

# Measuring prehistoric mobility strategies based on obsidian geochemical and technological signatures in the Owens Valley, California

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Received 4 March 2007; received in revised form 24 May 2007; accepted 24 May 2007

## Abstract

We compare the organization of obsidian flaked stone technologies in two different time periods at CA-INY-30, a village site in southern Owens Valley, eastern California. Previous archaeological studies suggest a reorganization in settlement patterns between the Newberry (ca. 3500–1500 BP) and Marana (ca. 650-contact) periods, from a highly mobile to a more residentially sedentary one. New geochemical data, based on laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS) analyses of obsidian artifacts associated with discrete house floors, support this basic settlement model, but reveal new detail in how people moved across the landscape and accessed, extracted, reduced and used obsidian resources. In the earlier Newberry period, there is no relationship between flake size and distance-to-source, and the falloff curve relating frequency of obsidian against distance is more gradual, as expected, but contrary to our expectations, source diversity is not higher. These factors suggest extremely high mobility, but also selective extraction of particular sources. Newberry obsidian may have been acquired by groups of hunters who embedded quarrying within long-distance trips to distant hunting grounds, and subsequently transported bifacial cores to base camps. By contrast, Marana patterns show strong relationships between flake size and distance from source and steeper fall-off curves, suggesting groups acquired their obsidian primarily from closer sources, likely via exchange networks. At the same time, geochemical diversity, especially among smaller resharpening flakes, is higher in the Marana period, highlighting the wide-ranging conveyance systems through which obsidian moved.

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*Keywords:* Obsidian; Provenance analysis; Lithic technology; LA-ICP-MS; Mobility strategies; Owens Valley

## 1. Introduction

Obsidian studies in California and the Great Basin have been immensely useful to archaeologists. Not only can we date sites and individual artifacts using hydration, but we have learned much about a range of prehistoric behaviors including settlement patterns, trade and exchange, and the organization of hunting and lithic technologies. New and developing analytical techniques allow us to ask increasingly refined questions of the archaeological record.

We report and discuss compositional analyses to determine source provenance of obsidian flakes associated with 10 house floors in Owens Valley using laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). This technique is nearly non-destructive, requires little sample preparation, provides rapid results, and can have high throughput for small items (ca. 6 artifacts per hour), making it a cost-effective alternative to other techniques. More importantly, LA-ICP-MS allows archaeologists to determine source provenance for extremely small artifacts, even those less than 1 mm in size. This is an important development because it allows archaeologists to easily analyze artifacts not suitable for other commonly used techniques, such as X-ray fluorescence (XRF). XRF requires samples to be larger than approximately 8 mm

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in diameter and 1.5 mm in thickness (Davis et al., 1998; though these limits vary slightly depending on equipment and the level of precision needed). Selecting larger artifacts for analysis can introduce significant distributional bias that has the potential to alter interpretations of prehistoric behavior (Eerkens et al., in press).

In this paper we test a settlement model that has been put forward for the Western Great Basin. This model suggests that inhabitants practiced high mobility prior to 1500 years ago, shifting to a system marked by much greater settlement stability 650–150 years ago. The intervening period between 1500 and 650 BP has been less well studied, but seems to conform to low mobility (Eerkens, 2003). The traditional viewpoint regarding high mobility prior to 1500 BP has been that movements were largely residential in nature (Basgall, 1989; Bettinger, 1989, 1999a; Delacorte, 1999), with entire groups of people picking up and moving together across the landscape. More recent research (e.g., McGuire and Hildebrandt, 2005; McGuire, 2002) argues that mobility was high, but was largely centered on logistically organized activities, especially hunting.

The model has been developed from regional excavation and survey data, primarily in Owens Valley. This paper tests the model from the perspective of a single site in Owens Valley, CA-INY-30, based on new geochemical and metric data on obsidian artifacts associated with individual houses.

