

REDUCTION STRATEGIES AND GEOCHEMICAL CHARACTERIZATION OF LITHIC ASSEMBLAGES: A COMPARISON OF THREE CASE STUDIES FROM WESTERN NORTH AMERICA

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Based on a simple model of lithic procurement, reduction, and use, we generate predictions for patterns in source diversity and average distance-to-source measurements for flaked stone assemblages left behind by small-scale and residentially mobile populations. We apply this model to geochemical data from obsidian artifacts from three regions in western North America. As predicted, results show markedly different patterns in the geochemical composition of small flakes, large flakes, and formal tools. While small flakes and tools tend to have greater source diversity and are on average farther from their original source, the large flake assemblage is composed of fewer and closer sources. These results suggest that a failure to include very late stage reduction (e.g., pressure flakes) and microdebitage in characterization studies may bias interpretations about the extent of residential mobility and/or trade patterns because more distant sources will be underrepresented.

Basado en un modelo sencillo de obtención, reducción y uso líticos, generamos predicciones para patrones de diversidad de fuentes y medidas de media-distancia desde las fuentes de colecciones de piedras talladas dejadas por poblaciones ambulantes. Aplicamos este modelo a los datos geoquímicos reunidos de artefactos de obsidiana procedentes de tres regiones norteamericanas-occidentales. Como era previsto, los resultados muestran patrones notablemente distintos en la composición geoquímica de las lascas pequeñas y grandes y de herramientas formales. Mientras las herramientas y lascas pequeñas suelen tener una mayor diversidad de fuentes y como promedio se encuentran más lejos de sus fuentes originales, las lascas grandes tienden a componerse de menos fuentes que también están más cercanas. Los resultados sugieren que el dejar de incluir reducciones (desbastes) y microdebitage (micro desechos) de las etapas finales (e.g., lascas de presión) en los estudios de fuentes, se puede sesgar las interpretaciones sobre la extensión/los límites de movilidad residencial y/o patrones de comercio porque las fuentes más lejanas quedan sub-representadas.

Over the last 40 years, determining the geologic source or provenance of stone tools and waste flakes has become standard practice in archaeological research in western North America. Provenance information is regularly used to reconstruct settlement patterns and investigate the organization of stone tool technologies, tool curation, exchange systems, territoriality, and quarrying behavior, among other topics (e.g., Basgall 1989; Bayman and Shackley 1999; Beck et al. 2002; Bettinger 1982; Bouey and Basgall 1984; DeBoer 2004; Eerkens and Rosenthal 2004; Gilreath and Hildebrandt 1997; Hall 1983;

Hughes 1994, 1998; Jones et al. 2003; Ramos 2000; Roth 2000; Shackley 1996, 1998, 2005).

Due to the relative chemical homogeneity of flows, the limited geographic range over which many source materials are typically available, and widespread prehistoric use in western North America, obsidian has been the main toolstone subjected to provenance analyses in American archaeology. However, provenance research has also targeted andesite, basalt, chert, rhyolite, steatite, and turquoise artifacts, among other raw materials (e.g., Allen et al. 1975; Bostwick and Burton 1993; Feyhl 1997; Hermes and Ritchie 1997; Jones et al. 1997;

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American Antiquity, 72(3), 2007, pp. 585–597

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Latham et al. 1992; Luedtke 1978, 1979; Malyk-Selivanova et al. 1998; Parsons 1990; Truncer et al. 1998; Waechter 2002; Weigand et al. 1977; see also Ogburn 2004). A range of analytical techniques has been used to assign geographic provenance of stone artifacts (e.g., Instrumental Neutron Activation Analysis [INAA], Inductively Coupled Plasma-Mass Spectrometry [ICP-MS], Proton Induced X-Ray Emission [PIXE], among others), but analysis by X-ray fluorescence (XRF) spectrometry has been the dominant method in North America. This popularity likely stems from the widespread availability of XRF instruments, the potential to analyze artifacts non-destructively, the relatively low cost, and historical factors (e.g., familiarity with the technique and comparability between individual artifacts and across studies). However, as discussed later, there are some potential drawbacks to relying only on this technique.

A Model of Lithic Procurement and Use

Models developed from economic theory and lithic studies can be used to predict the representation of different lithic sources among artifact classes (e.g., Bamforth 1986, 1990; Basgall 1989; Binford 1979; Kelly 1988; Renfrew 1977; Roth 2000). A commonly invoked model, based in part on the law of monotonic decay discussed by Renfrew (1977), concerns toolstone use among small-scale and residentially mobile groups of people. As such groups move across a landscape, they deplete and replenish their supply of raw toolstone in a patterned manner, leading to the deposition of artifacts of different types, sizes, and raw materials (e.g., Bamforth 1991; Basgall 1989; Beck et al. 2002; Brantingham 2003, 2006; Cowan 1999; Jones et al. 2003; Kuhn 1989; Parry and Kelly 1987; Shott 1989, 1994). Spent and broken tools are discarded and replaced with new ones as groups encounter sources of raw material on the landscape. It is at these source areas that many of the primary flintknapping activities are performed, such as core preparation, removal of cortex, and percussion flaking to produce a preform or finished artifact. Tools may be further reduced to a finished state on-site or at nearby "lithic workshops" and residential sites resulting in the deposition of smaller flakes from local toolstone sources. The tools produced from these flintknapping activities are typically removed from the pro-

duction site and curated for later use, leaving behind only waste flakes. This is especially true when toolstone sources are unevenly distributed across the landscape and people plan to visit areas known to lack significant quantities of suitable flintknapping materials.

