano Guadalupe Vallejo and situated just north of San Francisco Bay (FIG. 1). This rancho was established in 1834, but was in serious decline by 1850 following the annexation of California by the United States two years previously. At its peak, the rancho had 600–1000 hunter-gatherers and missionized Indians from several language groups and regional communities who provided almost all labor relating to livestock, agricultural production, and manufacturing. Native individuals labored at ranchos for a variety of reasons, ranging from indebtedness and force to volition and incorporation into seasonal rounds (Silliman 2004).

Currently, Rancho Petaluma is partially protected by the roughly 17-ha Petaluma Adobe State Historic Park in Sonoma County (FIG. 2). These state lands have been the focus of intermittent archaeological research over the last 40 years with a recent attempt to document Native American activity since historical documents had provided only incomplete views (Silliman 2004). The effort successfully discovered a Native living area approximately 120 m east of the main colonial building, the Petaluma Adobe. The site, CA-Son-2294/H, contains a dense midden along the east bank of the stream and a collection of pit features, refuse dumps, and general artifact scatter approximately 15–25 m east of the midden. The excavated portions of the site, or approximately 50 sq m, contained almost 3000 glass shards, more than 1000 glass beads, a comparable number of metal artifacts, over 300 ceramic sherds, and less than 25 examples each of roof tile fragments, clay pipe pieces, and buttons. The colonial artifacts co-occurred with "traditional" Native artifacts: approximately 1300 obsidian artifacts, almost 1200 microcrystalline silicate (mostly chert) artifacts, over 500 pieces of other chipped stone, 25 ground stones and fragments, and several worked bone artifacts and clamshell disk beads. Faunal and floral remains show a wide variety of wild plant and animal species as well as introduced livestock and crops (Silliman 2004). Of particular interest is the association of lithic artifacts with all other artifactual and ecofactual material. The consistent association demonstrates the continuity of stone tool technology into the 19th century (Silliman 2003), and in what follows, I focus on the obsidian artifacts and their unique contribution to the interpretation of the site.

Table 1. Obsidian source frequency and rounded percentage for analyzed artifacts having undergone energy-dispersive x-ray fluorescence (EDXRF) and obsidian-hydration (OH) analysis.

Source	*EDXRF n*	*EDXRF %*	*OH n*	*OH %*	*Effective OH* n*	*Effective OH %*
Annadel	106	44.4	57	37.7	40	36.0
Borax Lake	1	0.4	1	0.7	1	0.9
Franz Valley	6	2.5	3	2.0	2	1.8
Mt. Konocti	1	0.4	1	0.7	1	0.9
Napa Valley	107	44.8	73	48.3	55	49.5
Oakmont	11	4.6	10	6.6	8	7.2
Unknown 1	1	0.4	1	0.7	0	0
Unknown 2	2	0.8	1	0.7	1	0.9
Unknown 3	2	0.8	2	1.3	2	1.8
Unknown 4	2	0.8	2	1.3	1	0.9
Total	239	100	151	100	111	99.9

* Excludes all "no visible hydration" (n = 38) and "diffuse" (n = 2) readings.

Obsidian Sourcing

Methods

Of the 1303 obsidian artifacts recovered during excavation, 239 (18.3%) were geochemically characterized with a subsample of 151 submitted for obsidian-hydration analysis (TABLE 1). Heeding published advice (e.g., Freter 1993: 299), sampling of the original collection was designed so that contexts would not be preferentially selected in ways that might bias the sourcing or dating efforts. Within this broad protocol, artifacts were sampled from multiple units across the site from both general midden deposits and specific pit and refuse features. These samples derived from contexts both near the surface and up to 50 cm below the surface, from both arbitrary levels excavated into undifferentiated alluvium and stratigraphically distinct features, and from both bioturbated sediments and intact deposits. The protocol also sought to represent each of the five major excavation loci in the sourced collection, but care was exercised to improve the representation of well-defined contexts such as small pit features and refuse piles over undifferentiated arbitrary levels. The sample included formal tools and tool fragments, cores, flakes, and other debitage in order to cover the entire range of lithic technology, but the tools are intentionally over-represented in the sourced collection relative to their frequency in the entire obsidian subassemblage.

The EDXRF analysis was performed on the Rancho Petaluma obsidian sample in the Department of Geology and Geophysics at the University of California, Berkeley, with standard instrumentation (Silliman 2000a: appendix B). The international RGM-1 standard for rhyolite was included in every analytical run to insure proper machine calibration based on concentration values reported in Govindaraju (1989), and all runs demonstrated statistically identical values to that standard. Sources were assigned by comparing quantitative data to the elemental profiles reported for published sources in NW California (Jackson 1986, 1989), NE California (Hamusek-McGann 1995; Hughes 1986a), eastern California (Davis et al. 1998: table 7.3; Hughes 1988, 1989, 1994), southern California (Hughes 1986b; Shackley 1994), Oregon and Washington (Ambroz, Glascock, and Skinner 2001; Skinner 1983), and nearby regions (e.g., Hughes 1990; Nelson 1984; Shackley 1995).

All source assignments were made with a combined use of raw part-per-million (ppm) inspection, bivariate element plots, and element ratios. Archaeologists have demonstrated the elegance of multivariate statistics for obsidian source characterization and assignment (Bishop and Neff 1989; Braswell and Glascock 1998; Glascock, Braswell, and Cobean 1998), and were I characterizing actual sources through controlled samples, I would have opted for such treatments. Echoing Baxter (1992), "[i]t is clear that in many cases the bivariate plots may be a more accurate reflection of source heterogeneity, as well as a better media for source assignment" (Shackley 1998a: 13). Fortunately, the known obsidian sources in northern California can be identified reliably through bivariate plots and ratios of rubidium (Rb), strontium (Sr), and zirconium (Zr) ppm concentrations. Using ratios is an acceptable complementary method of source assignment as long as raw values are monitored to insure that other sources with similar element ratios, but different absolute parts-per-million (ppm) values, are not classified incorrectly (Hughes 1998: 107). Ratios also help to control for uniformly-reduced element concentrations that may occur with obsidian samples that approach or fall below the minimum size requirements of analyzed samples, as outlined by Davis and her colleagues (1998).

Table 2. Summary statistics of select element concentrations in parts-per-million for sourced artifacts. Values in parenthesis are ranges.

	Annadel, n = 106		*Borax Lake, n = 1*		*Franz Valley, n = 6*		*Mt. Konocti, n = 1*		*Napa Valley, n = 107*		*Oakmont, n = 11*	
Element	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
Ti	1365.6	184.6	604.8	–	1417.0	57.8	1835.8	–	837.7	161.5	1186.5	130.8
	(1042.1–2045.0)		(–)		(1344.3–1479.9)		(–)		(523.2–1522.8)		(1050.1–1402.3)	
Mn	336.5	41.9	150.9	–	251.2	39.1	222.5	–	162.4	26.2	303.1	35.4
	(183.5–468.4)		(–)		(202.7–318.4)		(–)		(96.2–234.2)		(208.6–348.1)	
Fe	17,375.1	1646.3	8981.5	–	15,405.9	1444.9	12723.6	–	11,364.5	981.6	15,419.8	855.4
	(10,413.1–23,752.5)		(–)		(13,988.2–17,948.9)		(–)		(8662.4–17,948.9)		(14,207.1–16,492.4)	
Th	28.7	10.5	22.7	–	30.8	7.5	33.7	–	29.8	6.5	24.6	7.8
	(0.0–45.3)		(–)		(21.0–39.2)		(–)		(10.1–39.9)		(17.6–37.2)	
Rb	141.8	11.8	216.5	–	171.9	10.8	234.9	–	190.4	14.7	149.1	7.3
	(102.4–175.3)		(–)		(158.5–185.6)		(–)		(145.5–222.5)		(139.3–158.9)	
Sr	50.6	4.9	7.0	–	46.1	4.7	76.1	–	6.2	1.7	71.3	2.9
	(32.7–65.6)		(–)		(38.8–53.1)		(–)		(2.1–12.8)		(65.6–74.1)	
Y	47.3	5.2	41.7	–	38.4	4.9	38.3	–	42.6	4.4	35.2	4.0
	(34.7–57.7)		(–)		(28.8–41.7)		(–)		(29.8–49.5)		(27.0–39.4)	
Zr	281.3	24.5	99.6	–	250.1	14.4	209.0	–	234.7	19.4	244.6	13.6
	(196.7–344.7)		(–)		(222.0–263.8)		(–)		(175.6–272.1)		(218.9–261.4)	