## 2. Models of lithic organization

Over the last 25 years archaeologists have developed a number of theoretical models to explain and predict the composition of lithic assemblages based on both basic economic principles and analogies to ethnographic examples. Building on foundational work by Binford (1979); Luedtke (1976), and Renfrew (1977), a common theme running through these models examines the interplay between mobility patterns and toolstone acquisition (e.g., Bamforth, 1986, 1990, 1991; Basgall, 1989; Beck et al., 2002; Brantingham, 2003, 2006; Cowan, 1999; Jones et al., 2003; Kelly, 1988; Kuhn, 1989; McGuire, 2002; Parry and Kelly, 1987; Roth, 2000; Shott, 1989, 1994).

In these models, as hunting and gathering groups perform various activities, they deplete and replenish their supply of raw toolstone in a patterned manner, leading to the deposition of structured assemblages of artifacts of different types, sizes, and raw materials. A basic distinction within many models concerns the acquisition of toolstone by residentially mobile versus residentially stable groups. These models suggest that residentially mobile groups often acquire toolstone directly by embedding raw material extraction within other subsistence activities and transport such materials to places where they are needed. Spent and broken tools are discarded and replaced with new ones as groups encounter sources of raw material on the landscape. By contrast, residentially stable populations often either directly procure and make use of inferior and locally-available materials or acquire higher quality raw materials indirectly through trade. However, toolstone access for

stable populations may be tempered by the degree of logistical mobility, where greater distances covered during logistical trips may allow knappers to directly access a more steady supply and a greater range of non-local and/or higher quality materials (Binford, 1979, 1980).

As a basic model, we find the distinction between mobile (logistical and residential) and sedentary populations useful for deriving predictions for the archaeological record. We realize such a black-and-white model is oversimplified in that mobility is often organized along a range of different axes beyond merely the degree of residential permanence (e.g., Kelly, 1983). Indeed, our analyses below point out some interesting departures from this basic model that highlight important details in how hunter-gatherers in the Owens Valley integrated various aspects of mobility within the organization of their lithic technologies. From these basic models, we derive these predictions:

*Prediction #1:* Lithic materials in an embedded and mobile settlement system will be, on average, from further away than those in a more restricted settlement pattern. As well, when the percentages of lithic materials from different sources are plotted against distance, more distant sources will comprise a greater percentage of the total tool assemblage resulting in a more gradual “fall-off” curve (Renfrew, 1977). The steepness of this curve is inversely related to the degree of mobility, as measured by the distance covered.

*Prediction #2:* All other things being equal, flakes from more distant sources will be larger in size, on average, within the mobile system. Such flakes should also be more variable in size, representing a greater range of reduction activities including both earlier shaping and later finishing debris in more restricted settlement patterns, flakes from distant sources should be smaller and consistently so, representing primarily resharpening behaviors.

*Prediction #3:* Assuming lithic resources are distributed fairly evenly across the landscape, the diversity of lithic materials within the mobile system will be higher than within the more restricted one. This is due to the larger territory covered by the more mobile group and the greater distance across which they transport tools in various states of reduction.

Again, these predictions are based on an oversimplified model of settlement pattern and toolstone acquisition, but are useful for guiding our observations of the archaeological record. Other factors, such as quality of raw material, the size and types of tools produced, and the degree to which settlement patterns are fixed or range spatially across the landscape will modify these predictions. Where possible, we attempt to account for these other factors.

## 3. Owens Valley, California

Owens Valley is in eastern California (see Fig. 1) and is home to the Owens Valley Paiute. The valley lies at the intersection of