In western North America, especially the Great Basin, where the production of bifaces was of central importance (e.g., Bamforth 1990; Basgall 1989; Gilreath and Hildebrandt 1997; Kelly 1988; Minor and Toepel 1989; Yohe 1998), the organization of these activities creates the well-known "disjunction" between core/flake and tool source profiles. This is a pattern familiar to many lithic analysts who study mobile societies. In particular, waste flakes and cores at archaeological sites are composed primarily of local raw materials, while (discarded) tools at those same sites are disproportionately composed of more exotic toolstone.

A less-studied corollary of this model, however, is the predicted disjunction between the source profiles of large and small flakes. In particular, debitage from local sources should represent all stages of manufacture, especially larger and early-stage flaking debris, while debitage from exotic sources will be restricted to small tool-maintenance debris (e.g., resharpening and rejuvenating of used or broken tools) and tool-use microdebitage (e.g., Clark 1986; Fladmark 1982; Hull 1987). Thus, the more general tool-flake disjunction mentioned above is, in fact, primarily between tools and large flakes, not all flakes. When using excavation techniques that only recover larger flakes, such as screening with 1/4 inch mesh or using characterization techniques that require larger artifacts, such as visual characterization or XRF analysis (e.g., Bettinger et al. 1984; Davis et al. 1998; Skinner 2001), size limitations will usually ensure that the more-general tool-flake disjunction will hold. Based on the model presented above, small flakes and tools may, in fact, have similar source profiles, especially if there was only minimal tool production taking place on the site.

In regions where groups of people encounter multiple sources of toolstone during their seasonal movements, a second pattern should also hold. In particular, the types of raw materials represented among large flakes should be less diverse, again representing mainly the closest raw materials, while smaller flakes and formal tools should include a

more diverse range of materials, representing local as well as more distant sources from where curated tools were carried. The strength of this pattern will be related to several factors, including the number of toolstone sources regularly visited, the average distance between lithic resources, and the length of time formal tools were curated (i.e., tool use-life).

Three Case Studies from Western North America

To test the model described above, patterns in source profiles between formal tools, large flakes, and small flakes were examined from three different areas in western North America. From south to north these areas are Sherwin Summit at the Long Valley-Owens Valley transition in central-eastern California, Mohawk Valley in northeastern California, and Bone Cave in central Oregon. Each study was initiated independently by one of the authors, but with similar overall goals in mind, that is to understand obsidian source variability and/or date sites using source-specific hydration data. In no case were artifacts selected for geochemical analysis based on color, visual appearance, or any other factor that would, to our view, obviously influence source ascription. None of the project areas was directly within an obsidian source or quarry, though all contain sites with significant numbers of obsidian artifacts. Figure 1 shows the location of the three study areas and obsidians encountered.

For each of the three case studies, artifacts were split into three categories: formal tools (including projectile points, bifaces, and formed flake tools), large flakes (including utilized flakes), and small flakes (unmodified waste flakes under 10 mm in diameter and 1.5 mm in thickness, including flake fragments, pressure flakes, microdebitage, and the like). None of these assemblages contained cores, and hence, this artifact type is not included in our analyses. Distance to source was calculated for each artifact by calculating as-the-crow-flies two-dimensional distance between the datum of the site from which that artifact was collected (based on UTM data) and the approximate center of obsidian source zones.

Formal tools and large flakes were analyzed using XRF methods in two labs: Geochemical Research Laboratories in Portola Valley, California (Richard Hughes) and Northwest Research

Obsidian Studies Laboratory in Corvallis, Oregon (Craig Skinner). All flakes under 10 mm in diameter were analyzed by INAA at Missouri University Research Reactor (MURR), Columbia, Missouri, according to the abbreviated procedure outlined by Glascock et al. (1994; Glascock 1998). XRF and INAA both provide compositional data for a range of elements (e.g., zirconium, strontium, iron, etc.) as parts per million concentrations. The use of standards ensures that the data produced are comparable between labs. Moreover, each lab has independently analyzed source samples allowing provenance ascriptions to be made based on primary data.

Typically in obsidian studies, some pieces are not attributable to a distinct source. This may be due to instrument error, the presence of chemically anomalous or "outlier" specimens from known sources, or the presence of an obsidian artifact from a source that has not yet been characterized. For purposes of comparison, unknown samples were eliminated from the analysis. This was necessary for three reasons. First, as they are not assignable to known sources, distance measurements obviously could not be calculated. Second, treating possible chemical "outliers" as unique sources would artificially inflate diversity measures. Finally, since raw data were not always available, it was not possible to track the same "unknown" sources across different studies. For example, it was unclear whether "Unknown A" in one study was the same as "Unknown 1" or "Unknown A" in another study, or if sources known to one lab were unknown to another, especially when those studies were carried out across several decades as in the Mohawk Valley case. In the Sherwin Summit and Bone Cave study there were few unknowns. The frequency of unknowns in the Mohawk Valley study was greater. As discussed below, we do not believe that omitting unknown specimens significantly skews the results.