Results

For the 239 obsidian-sourced artifacts, 10 source areas were identified: Annadel, Borax Lake, Franz Valley, Mt. Konocti, Napa Valley, Oakmont, and four unknowns (FIG. 3). Table 2 presents summary EDXRF statistics for ppm values of select elements. With the possible exception of the unknowns, the identified source areas are local to the North Coast Ranges of northern California. As Jackson discovered, ppm values and proportions of trace elements of Rb, Sr, and Zr can reliably discriminate these regional sources (Jackson 1986: 75–76), and all assignments here were made using his reference data after insuring that no other known sources outside the North Coast Range region mimicked the geochemical profiles. Using Sr–Rb and Zr–Rb bivariate plots to flatten the three-dimensional view, the results were quite clear (FIGS. 4, 5).

Because the obsidian artifacts varied greatly in size, examining ratios was an important step for the source assignments since very small artifacts might produce depressed ppm values in the x-ray fluorescence compositional analysis. For instance, artifact size seems to account for the larger spread of ppm concentrations that I obtained for Napa Valley and Annadel when these sources otherwise have been reported with fairly uniform geochemical compositions (Bowman, Asaro, and Perlman 1973; Jack 1976; Jackson 1986, 1989). Despite the compositional spread, a scatter plot of ratios of Rb and Sr ppm values relative to the sum of Rb, Sr, and Zr clearly separates Franz Valley from Annadel, Borax Lake from all others, and the four possible unknowns from each other and from Napa Valley (FIG. 6). The former is critical because few archaeologists have ever recognized Franz Valley obsidian in archaeological contexts (Jackson 1986; Lightfoot and Silliman 1997; Psota 1994). Furthermore, the tightness of the ratios for Annadel serves as justification for classifying as part of that source the two artifacts in Figures 4 and 5 with question marks that otherwise have ppm values too high or too low for average concentrations detected here and for published concentrations reported elsewhere (Jackson 1986, 1989). The only artifact that may subtly indicate a different geological source is the questionable Napa Valley sample that seems to fall outside the main cluster in both raw concentration and ratio plots. Future regional characterization studies may reveal this outlier to be part of another obsidian source, but I have no reason to propose that here since the ratio evidence suggests it may very well belong to Napa Valley.

The six known source areas are located in the North Coast Ranges (FIG. 7). Four sources—Annadel, Borax Lake, Mt. Konocti, Napa Valley—are those commonly identified in regional sites. Not surprisingly given the site location, two sources dominated the subassemblage in relatively equal proportions (TABLE 1): Napa Valley at 44.8% (107 artifacts) and Annadel at 44.4% (106 artifacts). The Napa Valley source sits roughly 35 km NE of Petaluma and includes several collection and quarry areas as well as secondarily-deposited material north and west of Petaluma near Santa Rosa and along the Napa River (Jackson 1986: 54–57, 1989). The primary Annadel source lies 23 km north of Petaluma, but its products also occur in secondary deposits along Sonoma Creek to the east (Jackson 1989: 83). Artifact types for Napa Valley and Annadel samples in this collection included both tools and flake debris.

Unknown 1, n=1		*Unknown 2, n=2*		*Unknown 3, n=2*		*Unknown 4, n=2*	
μ	σ	μ	σ	μ	σ	μ	σ
1232.2	–	883.9	89.4	1028.8	5.7	642.8	105.9
(–)		(820.7–947.1)		(1024.7–1032.8)		(567.9–717.7)	
188.0	–	263.9	85.3	170.8	4.5	235	4.3
(–)		(203.5–324.2)		(167.6–173.9)		(231.9–238.0)	
12,739.5	–	10,837.1	1240.3	11877.3	92.5	8742.6	139.7
(–)		(9960.0–11,714.1)		(11,811.9–11,942.7)		(8643.8–8841.3)	
37.3	–	37.5	0.4	33.9	0.6	25.4	1.6
(–)		(37.2–37.8)		(33.5–34.3)		(24.3–26.5)	
228.9	–	186.9	7.5	187.4	4.0	451.6	0.5
(–)		(181.6–192.2)		(184.6–190.2)		(151.3–151.9)	
16.7	–	15.8	1.4	20.1	1.6	9.1	0.7
(–)		(14.8–16.8)		(19.0–21.2)		(8.7–9.6)	
34.2	–	51.6	5.3	40.6	0.8	47.0	2.1
(–)		(47.8–55.3)		(40.0–41.2)		(45.5–48.5)	
211.9	–	135.0	6.8	237.3	3.0	123.6	5.5
(–)		(130.3–139.8)		(235.2–239.4)		(119.7–127.4)	