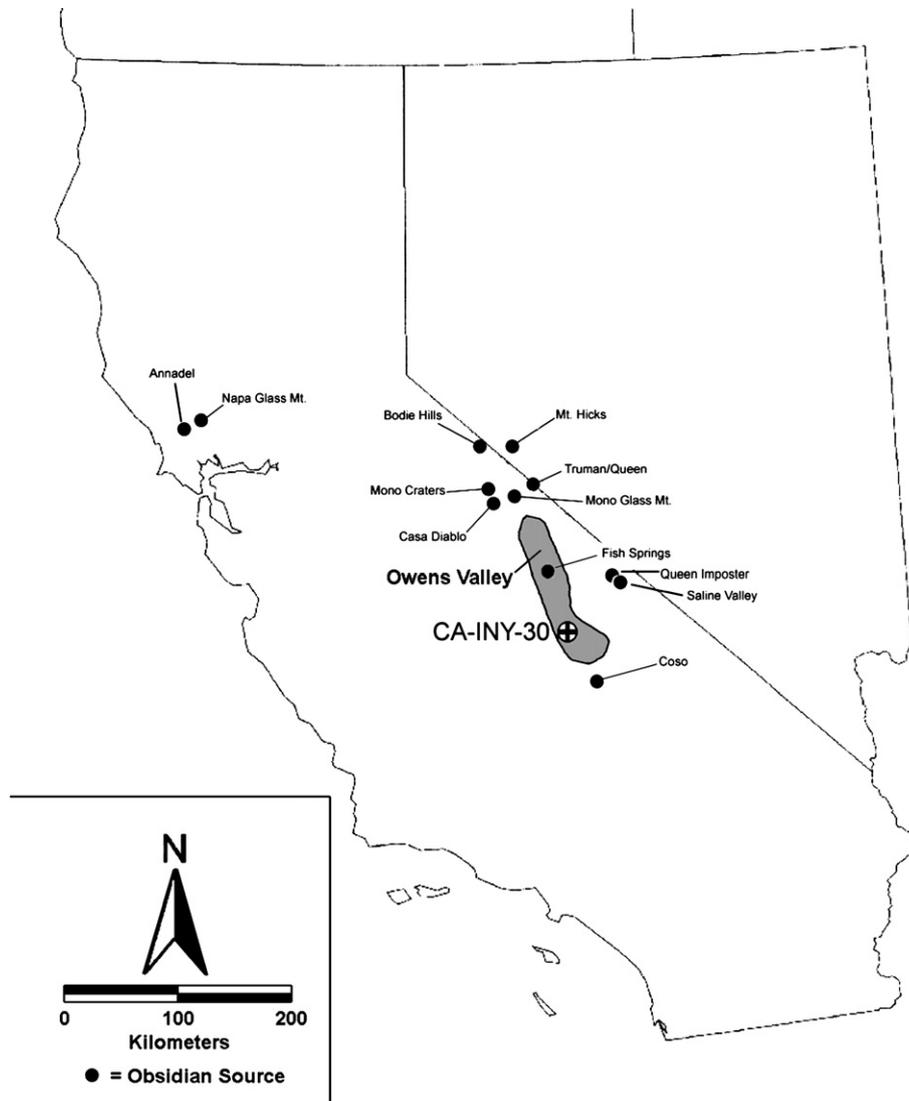


Fig. 1. Map showing CA-INY-30 and relevant obsidian sources.

two large and traditionally recognized North American “culture areas,” California to the west, and the Great Basin to the east. The valley was the site of important ethnographic fieldwork in the 1930s by Julian Steward (e.g., 1933), and has received considerable archaeological attention over the last 30 years (e.g., Basgall, 1989; Basgall and McGuire, 1988; Bettinger, 1983, 1989, 1999a,b; Delacorte, 1999; Eerkens, 2003, 2004; Gilreath and Holanda, 2000).

Owing to the high degree of volcanism, the region surrounding Owens Valley contains many sources of obsidian, a raw material that was intensively used by prehistoric inhabitants. Typically, obsidian accounts for 90% or more of flaked stone materials at prehistoric sites, with only small amounts of chert, basalt, and other flakable toolstone. Our analyses are focused on obsidian for the obvious reason that it is dominant in local flaked stone assemblages, but also because it can easily be analyzed for provenance, providing information on its extraction, reduction, and movement.

For the present study, we examine obsidian artifacts associated with discrete house floors at CA-INY-30. At the time the

site was excavated, XRF was the primary geochemical technique used in the region. While a small sample of obsidian artifacts were analyzed at the time by XRF, the vast majority, especially small flakes, were not because they were too small. The development of LA-ICP-MS now allows us to analyze all obsidian artifacts recovered from these floors, providing the opportunity to refine our understanding of obsidian acquisition and consumption over time.