Finally, in many areas where obsidian is available, specimens display more than one distinctive geochemical signature (e.g., Eerkens and Glascock 2000; Eerkens and Rosenthal 2004; Hughes 1986, 1988, 1989, 1994; Johnson et al. 1999; Shackley 1994, 1998). Such geochemical types or "sub-sources" often represent distinct extrusive volcanic events, separated in time but drawn from the same magma pool. Although they may have different

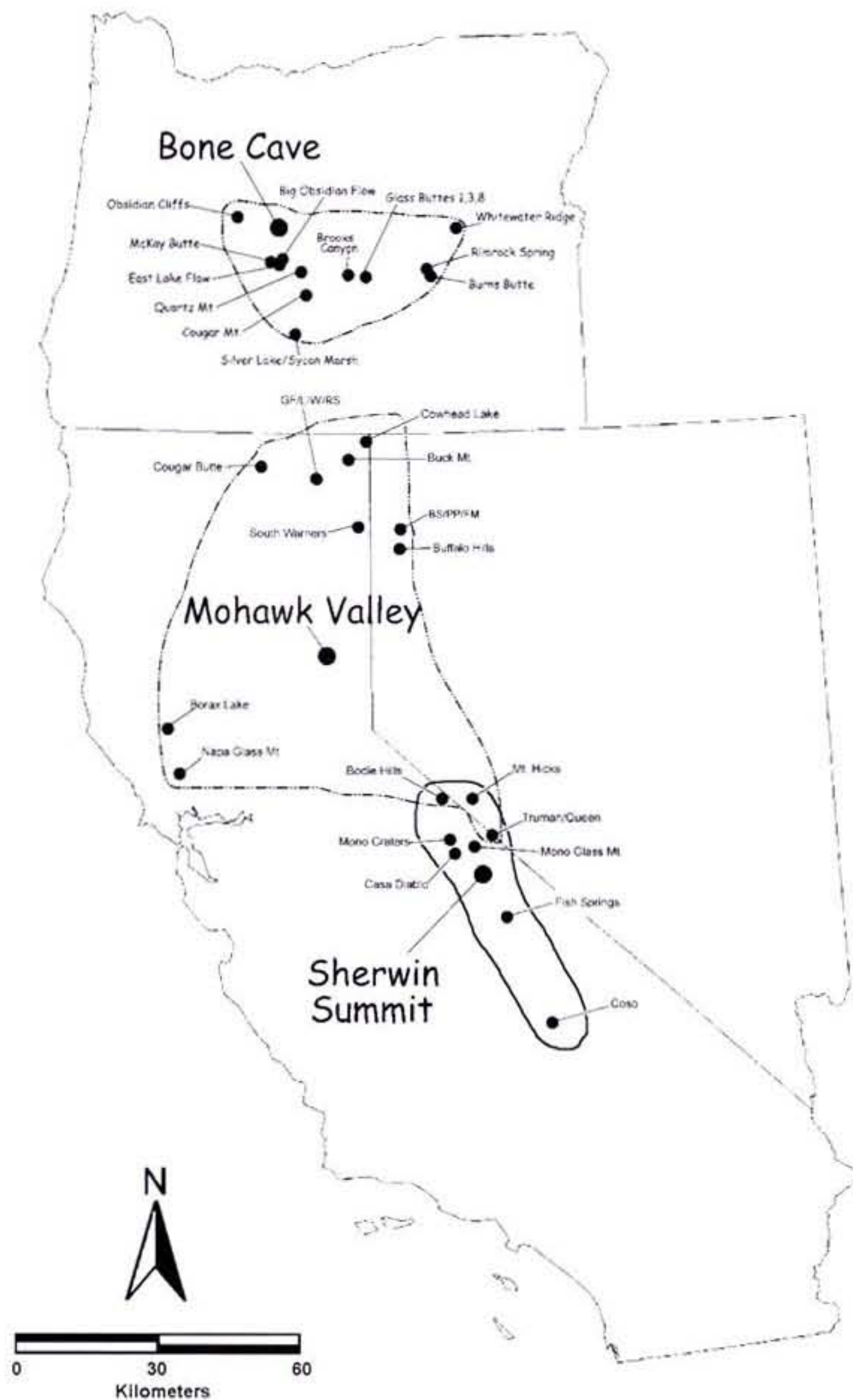


Figure 1. Location of study areas and obsidian sources.

flaking properties and be differentially preferred by flintknappers, they are obtained from the same geographic area often within a few kilometers of one another. Because we were modeling long-distance conveyance and toolstone reduction, we lumped such subsources. For example, the Casa Diablo area contains at least three distinct geochemical types, including Sawmill Ridge, Lookout Moun-

tain, and Prospect Ridge (Hughes 1994) which we lumped into a single analytical unit, namely Casa Diablo. The same is true of several sources in northwest Nevada (e.g., Hughes 1986; Young 2002) where we have combined chemically distinct obsidians from Bordwell Spring, Pinto Peak, Fox Mountain, and Hart Mountain into a single category termed BS/PP/FM, and northwest California where

Table 1. Comparison of Source Diversity by Artifact Category for Sherwin Summit.