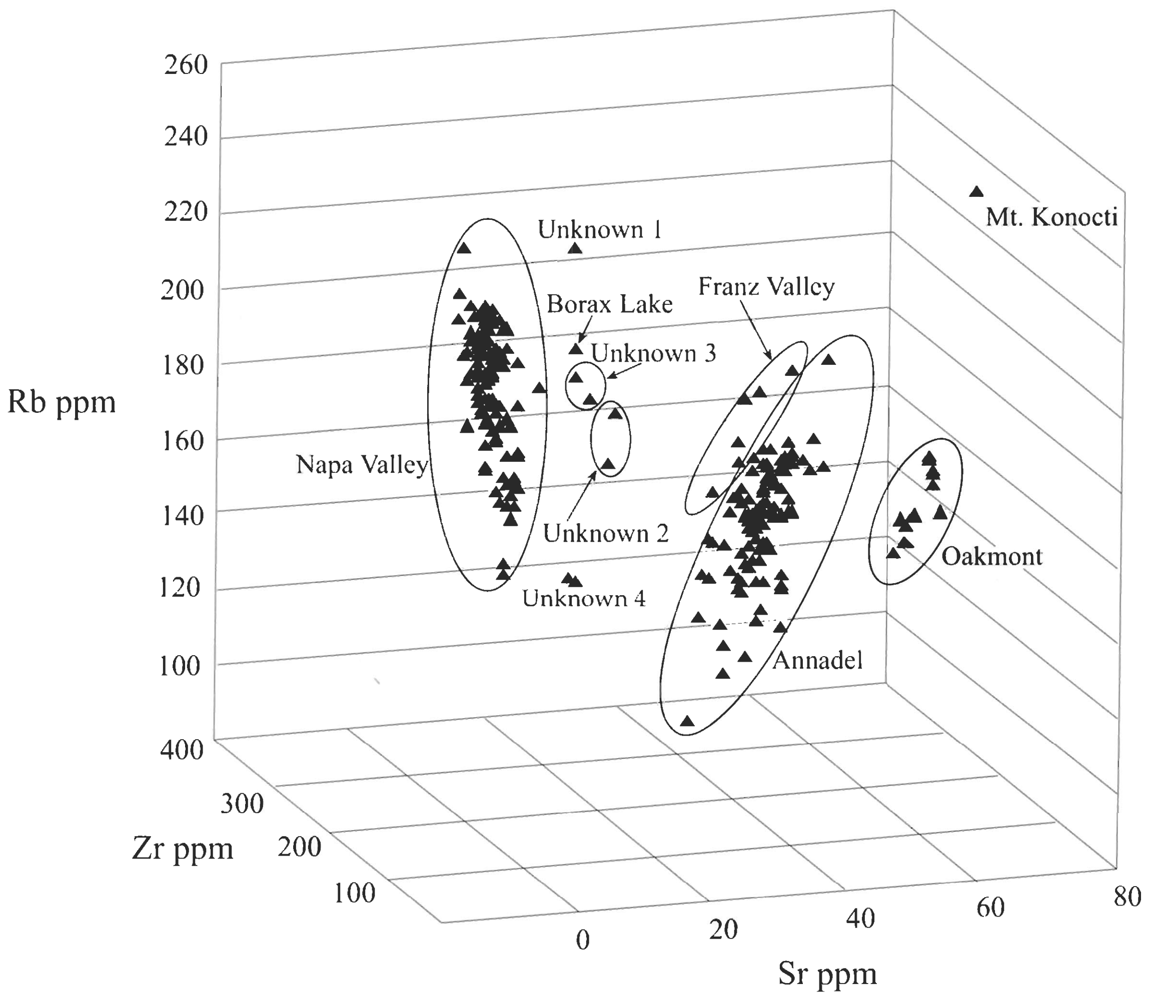

Figure 3. Three-dimensional plot of Rb, Zr, and Sr ppm values. Ellipses are for visual demarcation only; they are not statistically derived. Superposition of symbols creates the appearance of fewer than 239 samples.

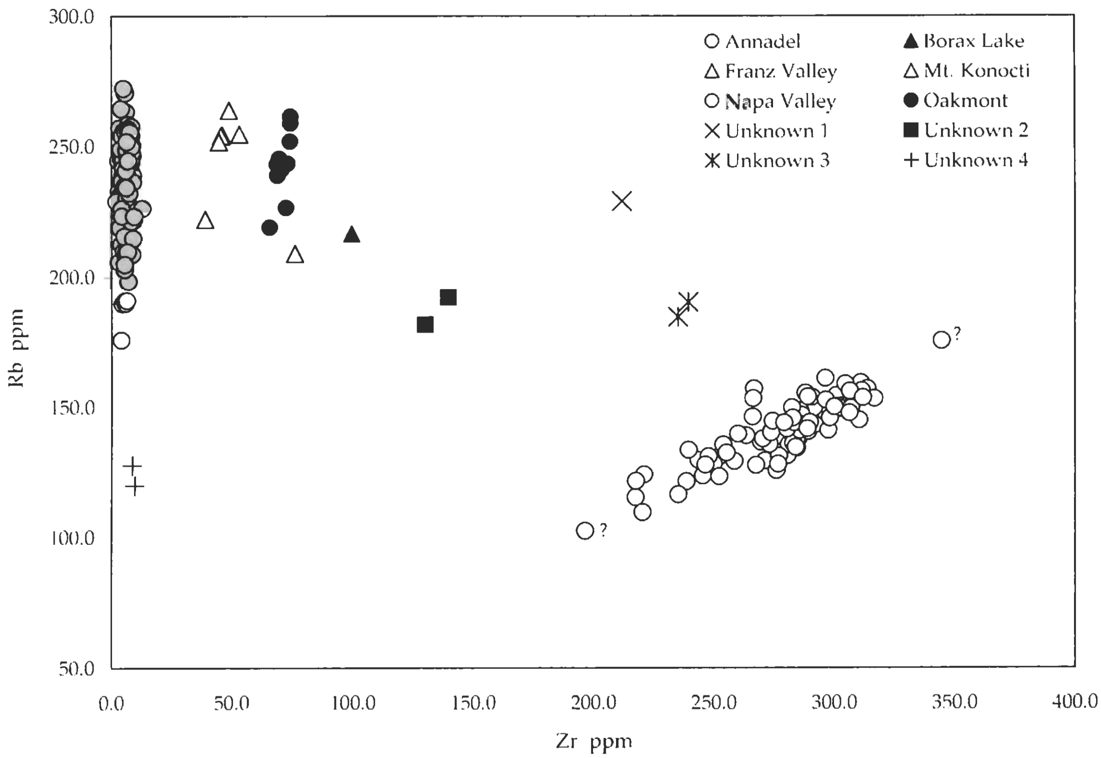

Figure 4. Bivariate plot of raw Rb and Zr values. Symbol superposition creates the appearance of fewer than 239 samples.

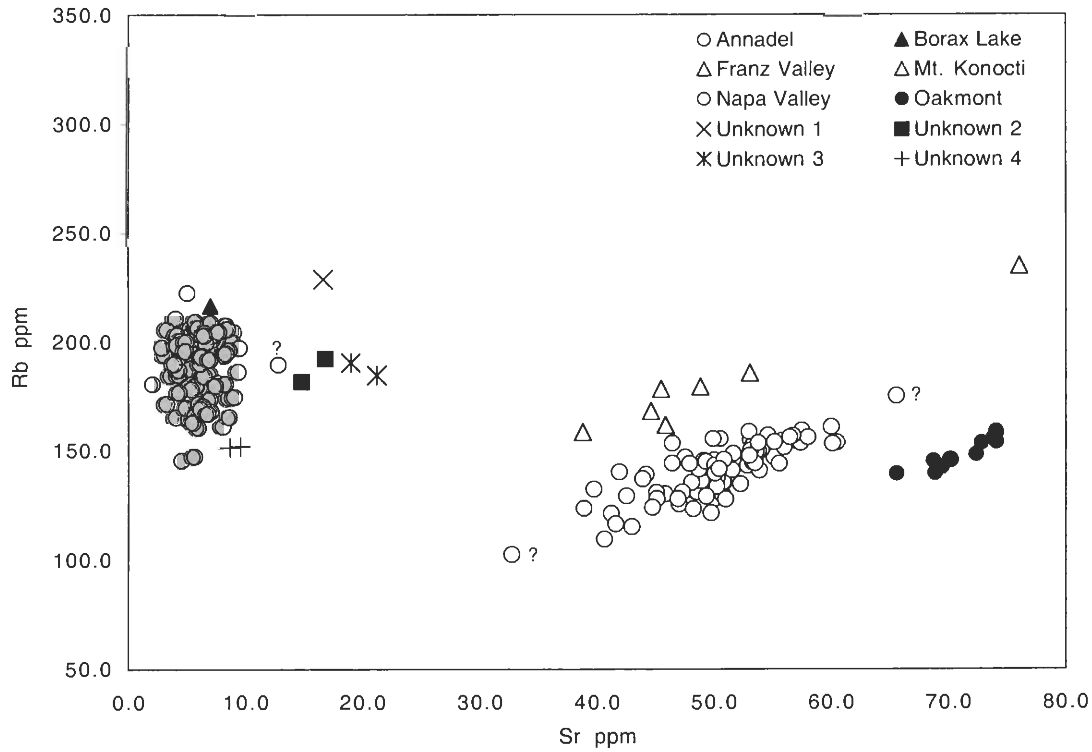

Figure 5. Bivariate plot of raw Rb and Sr values. Symbol superposition creates the appearance of fewer than 239 samples.