### 3.1. Culture history

The basic culture historical sequence in Owens Valley has been well established through survey and excavation (e.g., Bettinger, 1989; Bettinger and Taylor, 1974). For this paper, the last 2000 years of prehistory are of interest encompassing three culture historical units. Locally these are referred as the Late Newberry (ca. 2000–1500 BP), Haiwee (ca. 1500–600 BP), and Marana (600 BP to contact). For this study, we focus on the Late Newberry and Marana periods.

Late Newberry patterns are marked by highly mobile populations moving in a north–south annual round that included the establishment of a number of base camps from which various logistical activities took place (Bettinger, 1999b; Delacorte, 1999). It has been argued that a focus on large game hunting using atlatls, mainly for prestige-seeking males, characterized this period (Hildebrandt and McGuire, 2002; McGuire and Hildebrandt, 2005). There is also ample evidence that obsidian stoneworking, primarily for producing bifaces, peaked at all the major obsidian quarries (Gilreath and Hildebrandt, 1997). Whether such bifaces were produced for exchange or to support increased hunting activities is not yet known.

By contrast, the Marana period (600 BP to contact) is marked by semi-sedentary settlements and the introduction of new material technologies. A new type of projectile point is introduced, the Desert-Side Notched (DSN), as well as cooking pots, which were used to boil the increasing levels of small seeds that were harvested (Eerkens, 2004). There is also a marked increase in the density of groundstone and a focus on the harvesting of “green” piñon nuts, that is, cones that are not yet naturally ripened (Eerkens et al., 2004). All of this indicates a heavy reliance on gathered resources, and presumably heavy demands on the time and labor of women.

### 3.2. CA-INY-30

CA-INY-30 was excavated in the mid-1980s by Far Western Anthropological Research Group as part of a highway expansion project (Basgall and McGuire, 1988). Twelve circular domestic structures were excavated, the majority by means of a trench bisecting the feature. Radiocarbon dates and time-sensitive artifacts place four of these between 1800 and 1400 BP, in the late Newberry period. Three of the four Newberry houses were found closely situated to one another in the south-central part of the site (structures 11, 12, and 15), while the fourth (structure 12) was found some 120 m west of this cluster. We analyzed debitage assemblages from three of these houses, two of the former and the latter.

In addition, seven excavated structures from CA-INY-30 date from the Marana period, between 500 and 100 BP. These houses comprise two clusters of three in the southeast (structures 1, 5, and 6) and north-central parts of the site (structures 7, 8, and 9), with a seventh in the southwest part of the site (structure 10, possibly isolated from contemporaneous houses). Marana houses are more shallow (generally 0.5–1 m in depth) and widely spaced than the Newberry structures.

There were additional circular depressions at the site indicating the presence of yet further houses, but these were not excavated. As well, one house (structure 13) was excavated but has more ambiguous temporal affinities. A radiocarbon date places it in the early Marana or late Haiwee, ca. 710 BP, but several aspects of the assemblage suggest an earlier Newberry age. As well, it contained intrusive pits dug into the floor from above that are clearly Marana in age. We did analyze debitage from this house, but due to the temporal uncertainties we do not include those results in the discussions

below (but note in passing that patterns are much like those of the other Newberry houses).

For both time periods at CA-INY-30 (Newberry and Marana), calibrated radiocarbon dates overlap for the houses at the two-sigma ranges (i.e., Newberry house dates overlap with each other, and Marana dates overlap). Although it is difficult to demonstrate contemporaneity directly, it was thought by the excavators that many of the houses were occupied simultaneously (Basgall and McGuire, 1988).

### 3.3. Obsidian sample

Obsidian flakes are the most common artifact at CA-INY-30 and were associated with houses from both periods, although the density of flakes is significantly higher in the earlier Newberry houses. From ten of the houses (three Newberry and seven Marana) we selected a random sample of flakes ( $n = 20–40$ ) for provenance analysis using LA-ICP-MS. In most cases we were able to limit the sample to flakes found directly on the floor, however in some cases we had to relax our strategy to include flakes within 10–20 cm of the floor to get meaningful sample sizes. This sampling method allows us to control for site context and chronological period, an issue we revisit in the discussion section. Prior to LA-ICP-MS analysis, each flake was measured for maximum length (perpendicular to the striking platform) and maximum width (parallel to the striking platform). Incomplete measures, where flakes were broken across a particular dimension, were noted. Table 1 gives the sample size and relevant information for each house.