Source Artifact	Casa Diablo	Mono Glass Mtn.	Queen	Fish Springs	Mono Craters	Bodie Hills	Mount Hicks	Coso	Totals
Formal Tools	51	16	13	5	-	-	2	-	87
Large Flakes	166	65	10	18	1	1	-	1	262
Small Flakes:									
Non-pressure	24	10	2	1	1	-	-	-	38
Pressure	7	3	7	1	1	-	-	-	19
Totals	248	94	32	25	3	1	2	1	406

we have combined Grasshopper Flat, Lost Iron Well, and Red Switchback into a single category GF/LIW/RS (see Hughes 1982; Skinner 1995).

Sherwin Summit

Sherwin Summit is located in central-eastern California on a sloping grade that separates Owens Valley, to the south, from Long Valley, to the north. The artifact sample drawn for this study comes from 14 archaeological sites located along a linear corridor, ranging in elevation between 1,400 and 2,100 m. Excavations at these sites were undertaken in 2001 by one of the authors (Eerkens) and his colleagues as part of a highway expansion project (Eerkens and King 2002). A distance of 18 km separates the two farthest sites. Analyses of flaked stone artifacts from project area sites indicate that reduction of obsidian from the two closest sources, Casa Diablo and Mono Glass Mountain (both within 30 km), into bifaces was an important part of the activities leading to the formation of these sites.

All but two of the project sites currently lie within a piñon-juniper forest on a volcanic tuff deposit, while the remaining two lie within a desert-scrub environment just below the modern piñon-juniper zone. The surrounding area is rich in obsidian, with no fewer than eight chemically distinct sources within 100 km. This is reflected in the counts of non-obsidian artifacts, which comprise less than 1 percent of the flaked stone assemblage. Obsidian hydration readings suggest nearly all the artifacts included in this study date between 2,500 and 1,000 years ago (Eerkens and King 2002).

Artifacts subjected to chemical characterization from Sherwin Summit include 262 large flakes (including 17 casual flake tools), 87 formal tools (bifaces and projectile points), and 57 small flakes. Samples of roughly equal size were drawn at random from nearly 30 discrete lithic concentrations.

For this study, small flakes were further categorized by technological attributes prior to analysis by INAA, including the identification of complete late-stage reduction flakes, shatter, and flake fragments. As discussed below, this division proved particularly useful for delineating important trends in the source distribution of smaller flakes.

All 406 artifacts were attributable to known obsidian sources. Table 1 presents the results of the characterization analyses, broken down by artifact type. Note that small flakes are broken down into "pressure" vs. "non-pressure" types. As classified by Eerkens and King (2002), pressure flakes include thin and complete or nearly complete flakes that represent the latest stages of tool reduction (i.e., tool finishing). Non-pressure pieces include primarily fragments of flakes from earlier stages of reduction, as well as non-diagnostic shatter, although we do acknowledge that it is possible to produce small complete flakes with percussion flaking.

As Table 1 shows, eight different sources are represented among the 406 artifacts. However, the two sources closest to the project area, Casa Diablo and Mono Glass Mountain, account for 84 percent of the sample. Two slightly more-distant sources, Queen and Fish Springs, account for an additional 14 percent, while the remaining four sources account for only 2 percent of the artifacts. At the same time, the table also shows that while Casa Diablo and Mono Glass Mountain account for 88 percent of the large flakes, they account for a smaller fraction of the formal tools (77 percent) and small flakes (77 percent), especially pressure flakes (53 percent). A χ^2 test on the 3x2 table partitioning artifact type by geochemical source (grouping Casa Diablo with Mono Glass Mountain and Queen with Fish Springs) is significant ($p = .02$). In accordance with our model, formal tools and small flakes are more frequently from distant sources and rep-

Table 2. Comparison of Source Diversity by Artifact Category for Mohawk Valley.

Source Artifact	Buf. Hills	South War.	BS PP FM	GF LIW RS	Cow. Lake	Coug Butte	Buck Mtn.	Napa	Borax Lake	Bodie Hills	Mt. Hicks	Queen	Totals
Formal Tools	1	3	4	3	1	1	1	-	-	-	-	-	14
Large Flakes	4	13	12	5	-	-	-	1	-	2	-	-	37
Small Flakes	14	-	8	2	-	3	1	8	2	6	3	1	48
Totals	19	16	24	10	1	4	2	9	2	8	3	1	99

Notes: Sources are, left to right, Buffalo Hills; South Warners; Bordwell Spring/Pinto Peak/Fox Mountain/Hart Mountain (BS/PP/FM); Grasshopper Flat/Lost Iron Well/Red Switchback (GF/LIW/RS); Cowhead Lake; Cougar Butte; Buck Mountain; Napa Valley; Borax Lake; Bodie Hills; Mt. Hicks; and Truman/Queen.

represent a more diverse distribution of sources, while large flakes are dominated by nearby sources.