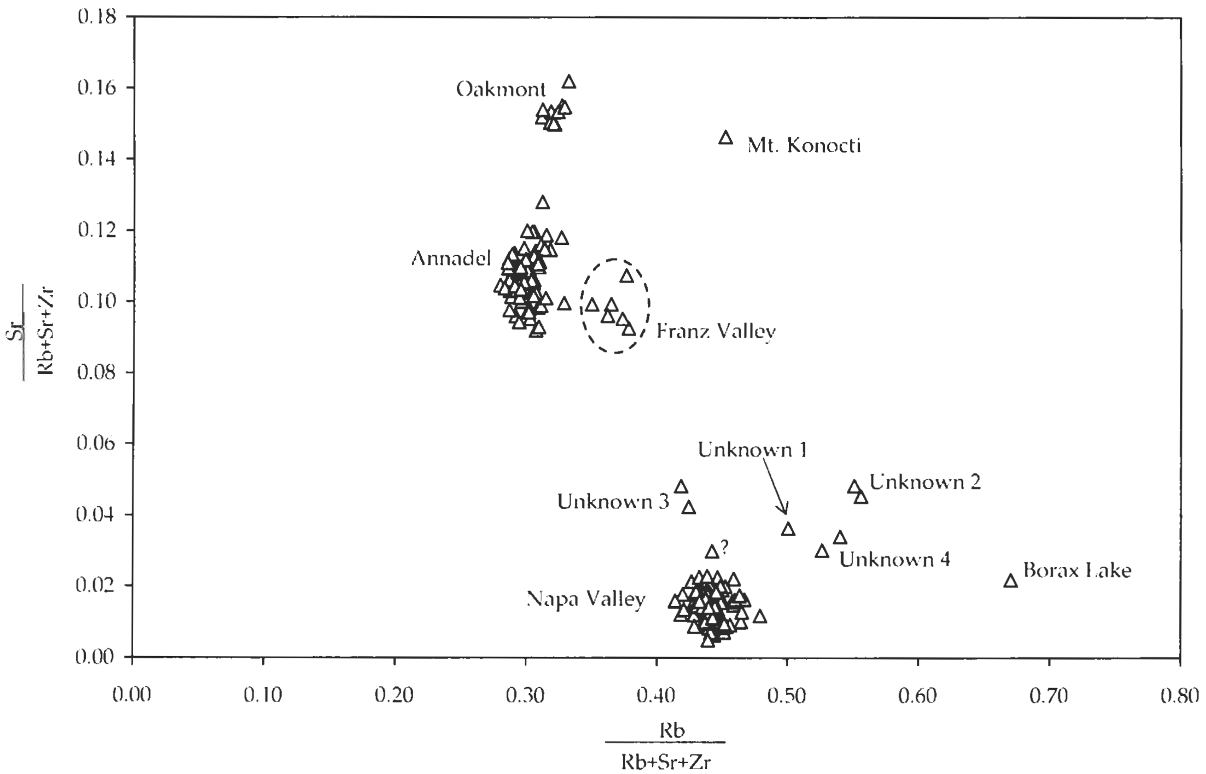

Figure 6. Plot of the ratio of Sr and Rb to the sum of ppm values for Rb, Sr, and Zr. Superposition of symbols creates the appearance of fewer than 239 samples.

The other sources occur as 4.6% for Oakmont (11 artifacts), 2.5% for Franz Valley (six artifacts), and less than 1% for Mt. Konocti (one large flake), Borax Lake (one corner notch projectile point), and each of the four seemingly unique unknowns (seven artifacts). Both Mt. Konocti and Borax Lake sources are located near Clear Lake about 80 km north of Petaluma. Artifacts made of material from Franz Valley, a source located approximately 37 km north of the Petaluma Adobe, number only six (2.5%), including one virtually complete projectile point and five flakes and shatter pieces. Unlike the intensive pre-contact use of Annadel and Napa Valley obsidian, Franz Valley seems to have been used by California Indians primarily in sites near the source and its non-quarry secondary deposits, according to the only study ever devoted to examining its distribution (Psota 1994). To date, only a few sites outside this range have produced Franz Valley artifacts (Jackson 1986: table 2; Lightfoot and Silliman 1997), perhaps due in large part to the sourcing methods discussed in more depth below. Interestingly, one of the six pieces sourced to Franz Valley was a projectile point, a notable find given that Jackson (1986) discovered only three Franz Valley projectile points out of 1126 from Late Period sites across this region. All occurred at a site (CA-Mrn-307) SW of the Petaluma Adobe in association with one Borax Lake projectile point (Jackson 1986: 84).

The one core, eight flakes and flake shatter, and two pieces of angular shatter of Oakmont obsidian are enigmatic because, to the best of my knowledge, no one has ever recognized this source in archaeological contexts. The source was named in Silliman (2000b) based on three samples (Oak10, Oak13, Oak20) previously collected and geochemically analyzed by Jackson from Sonoma Volcanics deposits near Oakmont (Jackson 1986: table A1: 19) and then re-identified as a distinct group after finding similar artifacts in the Petaluma collection. Oakmont obsidian can be found in Glen Ellen Formation deposits less than 3 km SE of Annadel, but the exact source is unknown.

In addition, four of the ten sources recovered in the Rancho Petaluma excavations are unknowns. The unknowns include flakes, flake shatter, angular shatter, and an unflaked nodule, but no formally-defined tools. The presence of debitage rather than tools suggests fairly local acquisition rather than trade. As noted above, geochemical profiles for all known sources in western North America, including unknowns reported in Jackson's (1986) study of northern California obsidians, were consulted before labeling these specimens as unknowns, and I tentatively con-