The majority of our samples consist of small tool finishing and retouching debris, likely overlooked during house cleaning events. Indeed, pressure flakes account for one-third to one-half of all obsidian flakes associated with house floors in both time periods, with indeterminate flake fragments comprising an additional 30–40% (Basgall and McGuire, 1988, p. 211). The excavators did not find significant differences in debitage profiles (i.e., in terms of the relative percentage of types of flakes) by time period. Obsidian cores are extremely rare at the site (less than 1% of all obsidian tools), and are absent altogether from the house floor assemblages. However, it

Table 1  
Sample of houses for geochemical studies and relevant information

Cultural period	Site	Structure	Uncalibrated <sup>14</sup> C date(s)	House size (m <sup>2</sup> )	Our sample size
Marana	INY-30	1	310 ± 70; 470 ± 70	11.3	29
	INY-30	5	410 ± 80	10.2	20
	INY-30	6	None	14.5	40
	INY-30	7	480 ± 60	8.0	37
	INY-30	8	270 ± 70; 470 ± 50	9.1	39
	INY-30	9	180 ± 60	12.0	25
Newberry	INY-30	10	330 ± 60; 390 ± 90	12.0	36
	INY-30	12	1530 ± 80; 1860 ± 70	15.9	30
	INY-30	14	1650 ± 100; 1840 ± 80	13.9	30
	INY-30	15	1460 ± 60	18.1	30

is likely that bifaces were used as sources of flakes for additional knapping (Delacorte, 1999; Elston and Zeier, 1984; Garfinkel et al., 2004; Yohe (1998)). The frequency of bifaces relative to other flake tools is variable among the houses, but is not noticeably higher in either the Newberry or Marana periods (Basgall and McGuire, 1988; see also Eerkens, 2003).

Altogether, the technological information from flaked stone assemblages of indicates similar types of reduction activities taking place in both Newberry and Marana houses (note, however, that the original INY-30 comparisons included artifacts from the “fill zone” of houses, not just those on or directly above the floor, as in our study). This result is supported by studies at the stratified site of CA-INY-372 some 40 km to the south, where Yohe (1998) documented similar and fairly stable reduction strategies over time, with only slight decreases in the size of bifaces and biface thinning flakes after 600 BP.

#### 4. Methods

Samples were analyzed using LA-ICP-MS at the Interdisciplinary Center for Plasma Mass Spectrometry at UC Davis. The ICP-MS system is an Agilent 7500a quadrupole instrument coupled to a Nd:YAG New Wave UP 213 laser. At the beginning of each day the ICP-MS was optimized for sensitivity during line scans that rastered across a polished NIST 612 glass standard. The production of both ionized oxides and doubly charged ions was also monitored and lowered to 0.5%. Helium was the transport gas from the laser ablation cell (~0.85 L/min) and was mixed with argon gas (1.02 L/min) before entering the ICP-MS.

Data were collected in a time-resolve mode for 90 s, which included 30 s of background signal, 30 s for sample signal (dwell time), and washout time (30 s). Each spot was pre-ablated for 5 s to remove surface contaminants. Laser parameters were set to 80% power, 10 Hz, and 80  $\mu$ m diameter spot size. Five spots were analyzed on each standard and obsidian sample. Twenty-eight different isotopes were measured. The NIST 612 glass served as a calibration standard and was analyzed five times at the beginning and end of each sample slide and after every 4–6 obsidian samples. To assess LA-ICP-MS performance, one of the Mt. Hicks obsidian source samples was analyzed daily and showed excellent precision from day to day. Moreover, the USGS andesite standard (AGV-2) was analyzed each day and showed good agreement with the accepted concentrations, ranging between 4 and 10% relative standard deviation (RSD) for most elements.