Mohawk Valley

Five archaeological sites in the Mohawk Valley of northeastern California were included in this study, CA-PLU-130/H, CA-PLU-131, CA-PLU-226, CA-PLU-237, and CA-PLU-421 (Dreyer and Kowta 1986; Neuenschwander 1991; Waechter 2001, 2002). This region is located along the Middle Fork of the Feather River at approximately 1350 m in elevation. Unlike the Sherwin Summit area, there are no sources of obsidian in the surrounding area. The closest obsidian source is in the Buffalo Hills (formerly known as "Unknown B"), some 145 km to the northeast.

Inhabitants of Mohawk Valley made great use of high-quality basalt toolstone, which is immediately available in local moraines and the Feather River bedload. Basalt typically represents more than 90 percent of waste flakes and 70 percent of formal tools, regardless of site type or age. At the same time, obsidian was clearly an important commodity in prehistoric times and was transported into the valley in large amounts. Despite its remoteness, obsidian typically comprises 2–10 percent of waste flakes and 10–30 percent of formal tools. Prior to work by one of the authors (SAW), only XRF methods had been used to determine obsidian sources. In these earlier XRF studies, a wide range of sources from several geographic areas in California and Nevada was identified, including some of the same sources encountered in the Sherwin Summit study. INAA small-flake samples submitted to MURR by Waechter (2002) expanded the range of sources even further.

For the geochemical analyses, all artifacts large enough to be analyzed by XRF were characterized. The small-flake sample represents a complete sam-

ple of flakes from only two sites (PLU-131 and PLU-421). In total, 16 formal tools (seven projectile points, nine bifaces), 52 large flakes, and 56 small flakes analyzed by XRF and INAA were included in this analysis. Of these, two formal tools, 15 large flakes, and eight small flakes were not attributable to a known obsidian source and are not included in the analysis. Hydration analyses indicate that the vast majority were deposited after 3500 B.P. Although not specifically tabulated, the small-flake sample is believed to represent a high proportion of latest-stage tool finishing and tool maintenance debris. Table 2 shows the results of the combined characterization studies for Mohawk Valley without the specimens of unknown provenance.

Results show that more diverse obsidian sources were brought into the Mohawk Valley sites than into the Sherwin Summit sites. Even though only 99 artifacts are attributable to source, no less than 12 geochemically distinct obsidians are present, representing at least four geographical areas, including the North Coast Ranges of western California, the Mono Basin area of central-eastern California, northwestern Nevada, and extreme northeastern California. In addition, between six and ten additional "unknown" obsidian sources are represented. We cannot resolve the exact number because the older XRF studies (Dreyer and Kowta 1986; Neuenschwander 1991) did not report raw data by artifact, making it impossible to compare the INAA unknowns ($n = 4$ discrete sources) to the XRF unknowns ($n = 6$). We address this issue below.

Despite the small sample size, several patterns are evident. First, as with Sherwin Summit, larger flakes are far more likely to be from closer sources than other artifacts. Thus, the three closest sources, including Buffalo Hills, South Warners, and the combined Bordwell Spring/Pinto Peak/Fox Moun-

tain/Hart Mountain source, account for 78 percent of the large flakes, but only 57 percent of the formal tools and 46 percent of the small flakes. Second, despite nearly equal sample sizes for the two flake classes, only six sources are present among the larger flakes, while 10 are represented among the smaller flakes. Third, the small-flake analysis highlighted several patterns that were only weakly evident or nonexistent in the large flakes and tools. In particular, it emphasized the wide ranging access Mohawk Valley inhabitants had to obsidian from the North Coast Ranges of western California and the Mono Lake area of central-eastern California. Without the small-flake geochemical data we would have entirely missed the archaeological evidence for these conveyance systems.

As mentioned, there were several unknown sources identified in the characterization studies, comprising 14 percent of the tools (two geochemical sources), 28 percent of the large flakes (five sources), and 14 percent of the small flakes (four sources). The majority of the unknown samples (17 of 25 artifacts) derive from a single study carried out in the early 1980s, where nearly 40 percent of the artifacts were unknowns. Although this issue has the potential to complicate the interpretations drawn above, we do not think they significantly skew them. First, removing the 1980s sample from the study altogether does not change the patterns observed, though the sample sizes are smaller and, hence, statistical comparisons less significant. Second, adjusting for sample size, the number of unknown sources is roughly equal between the different artifact categories. Thus, relative source diversity is likely to increase among all categories in roughly the same proportions if we could assign the unknowns to known sources. Third, because the INAA small-flake study was carried out more recently than the XRF study and contains more geochemical sources that have known geographic provenance, it is likely that most of the small-flake "unknown" sources are from additional locations not listed in Table 2. On the other hand, the geographic location of some of the sources listed in Table 2 were not yet known in the mid 1980s (e.g., Buffalo Hills), and some of the "unknown" geochemical sources among the large flakes and tools are probably already listed in Table 2. In other words, if we could assign all the unknowns to source, source diversity among the small flakes

would likely increase substantially, while the same is not true of the large flakes and tools. Finally, even if we treat all of the "unknown" geochemical signatures in both studies as unique sources, we still get greater source diversity for small flakes ($n = 14$) than for large flakes ($n = 12$) and formal tools ($n = 9$).