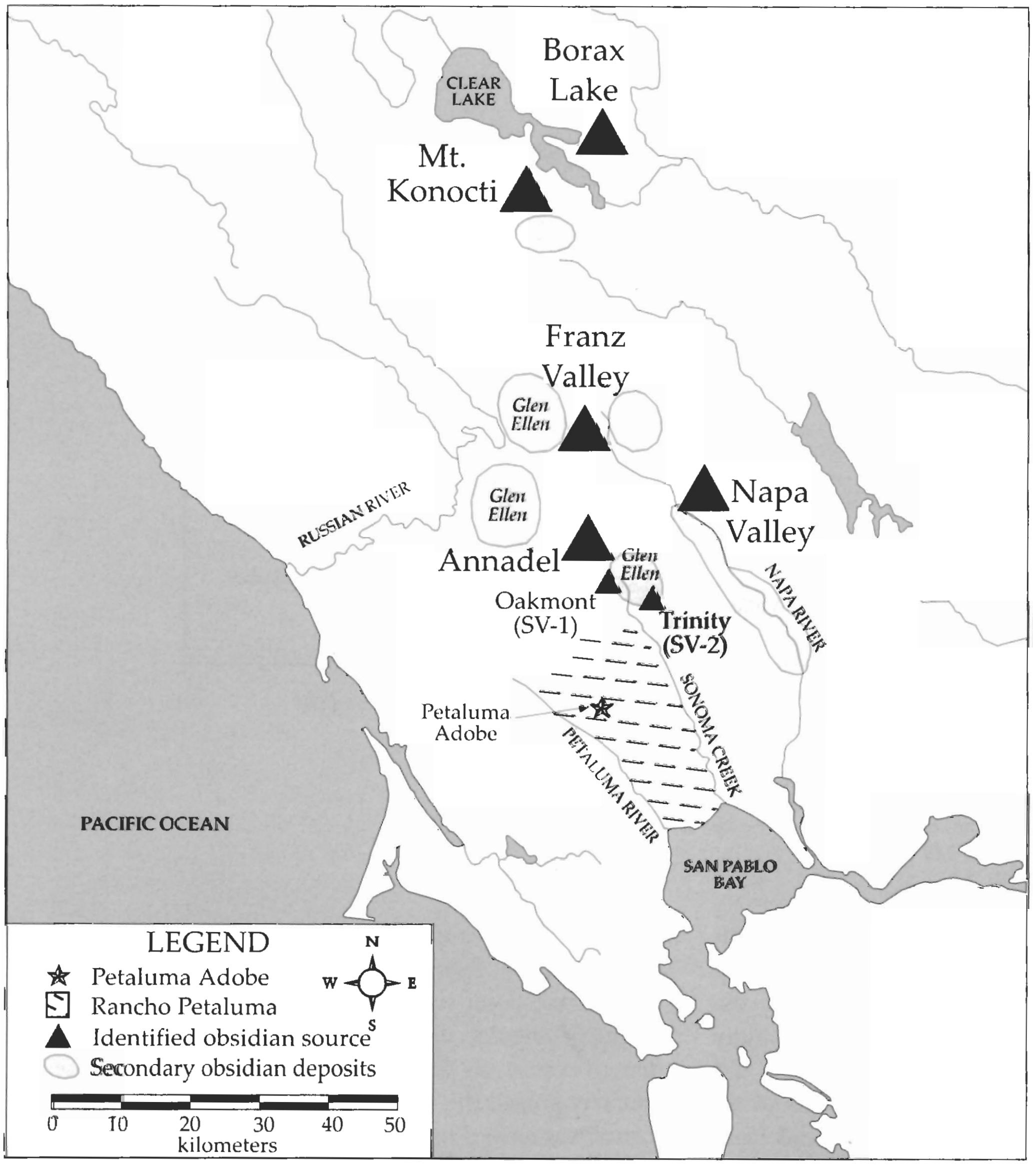

Figure 7. Map of relevant known obsidian sources and their secondary deposits in the southern North Coast Ranges. Smaller sources reported by Jackson (1986) but not recovered in excavations at CA-Son-2294/H or CA-Son-363/H are omitted.

sider these to be four distinct source profiles. To rule out instrument error and data unreliability, I reanalyzed each unidentified sample at the University of California, Berkeley, and Craig Skinner (personal communication, 2000) analyzed a sample of the unknowns with similarly-arrayed EDXRF parameters and found comparable signatures.

As well as pointing toward trade and procurement issues, the EDXRF data from this project underscore the need for more obsidian source characterizations and identifications. Studies in California (Hughes 1994) and other parts of the world (Braswell and Glascock 1998) have revealed that archaeologists need better control over intra-source variability, not only for refining source identifications, but also for applying obsidian-hydration rate equations. Eerkens and Rosenthal (2004) demonstrate this well for the Coso Volcanic Field in California. Despite Jackson's (1986, 1989) monumental work on geochemical characterizations of the known sources in northern California and his attention to possible subsources, no one has yet followed up with more intrasource sampling and mapping of Napa Valley, Annadel, Borax Lake, Mt. Konocti, Franz Valley, or any of the other smaller known sources. The unknowns reported here and in Jackson (1986) point to that deficit.

Obsidian Dating

Methods

Before turning to analytical specifics of the obsidian-hydration analysis, it is worthwhile to situate obsidian-hydration analysis in its regional context. Early research in California produced hydration rate equations for some North Coast Range sources (Clark 1961; Ericson 1977; Michels 1982), but the studies were fraught with difficulties (Origer 1987: 54–55) and are incompatible with revised typologies (Bouey and Basgall 1984: table 6). Currently, there is only one published, useable diffusion rate equation for Napa Valley and Annadel and none for Mt. Konocti, Borax Lake, Franz Valley, the newly-named Oakmont source, or the unknowns. Correlating obsidian rim readings to a small number of radiocarbon dates, Origer constructed an empirical diffusion curve for the Napa Valley and Annadel sources: $T = 153.4\ x^2$ (Napa) and $T = 184.6\ x^2$ (Annadel), where T = time in years before present and x = reading in microns, or μm (Origer 1987: 56). Since the effective hydrating temperature of the Petaluma area is statistically identical to that reported in Origer's study (Origer 1987: table 1), the proposed equations should be broadly applicable. Due to the influence of ambient soil temperature on hydration rates (Jones, Sheppard, and Sutton 1997; Ridings 1991), the equations must be used tentatively, however, in the absence of site-specific temperature controls.

Experimental induced-hydration research on Napa Valley, Annadel, Mt. Konocti, and Borax Lake obsidian has not yet produced viable diffusion rate equations, but Tremaine's induced-hydration experimental runs indicate that the sources seem to develop hydration rims at the same proportional rate (Tremaine 1989; Tremaine and Fredrickson 1988). Therefore, she suggests that "conversion constants" can transform one source's micron readings into another's for intersource comparisons (TABLE 3). Some archaeologists in northern California have calibrated obsidian data to Annadel (Lightfoot and Silliman 1997; Lightfoot, Wake, and Schiff 1991: 66–119) and Napa Valley (Psota 1994), but the potential ± 0.2 μm measurement error in equipment commonly used to record obsidian-hydration rims (Scheetz and Stevenson 1988) renders "conversion" of values ≤ 1.0 μm, or roughly the last two centuries, misleading. For instance, my initial conversion attempts produced spurious split peaks per source for the recent period of interest.

The discrepancy between dates produced during permutations of the diffusion formulas and conversion constants is significant, and it is extremely difficult to estimate individual error ranges without additional experimental and site-specific studies. In light of the error introduced by varying effective hydration temperatures, optical limitations, possible surface dissolution, and other factors, one response might be to discard obsidian-hydration altogether. A more positive response is to focus on broad patterns in hydration data rather than on specific hydration readings (Jackson 1984: 110). The broader pattern reveals that < 1.1 μm on Napa Valley, Mt. Konocti, and Borax Lake obsidian and < 1.0 μm on Annadel obsidian clearly indicate a date in the 19th century (Silliman 2000a: table 6.16). There is currently no way to know, however, about the development of the first micron in the unknown and newly-identified sources, but it seems unreasonable until future studies are completed to believe that these new sources would reach 1.0 μm at a rate so much slower or faster than the studied sources so as to disrupt the broad temporal pattern.

For the Rancho Petaluma samples, two different analysts in California supplied the obsidian-hydration data: Thomas Origer, who supervised the Sonoma State Obsidian Hydration Laboratory, and Kathleen Hull, who worked as an archaeologist for Dames and Moore, Inc. in Chico. Where possible, the first analyst returned six readings per cut in microns, and the second returned eight. The mean value of the six or eight readings is presented here. Both analysts selected hydration cut locations to sample the youngest flake scars. Although methods were comparable in slide preparation and use of traditional optical readings, interobserver variation existed in the samples examined by both analysts (Silliman 2000a: appendix A). Space is too limited to address comparability here, but the Sonoma State readings were used when two values were available because this laboratory could read hydration rim values on more specimens without the assessment of "no visible hydration."

Table 3. Hydration value conversions for four common sources in northern California (from Tremaine 1989: 70 and Tremaine and Fredrickson 1988).