Raw data were reduced using GLITTER, the GEMOC Laser ICP-MS Total Trace Element Reduction software package. The intensity of each element was normalized to that of Na (considered the internal standard) and the background signal was subtracted from the main ablation signal. Concentrations were calculated based on the known concentration of an internal standard, which is slightly different for each sample. For previously analyzed pieces by Instrumental Neutron Activation Analysis (INAA), the concentration of the internal standard had been determined and was used to calculate

absolute concentrations. However, the internal standard was not previously measured for the unknown obsidian flakes, so elemental ratios were utilized instead, which eliminated the internal standard in the calculations, and proved to be useful in source discrimination.

Fig. 2 compares data on previously analyzed source specimens by INAA and our LA-ICP-MS data for obsidian samples analyzed by both techniques. The top part of the figure shows ratios of concentrations between the new LA-ICP-MS data and older INAA values for individual samples, and reports RSD measures for our internal Mt. Hicks obsidian standard. The bottom part of the figure plots the average concentrations in these same source samples for different elements, on a log-log scale.

As seen in the top part of Fig. 2, most LA-ICP-MS/INAA ratios hover near a value of 1, indicating good correspondence between the two techniques. Exceptions include Sc (not plotted because many values fell above a ratio of 2.0 outside the scale of the graph) where LA-ICP-MS concentrations were consistently and significantly higher than INAA, Sr where INAA tends to have poor precision (Glasco, 1992), and Ba and Zr where LA-ICP-MS concentrations were consistently lower, in spite of RSD measures near 10%. The bottom part of the figure shows that most elements fall on or close to the diagonal line, again indicating good (i.e., 1:1) correspondence between the two techniques. Exceptions again include Sc, Sr, and Zr.

We decided not to use Sc measures in our analyses because of the high RSD on internal standards, and inconsistencies noted above between INAA and LA-ICP-MS. As well, we did not use Rb because of high RSD measures. However, we did use Sr, Zr, and Ba due to their excellent discriminatory power for different geochemical obsidians and the low RSD values, indicating good internal consistency.

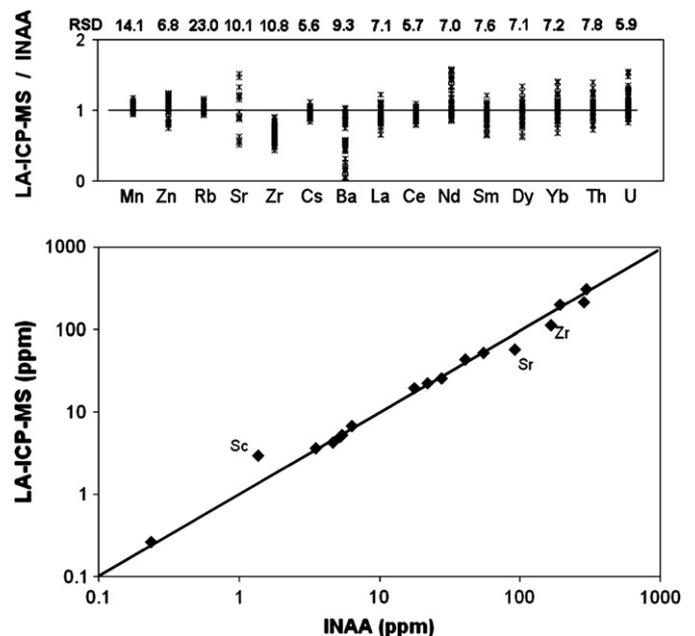


Fig. 2. Comparison of INAA and LA-ICP-MS data for source samples.