Bone Cave

Bone Cave is located in the high desert of central Oregon, just east of the City of Bend. Like Sherwin Summit, but unlike Mohawk Valley, this is an area rich in obsidian resources and less than five percent of the flaked stone artifacts at the site are non-obsidian. Although there is no obsidian on-site, there are at least four chemically distinct sources within 40 km of Bone Cave. The site is located within a lava tube and had been greatly disturbed by pot-hunting activities. Excavations were undertaken at the cave in 1999 by one of the authors (Ferguson) in an attempt to retrieve remaining archaeological information. Initially it appeared that the degree of disturbance would preclude any significant analysis and interpretation. However, faunal analysis, obsidian hydration dating, obsidian source analysis, and lithic analysis demonstrated that much can still be learned, even when cleaning up the mess of ardent pothunters (Ferguson 1999; Ferguson and Skinner 2005). The site occupation appears to have almost exclusively predated the eruption of Mt. Mazama at approximately 6,850 years ago.

During the course of excavations and laboratory analysis it was discovered that few formal lithic artifacts were left behind by pothunters. Only five formal obsidian tools were recovered, and all were submitted for XRF analysis. By comparison, numerous obsidian flakes were recovered. The sample subjected to geochemical analyses include 216 large and 58 small flakes randomly selected from the assemblage. Detailed technological analysis of the small flakes was not undertaken, but the majority are believed to represent complete late-stage reduction and maintenance activities rather than shatter or flake fragments. Results of the characterization studies for Bone Cave are presented in Table 3.

Of the 279 artifacts, 250 were assigned to known sources.¹ Among these, no less than 12 obsidian sources are represented. In accord with the model, there is 25 percent greater source diversity among

Table 3. Comparison of Source Diversity by Artifact Category for Bone Cave.

Source Artifact	Obs. Cliff	McK Butte	Big Obs.	East Lake	Qtz. Mtn.	Coug. Mtn.	Silver/ Sycan	Brooks Cyn.	Glass Butte	Burn Butte	Rimr. Spring	Whit. Ridge	Totals
Formal Tools	-	3	-	-	1	1	-	-	-	-	-	-	5
Large Flakes	23	64	67	-	14	1	15	-	-	-	1	2	187
Small Flakes	7	20	8	6	6	-	2	3	3	2	-	1	58
Totals	30	87	75	6	21	2	17	3	3	2	1	3	250

Notes: Sources are, left to right, Obsidian Cliffs; McKay Butte; Big Obsidian Flow; East Lake Flow (Newberry Crater); Quartz Mountain; Cougar Mountain; Silver Lake/Sycan Marsh; Brooks Canyon; Glass Buttes; Burns Butte; Rimrock Spring; Whitewater Ridge.

the smaller vs. larger flakes (10 vs. 8), despite the fact the large flake sample is over 300 percent larger (187 large vs. 58 small flakes). Adjusted for sample size, this amounts to a fourfold increase in source diversity in small flakes. The diversity of sources is much more evenly spread across the small flake sample (i.e., not dominated by a single or small number of geochemical sources). As well, the average distance to source of small flakes is farther than that for large flakes (see Table 4). In opposition to the predictions of our model, however, the average distance to source is shorter for formal tools than for both large and small flakes. This finding is likely attributable to the exceptionally small sample size ($n = 5$) of formal tools available for analysis. The small sample of formal artifacts also precludes statistically meaningful calculation of source diversity for comparison with the flake samples.

Discussion

All three case studies show a clear relationship between artifact type, distance from source, and source diversity. Table 4 summarizes the results from the three case studies. The average distance from site to source was calculated in kilometers. Diversity was calculated in two different ways. First, the Shannon-Wiener Diversity Index is given. This is a statistical index analogous to richness and is commonly used in ecological studies to gauge the diversity of species or samples within a community; higher numbers indicate greater diversity or richness. Since this measure does not take sample size into account, and sample size is often correlated with diversity as measured by the number of classes represented within a sample (Kintigh 1984), we created a second statistic to directly compare artifact types, because sample sizes varied greatly across our tool, large flake, and small flake

collections. We used the program Excel to generate 100 random subsamples at a size equal to the smallest data set (i.e., either tool, large flake, or small flake) within each region, in other words, we bootstrapped the larger samples. This was done by randomly picking (with replacement) a predetermined number of artifacts (i.e., the size of the smallest sample) from the full sample, and tallying the number of observed sources (i.e., the diversity). We then averaged these diversity measures across the 100 subsamples that were generated. In other words, if a study included 75 formal tools, 50 small flakes, and 250 large flakes, 50 artifacts (the smallest of the three) were randomly selected from the tool and large flake samples. This was done 100 times, with the number of unique sources in the subsample calculated each time. The average of the 100 diversity measures was then computed. This statistic was generated so that we could directly compare diversity between the three different samples. Table 4 reports this second diversity measure in the columns labeled "Avg # Srcs," which represents a sample-size-adjusted measure of diversity.