Desired source	*Conversion*
Napa	Borax Lake × 0.79
Annadel	Borax Lake × 0.62
Mt. Konocti	Borax Lake × 0.79
Napa	Annadel × 1.30
Mt. Konocti	Annadel × 1.30
Borax Lake	Annadel × 1.61
Annadel	Napa × 0.77
Mt. Konocti	Napa × 1.00
Borax Lake	Napa × 1.27
Napa	Mt. Konocti × 1.00
Annadel	Mt. Konocti × 0.77
Borax Lake	Mt. Konocti × 1.27

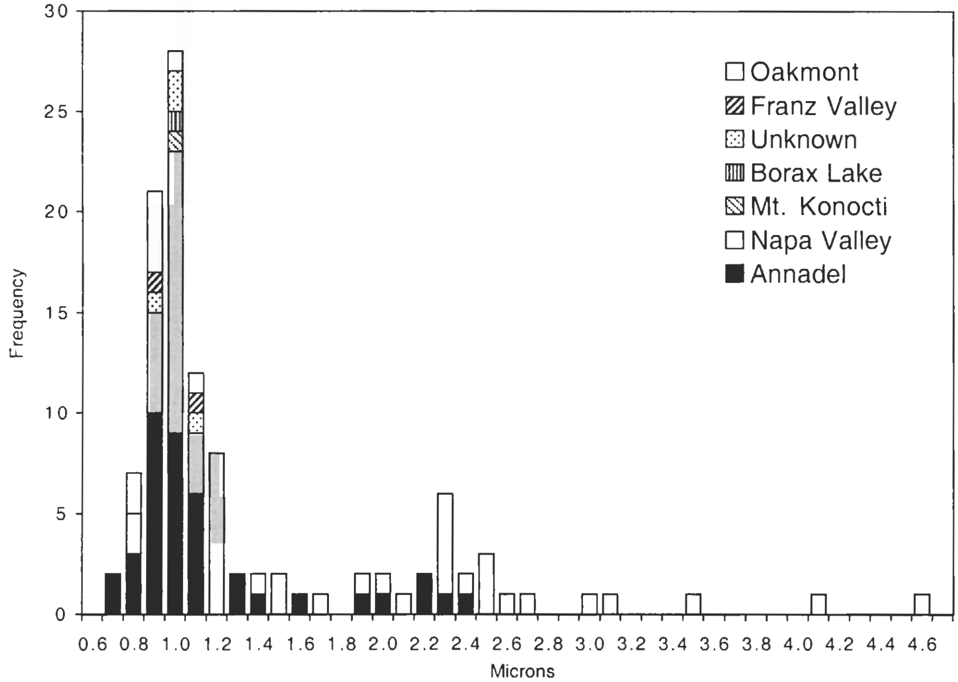

Figure 8. Frequency distribution of obsidian-hydration data per source for 111 artifacts.

Results

A total of 151 samples (63.2%) of the 239 EDXRF artifacts were selected for obsidian-hydration analysis. The protocol was to sample artifacts in percentages closely matching their frequency in the sourced collection and to cover a multitude of lithic types such as flakes, debris, tools, and cores. Since the EDXRF sample had already been chosen to maximize representation from multiple proveniences and to avoid undue bias toward potentially older or younger deposits, samples were drawn from the sourced collection only with respect to their technological type and not to their excavated context, except to insure that all major excavation loci had good representation. To refine the sampling, I sought to maximize information on underrepresented sources such as Franz Valley, Oakmont, and the unknowns since these appeared to be the most intriguing in the sourced data set, a protocol that increased their relative sample percentages (TABLE I). The total submitted for hydration analysis included 36 tools and tool fragments and 115 artifacts categorized as flakes, debris, and cores. After analysis, two obsidian-hydration rims were rejected as too diffuse and variable, decreasing the total obsidian-hydration sample to 149. Excluding 38 obsidian items (5 biface fragments, 33 flakes and shatter) with no visible hydration due to their ambiguous temporal attribution, the useable obsidian-hydration readings were effectively lowered to 111, or 8.5% of the total obsidian assemblage and 46.4% of the geochemically-sourced sample.

The hydration results, combined with sourcing data, suggest two things (FIG. 8). First, the graph indicates that Mt. Konocti, Borax Lake, Franz Valley, Oakmont, and the unknown obsidians do not appear at the site until 1.1 μm or later. All obsidian artifacts sampled from earlier periods were exclusively Napa Valley or Annadel. Second, obsidian use increased gradually but intermittently over time at the site with only minor peaks in pre-contact periods. The largest peak, between 0.8 μm and 1.2 μm, is the more significant temporal feature for the study of 19th-century lithic technology. Based on the large quantity of small micron values, the normal curve comprised of the 0.8–1.2 μm readings, and the potential ± 0.2 μm measurement error involved in obsidian-hydration analysis, the peak clearly represents 19th-century occupation by California Indians at Rancho Petaluma. Adding the 38 "no visible hydration" values excluded earlier would give even more weight to this trend if they are, as many argue, evidence of fairly recent knapping. I excluded them to be cautious, even though a sample of 12 "no visible hydration" readings returned by one hydration analyst were re-read or re-cut by the other with a mean of 0.9 μm (S.D. = 0.09 μm). This suggests that improvements in measurement technology may overcome some instances of "no visible hydration."

To supplement the interpretation, Figure 9 provides a

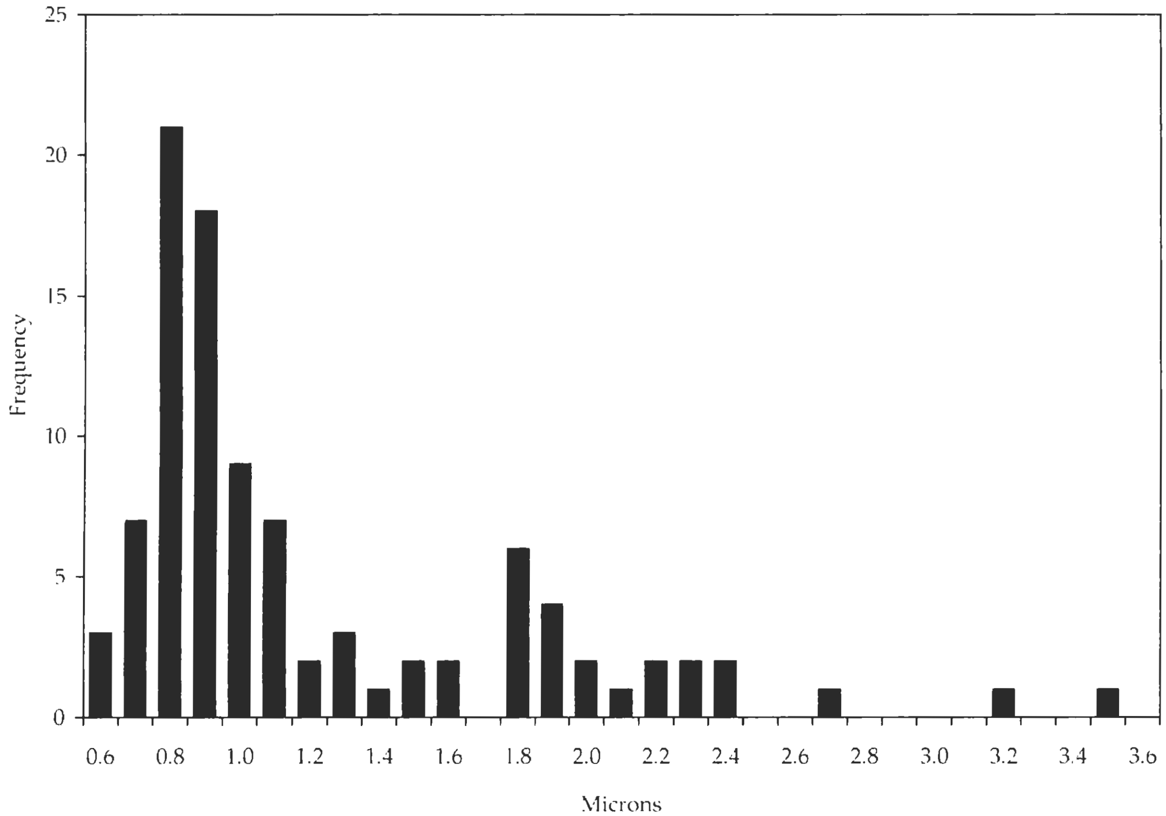

Figure 9. Frequency distribution of pertinent obsidian-hydration data for 97 artifacts converted to the Annadel source using conversion constants in Table 3.

frequency distribution of the 97 samples from Napa Valley, Annadel, Mt. Konocti, and Borax Lake standardized to Annadel using constants listed in Table 3. As there are currently no conversion constants or diffusion formulas for Franz Valley, Oakmont, or the unknown obsidian, they are excluded. Since the source conversion method is problematic for the 18th and 19th centuries for reasons outlined above, this graph suggests a tentative permutation. The result, however, is remarkably similar to, if not even more convincing than, Figure 8 at the "historical" end of the hydration distribution.