As shown in Table 4, small flakes (i.e., those under 10 mm) in each area are on average consistently farther from their source than larger flakes. For Mohawk Valley and Bone Cave, this distance is 13 percent and 21 percent farther, respectively. For Sherwin Summit sites, this distance is only 2.5 percent greater for small flakes, but increases to 13 percent if we consider only pressure flakes. With the exception of Bone Cave, where the formal tool sample is small, the average distance-to-source of formal tools is also greater than large flakes. In fact, the average distance-to-source is nearly equal for formal tools and small flakes, especially if we consider the pressure flake sample from Sherwin Summit rather than the total small flake sample, which includes flake fragments and pieces of shatter.

Table 4. Summary and comparative Statistics for Obsidian from the Three Case Studies.

	Sherwin Summit			Mohawk Valley			Bone Cave		
	Avg. Dist	S-W Div	Avg # Sres	Avg. Dist	S-W Div	Avg # Sres.	Avg. Dist	S-W Div	Avg # Sres.
Formal Tools	40.5	1.16	5.2	193.1	1.77	7.0	50.0	-	-
Large Flakes	36.4	1.01	4.2	174.0	1.49	4.4	51.2	1.49	5.8
Small Flakes	37.3	1.19	5.0	195.8	1.99	6.3	62.2	1.97	10.0
Pressure Flakes	41.1	1.34							

Notes: "Pressure Flakes" are a subset of "Small Flakes" and were determined only for the Sherwin Summit study. Avg. Dist = Average source-to-site distance for artifacts; S-W Div = Shannon-Wiener Diversity Index; Avg. # Sres. = The average number of sources represented in a sample, when adjusted for sample size.

Table 4 also shows that source diversity is consistently higher within the formal tool and small flake samples than among larger flakes, as measured by the Shannon-Wiener Diversity Index. The same result is obtained using other measures of diversity, including Simpson's Index of Diversity and measures of richness. However, these statistics were not computed for the Bone Cave formal tools due to the small sample size. Similarly, when adjusted for sample size, the number of sources encountered among small flakes and formal tools is consistently higher than among large flakes, as seen in the "Avg # Sres" column.

Conclusions

Earlier in this essay we presented a model for the production and use of knapped stone resources for small-scale and residentially mobile populations. Based on this model, we predicted that there would be differences between the distances and proportions of identified geochemical sources of formal tools and small flakes on the one hand, and large flakes, on the other. Formal tools and small flakes were predicted to represent a greater diversity of obsidians that would be, on average, farther from their geographic sources. This pattern held in all three case studies, and provides strong support for the general utility of the model in these regions. More specifically, the Sherwin Summit case demonstrated that the prediction for small flakes applies especially to very late-stage reduction flakes, rather than to all small flakes. This is likely to be true in most cases where obsidian is locally available. In those cases, more of the small flakes are likely to represent shatter, flake fragments, and other production debris, rather than tool maintenance and/or use. In other words, they will include

a larger fraction of nearby sources and will more closely resemble large flakes in terms of their geochemical makeup. In all three case studies, geochemical analysis by INAA of small flakes provided critical and complementary data to geochemical analyses for formal tools and large flakes, and could be used to resolve such discrepancies between tool production waste products and tool maintenance and use debris.

That the average source-to-site distance and source diversity measures are similar for formal tools and very late stage reduction/maintenance flakes suggests that the two measures may often be correlated within lithic assemblages. If so, in cases where the majority of formal tools have been removed either by native peoples (e.g., curated and used elsewhere) or by others (e.g., looting/collection by pothunters) it may be possible to gain *some* impression of the original source diversity by analyzing the smaller and more complete flakes. For example, in the Sherwin Summit and Mohawk Valley studies, source diversity among small flakes nearly mimicked simulated diversity among formal tools. At the same time, although simulated diversity measures may be similar, all studies showed differences in the particular sources represented within the small flakes vs. formal tools. In Mohawk Valley, small flakes include representation of entire source regions not present in the formal tools (e.g., North Coast Ranges obsidians, such as Napa and Borax Lake, and Mono Lake region, such as Bodie Hills and Mt. Hicks). Such differences may be important for drawing inferences about the directionality and the specific intensity of conveyance. In any case, to avoid such biases we think it is important to include all three categories (formal tools, large flakes, and small flakes) in any thorough geochemical provenance analysis, particu-

larly when all three artifact types are present.

While effective, we feel the model could be improved even further by the inclusion of additional factors. First, the effects of trade could be a confounding factor, depending on the state in which toolstone was moved. If tools were traded in complete or near-complete form, we suggest little modification to the model. On the other hand, if unmodified nodules were traded, as is evident during some time periods in parts of western North America (e.g., Fredrickson 1994), we predict that large-flake assemblages will contain a higher frequency of artifacts from distant sources. If the intensity of trade of unmodified nodules from distant sources is high enough, for example, to produce "ceremonial" bifaces from highly exotic obsidians, this factor could reverse some of the patterns outlined in the model. Detailed analysis of lithic assemblages, particularly the geochemical characterization of spent cores and/or examination of the context of various formal tools (e.g., large bifaces), should allow analysts to further explore such issues.