In addition to the seemingly normal curve arching over an unequivocal historical mean micron value of 0.99 μm (raw data, n = 80, range = 0.7–1.3 μm) or 0.90 μm (standardized "Annadel" data, n = 70, range = 0.6–1.3 μm) corroborating evidence tightens the argument for attributing the entire peak to the 19th century. As Braswell noted in his re-analysis of obsidian-hydration dates from Copán in Mesoamerica, "statistically it certainly makes great sense to exclude dates from either extreme of the distribution, unless they can be independently demonstrated to be valid" (Braswell 1992: 137). Whereas Copán researchers can demonstrate the validity of these tail-end dates and the inappropriateness of assuming a normal distribution for their hydration rims (Webster, Freter, and Rue 1993: 313–315), evidence for CA-Son-2294/H suggests that no such independence is warranted and that these are likely to be statistical outliers of a normal distribution rather than meaningful dates (Silliman 2000a: 222–223). That is, archival accounts suggest that the Petaluma area had emptied of indigenous communities as a result of missionization in the early 19th century before the establishment of Rancho Petaluma and that no Native American village sites existed in the expanding area of Petaluma city in the latter decades of the 19th century after the demise of the California rancho operation.

Discussion

The geochemical sourcing and obsidian-hydration data illuminate the issues, noted earlier, of site chronology, procurement, and trade. These issues dovetail with broader concerns in research methods in western North American archaeology.

Site Chronology

As expected, the obsidian-hydration data offer temporal insights into the Rancho Petaluma lithic subassemblage and the site as a whole. At a basic level, the study identifies pre-contact artifacts in the historical rancho deposits, perhaps as part of an underlying lithic scatter. This finding is critical because no other lines of evidence point to multiple occupations. No prehistoric features were located, and no significant stratigraphic breaks mark a pre-contact–post-contact transition. Furthermore, 19th-century mass-produced goods and organic remains occurred in association with almost all lithic debris. These factors weigh against assigning particular lithics as intrusive or reused in historical deposits based on context alone.

Although pre-contact artifacts undoubtedly entered historical deposits through bioturbation or accidental incorporation, the evidence suggests that recycling may account for many of these artifacts in the Rancho deposits. Despite the failure of three projectile points to reveal an additional hydration rim dating to the 19th century after being selected for re-analysis on younger flake scars, two artifacts in the original analysis revealed artifact reuse with bands of 0.9 μm (Napa Valley) and 1.0 μm (Annadel) juxtaposed with readings of 1.6 μm and 1.9 μm, respectively. In addition, no unequivocal pre-contact deposits or features were uncovered, even at depths of 0.6–0.7 m below the surface, and no significant, if any, correlation exists between hydration rim width and depth in different excavation loci (R^2 = -0.14 to 0.06). This suggests that pre-contact obsidian entered historical deposits via cultural or natural agents. Despite the obvious bioturbation, cultural agents are just as likely to be responsible.

Gravel and cobble fluvial surfaces at the base of several historical contexts provided a fairly impenetrable layer to burrowing that might have otherwise introduced older lithic materials into near-surface deposits. In other words, obsidian artifacts with "older" rims were found alongside glass bottle sherds, glass beads, metal artifacts, and fragile fish vertebrae and charred seeds, but were positioned above layers of cobble and gravel. To further examine this possible source of contamination, I selected an excavation locus, the Midden Trench (Silliman 2000a), with the least amount of fluvial underlayment to test the expectation that such an area should show more "pre-contact" obsidian artifacts if bioturbation were responsible for deposit mixing. This area had the most evidence of gopher disturbance and the least number of cobbles, but unlike other loci, it contained no obsidian artifacts unambiguously related to pre-contact times (n = 37, ≤ 1.2 μm, mean = 1.0 μm, median = 1.0 μm, S.D. = 0.1 μm). That is, the site locus unambiguously relates to the colonial period, a discovery that strengthens the dating of the entire assemblage since the midden contained 34% of all hydration readings in the analyzed sample and, therefore, should have improved the chances of catching rarer "pre-contact" obsidian.

In addition to contextual and stratigraphic information, the obsidian-hydration results provide strong evidence that the lithic assemblage is predominantly post-contact. A full 70.3%, or 78, of all analyzed artifacts date to the historical peak at ≤ 1.2 μm. Although physical associations between obsidian artifacts and material culture manufactured during the 19th century offer the most convincing support for stone tool use in that century, obsidian-hydration data provide the welcome indication that the site is not completely mixed and that the lithic materials in the historical deposits are not a fluke of post-depositional processes. Including the "no visible hydration" specimens, arguably the result of relatively recent flaking, further strengthens the argument for 19th-century obsidian use.

With chronology controlled, the hydration and sourcing data serve as a window into indigenous practices at Rancho Petaluma. The large peak in small hydration values signifies a notable increase in obsidian use and occupation intensity during the 19th century. In contrast to the low-intensity pre-contact use of the Adobe Creek floodplain, a larger Native American population lived there in more permanent ways in the 19th century. Not only is there a substantial increase in obsidian use, but also the obsidian artifacts are associated with unequivocal residential debris rather than with dispersed site use. Native individuals made or acquired projectile points, bifaces, and flake tools, and the variety of debitage and cores verifies that some manufacturing took place on-site (Silliman 2003). In fact, 53.0% of all obsidian flakes and manufacturing debris had a hydration rim ≤ 1.2 μm in width, but only 13.9% of tools fell below this threshold. The site was no longer a temporary camp as it may have been in pre-contact times; it was a location for full-scale stone tool production and use and a major habitation site linked to the Mexican-Californian rancho. The various obsidian sources represented in the lithic collection indicate that Native people who lived and worked at Rancho Petaluma maintained exchange relations off the rancho or procured obsidian on trips away from the colonial work and residential center. They also picked up and reused older stone tools that they discovered in or on the ground, perhaps exposed during the digging of trash pits, excavation of adobe foundation walls, and shallow plowing of rancho agricultural fields.

Procurement and Trade

Source assignments are an intriguing aspect of the obsidian data. At no time in the pre-contact occupation of the site did individuals use obsidian from any sources other than Annadel and Napa Valley. The prevalence of Annadel and Napa obsidian is common to the region (Jackson 1986), and the pre-contact record of CA-Son-2294/H and the nearby CA-Son-363/H (Petaluma Adobe) suggests that individuals living on or visiting the Adobe Creek floodplain did not use the Annadel source area until roughly 2900 years ago. Only in the 1800s and in conjunction with the establishment of Rancho Petaluma did individuals living on-site obtain obsidian from Mt. Konocti, Borax Lake, Franz Valley, Oakmont, and the unknown sources. The presence of 10 different obsidian sources at a single site is currently unprecedented for an archaeological site in the greater San Francisco Bay area. Sites in the region tend to contain little more than Napa Valley, Annadel, Borax Lake, Mt. Konocti, and sometimes Franz Valley obsidian, with their relative percentages a function of social relations and geographical proximity (Fredrickson 1989; Jackson 1989). In addition, one piece of flake shatter found in the basal construction fill of the nearby Petaluma Adobe that I assigne to the archaeologically-rare Trinity source in the Sonoma Volcanics (FIG. 7) further accentuates the Rancho Petaluma case, particularly when considering that this artifact also sported a 0.9 μm hydration rim and tends to occur in collection localities similar to Oakmont (see Jackson 1986: 53–54).