Second, the model does not account for the quality of knapped stone resources. If more local toolstone sources are available but not suitable for the production of certain types of formal tools, prehistoric groups may opt to transport unmodified toolstone across longer distances. Such a pattern may lead to the deposition of greater numbers of large flakes from more distant sources, which could violate the predictions of the model. Quality of toolstone is commonly evaluated in relation to technological factors, such as edge sharpness or the presence of phenocrysts and other impurities that typically reduce the control a knapper has over flake removal (e.g., Brantingham et al. 2000; Olausson 1998). However, to the native flintknapper, "quality" may also relate to other factors, such as which raw materials successful hunters or prestigious individuals are using, the color of the raw material, or ascription of ritual significance to certain toolstone materials. For example, Julian Steward (1933:257) was informed by an Owens Valley Paiute that certain types of obsidian were considered to be "poisonous." For the archaeologist, the physical attributes of toolstone are usually easier to evaluate than the more culturally ascribed qualities.

Finally, and most importantly, excavation and

later geochemical studies that fail to recover and include a sample of smaller flakes are likely to systematically introduce bias into measures of source diversity and average source-to-distance measures. Similarly, studies that depend on these measures to reconstruct patterns in prehistoric mobility, exchange, or any of the other factors listed above will also be biased. Because large and small flakes can represent different kinds of behaviors and activities (i.e., primary reduction vs. use/maintenance), analysis of some artifact classes to the exclusion of others will obviously mask certain behaviors. Moreover, because these different behaviors may be differentially distributed over time, we may be biasing our studies toward certain time periods. This is particularly relevant in situations where we depend on source-specific obsidian hydration readings to trace prehistoric activities over time. As discussed by Tremaine (1986), if we differentially select larger pieces for hydration analysis (e.g., because only those pieces can be characterized using a given technique), we may be systematically underemphasizing, or even dismissing altogether, certain time periods where small-tool use and maintenance were the dominant lithic reduction activities on those landscapes.

We could include other factors that might complicate our model relating mobility and reduction strategies such as the production of tools for exchange (see Renfrew 1977),² scavenging of older obsidian, the production of ceremonial items (e.g., bifaces) where highly exotic obsidians are preferred, and/or territoriality that limits access to certain obsidians. Our model did well in predicting the patterns observed, but we realize any of these other factors could also play a role in the observed patterns. Regardless of whether our model is correct, our purpose in this paper was less to explain the patterns in obsidian reduction in California than to point out the value of systematically subjecting small flakes to geochemical analyses. Empirically, it is clear that there are different source profiles among the artifact categories we examined. If we systematically ignore certain of these classes we introduce the possibility of limiting our ability to reconstruct past behaviors.

Analyzing small flakes in addition to large flakes and tools should give archaeologists a much more complete understanding of not only tool production, but of tool use and maintenance as well. Main-

stay geochemical characterization techniques such as XRF analysis are a proven, reliable, and cost-effective method to characterize large flakes and tools. Such analyses are easily supplemented through the use of alternative methods that can accommodate the analysis of smaller flakes. For example, INAA, a proven technique with a long history in archaeological research, can be used to analyze flakes as small as 5 milligrams (Glascok 1998), or approximately 2 cubic mm (e.g., 2 x 2 x .5 mm). Newer techniques such as inductively coupled plasma-mass spectrometry (ICP-MS), especially when combined with laser ablation (LA-ICP-MS), can also serve in this capacity and can characterize flakes that are even smaller (e.g., less than 1 x 1 mm; Speakman and Neff 2005). We hope that the case studies outlined above will inspire archaeologists to seek out and use such techniques when appropriate.

Acknowledgments. We thank Richard Hughes of Geochemical Research Laboratories; William Hildebrandt, Jerome King, and Pat Mikkelsen of Far Western; Denise Thomas, Tom Mills, and Todd Jaffke of California Department of Transportation; Linda Reynolds of the Inyo National Forest; and Kirk Halford of the BLM for earlier comments and for supporting the Sherwin Summit and Mohawk Valley research. The Bone Cave analysis was supported by the Anthropology Department at Oregon State University, Northwest Research Obsidian Studies Laboratory, MURR, and NSF grant BCS-0102325. We also thank James Bayman, Amy J. Gilreath, and several anonymous reviewers for comments on an earlier draft, and Douglas Bamforth and Barbara Roth for their comments and assistance with data interpretation. Finally, we thank Valerie McBride for the Spanish translation of the abstract.

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Notes

1. Of the 29 unknowns, 12 were assigned to "Unknown X," a commonly encountered geochemical type that is likely on lower western flanks of Newberry Volcano, but has not yet been located. Because the precise location is still not known we treat artifacts ascribed to this source as we do all other unknowns, and do not include it in our analyses.

2. Based on Renfrew's (1977) model, we believe the overall patterns will be similar when obsidian is exchanged versus when it is used during the course of seasonal mobility.

Received November 18, 2005; Revised October 16, 2006;
Accepted October 16, 2006.