The pattern suggests a potential shift in 19th-century obsidian procurement strategies. Possible explanations might include California Indians from different homelands living in the Petaluma area during the rancho period, individuals from villages far afield rotating through the colonial center on seasonal rounds, or rancho laborers altering their trade relations with outlying groups. The advent of Oakmont and the unknown obsidians may indicate the latter, since these are sources never before recognized in archaeological collections. The presence of debitage, core fragments, and nodules from these rare sources means that individuals crafted tools at this location, possibly after acquiring the raw material locally. Perhaps the influx of new people and the aggregation of them on the rancho property ushered in an intensified use of the local lithic landscape.

Implications for Future Reserach

I offer this interpretation of trade and procurement not as a final word on the local or regional patterns of obsidian use in 19th-century northern California, but as a hypothesis for further testing. The archaeological support for it is relatively strong, but caution is required since the reported pattern could be a function of sample size or sourcing methods. On the statistical side, the exciting discovery of a high proportion of historical obsidian artifacts is a mixed blessing—that is, higher quantities of 19th-century obsidian also produce a greater statistical probability of detecting more obsidian source diversity. The rare sources of Franz Valley, Oakmont, and the pieces of unknown origins must await discovery in pre-contact assemblages that are of sufficient sample size to detect infrequent sources. Additional excavation at or near the Petaluma Adobe State Historic Park will be crucial for this effort.

The sourcing aspect casts a somewhat longer shadow over archaeological interpretation. My analyses diverged from the standard practice of provenance studies in the southern North Coast Ranges of California in that I opted for geochemical EDXRF rather than macroscopic visual sourcing. The implication is that the lack of these newly-discovered 19th-century obsidian sources in pre-contact sites may be as much due to visual sourcing attribution errors than to any past reality. Unlike many areas of the world, obsidian sources in the southern North Coast Ranges of California possess macroscopic attributes that allow relatively reliable source identifications through visual inspection (Jackson 1986: 76; Origer 1987: 194–197; Psota 1994: 40–47). Much like that recently proposed for Guatemalan obsidians (Braswell et al. 2000), the visual sourcing protocol has been a cost-effective method of generating source data on large collections of northern California obsidian for many years, and it has proven even more reliable when samples of visually-sourced obsidian artifacts are submitted for EDXRF analysis to verify sources. The data presented here suggest, however, that visual sourcing in northern California is hampered, not by a lack of visually-distinguishable sources or by a lack of skilled visual analysts, but by a lack of intensive regional identification of all possible obsidian sources. Without having identified and analyzed the range of actual obsidian sources, archaeologists are destined to macroscopically assign all obsidian to known sources because new sources will be exceptionally difficult to recognize.

Larger questions loom as a result. Are the pieces of unknown origin in the Rancho Petaluma sample actually from localities within known sources, or are they from new sources? Were these unknown obsidians easily picked up by knappers alongside "known" obsidians such as Annadel and Napa Valley in secondary source environments like that of the Glen Ellen Formation north of Petaluma, such that individuals in the past made no distinction whatsoever between stream nodules (i.e., "sources") in such procurement areas? Answers will come only from more regional sampling and careful differentiation of subsources. Are visual sourcing efforts placing an unrecognized range of obsidian diversity into predefined and expected categories based on traditional assumptions and insufficient obsidian characterization studies? This is likely true, given that my own EDXRF analysis detected the rare and unknown sources in the Rancho Petaluma study that a trained visual analyst had not detected in an earlier source assignment effort of the same artifacts during hydration analysis. If there are many misidentified or unknown obsidian sources and subsources, what are the ramifications for hydration rates? Clearly more work is needed on this front since previous studies would predict the effects to be consequential, although a recent assessment of Coso obsidian in SE California suggests that subsource differentiation may not refine obsidian-hydration analysis in some geological source areas (Eerkens and Rosenthal 2004: 22). Finally, how much error is acceptable in obsidian source assignments, and how important is it to know source attributions for specific artifacts versus source percentages for artifact collections (e.g., Braswell et al. 2000; Silliman 2000b)? The answers are project-specific and typically based on budgets and research design, but the gaps in regional archaeology as a result of different sourcing success rates compromise the fine-grained questions that archaeologists may seek to answer with obsidian. Certainly, a protocol that carefully combines visual sourcing for a complete collection with nonrandom geochemical sourcing for a select sample may be a fruitful compromise (Braswell et al. 2000; Meighan 1984: 226), but the source landscape must be well understood geochemically and visually beforehand.

Conclusions

My analysis suggests that obsidian studies have much to offer historical archaeology. Obsidian sourcing and hydration dating have refined what can be learned about the 19th-century Rancho Petaluma site and offered critical new insights not available from traditional historical archaeology. The issues addressed—site chronology, stratigraphic integrity, trade, and lithic practices—are concerns that historical and pre-contact archaeologists in North America both share.

The study shows the benefits of using obsidian hydration as a complementary line of research inquiry at historical sites. Given the multiple and often intractable variables that affect the formation of hydration rims, archaeologists should not use obsidian hydration as an independent chronometric technique at historical sites with associated documentary records and mass-produced artifacts. Even archaeologists working on pre-contact times have a difficult time using obsidian hydration in this manner. Obsidian-hydration data can help answer some questions about chronology, stratigraphic integrity, and lithic use at historical sites, however, when compiled in a large data set and not used only as individual hydration readings. For the Rancho Petaluma case, hydration data filled gaps in the pre-contact record, identified pre-contact artifacts in otherwise historical deposits, tested the possibilities of reused ancient obsidian, and indicated a wealth of 19th-century lithic materials at the Rancho.

At the same time that obsidian studies make an important contribution to historical archaeology, post-contact and colonial sites can offer a unique contribution to obsidian studies. As demonstrated in the Rancho Petaluma case, the obsidian-hydration values hovering around a relatively well-known and short period of historical occupation further affirm the need to focus on large numbers of obsidian-hydration readings and to be wary of single values. The reason stems primarily from the inherent error of ± 0.2 microns in traditional optical measurements, which could obscure the otherwise finer temporal distinctions already known from documentary and other material culture sources. In addition, this 19th-century site has confirmed that archaeologists still have much to learn about the first micron of hydration development and about the rate of hydration for different sources. Plugging some of the smallest hydration values discovered in this study into the current diffusion formulas for the southern North Coast Ranges produced dates that were inconceivably late, indicating that however solid the empirical fit may be for calendrical dates further back in time, a different situation could hold for the last 100–200 years as the first micron develops. Historical archaeologists may hold the key to sorting out that initial hydration rim.

Although obsidian studies have a unique role to play in the archaeology of the last few centuries in North America and many other places by providing complementary evidence, they do not offer a problem-free archaeometric methodology. There is little consensus about the efficacy of obsidian hydration, although many archaeologists involved in this type of research are relatively optimistic about obsidian-hydration dating when the variables are appropriately controlled (Freter 1992, 1993; Hull 2001). The same is true for obsidian sourcing. Archaeologists hold strong, but often unpublished, feelings about whether geochemical methods should replace visual sourcing in the Mediterranean, Mesoamerica, and California and about what analytical chemical techniques are the most appropriate. This study has touched briefly upon that debate. Such discrepancies and disagreements have a significant impact on the viability of obsidian studies in historical periods, but the influence can spread in both directions. Historical archaeologists may be able to contribute to, rather than simply utilize, obsidian studies, often thought to reside only in the toolkits of prehistorians.

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