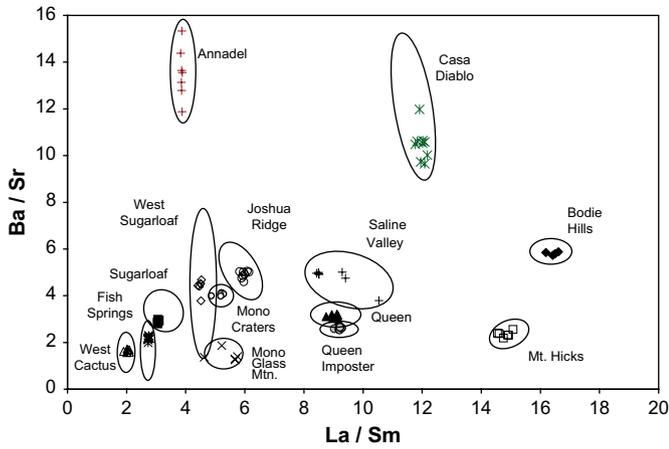


Fig. 3. Plot of Ba/Sr vs. La/Sm for obsidian source samples.

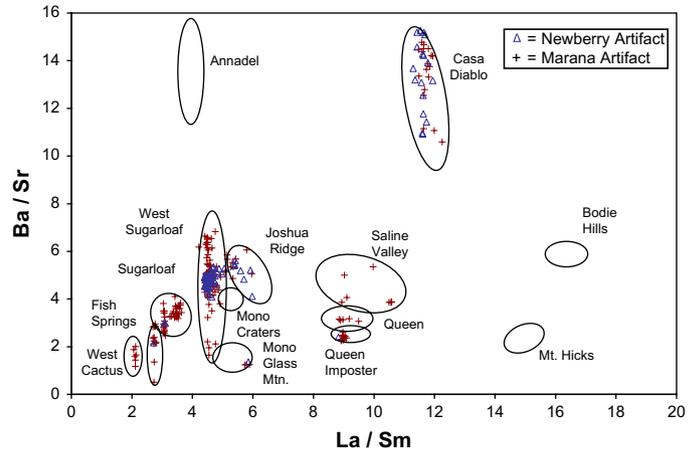


Fig. 4. Plot of Ba/Sr vs. La/Sm for CA-INY-30 artifacts.

5. Results

As seen in Fig. 3, it is possible to reliably discriminate between different obsidian sources in the region based on chemical signatures from LA-ICP-MS. Indeed, we are even able to discriminate between chemically related subsources, such as in the Coso Volcanic Fields where at least four different chemical signatures have been documented (West Sugarloaf, Sugarloaf, West Cactus Peak, and Joshua Ridge; see Eerkens and Rosenthal, 2004; Ericson, 1989; Ericson and Glascock, 2004 Gilreath and Hildebrandt, 1997; Hughes, 1988). Combined with the data presented in Fig. 2, this demonstrates that LA-ICP-MS is an effective and reliable tool for obsidian provenance analysis in the Western Great Basin. We found that using ratios of Zr/Y, Dy/Yb, Nb/Zn, La/Sm, Mn/V, Zn/Ti, and Ba/Sr to be particularly effective in discriminating Eastern California and Western Nevada obsidians. With these ratios, we performed a discriminant analysis in SPSS to define geochemical source groups, and used the resulting discriminant functions to assign our unknown flakes to geochemical source. SPSS reports the probability of group membership, given the range of variability among the source samples, and we defined a particular cut-off level ( $p = 0.05$ ), at which we accepted the

assignment of unknown to source group. However, we double-checked the discriminant source assignments by examining several biplots such as the one in Fig. 4, which plots all unknowns on the same two axes as Fig. 3, using the same ellipses. As can be seen in Fig. 4 and Table 2, a range of geochemical types are represented in the flakes, and other geochemical types are notably absent.

Table 2 shows that in terms of distance, there are basically two groups of obsidians represented at CA-INY-30, those between 40 and 60 km and those between 140 and 160 km from the source. This represents the natural availability of obsidians in the region. There are additional sources located at greater distances that are occasionally present in regional artifacts, such as Mt. Hicks, Bodie Hills, and Silver Peak. However, these geochemical types were not present in our sample.

To compare our flake sample against a set of formal tools, we turn to previously published geochemical data on temporally diagnostic projectile points from CA-INY-30. Although a useful comparison, there are certain issues to keep in mind when comparing the projectile point XRF data with the LA-ICP-MS debitage data. One is that several points analyzed by XRF were identified as “unknown” geochemical types, for which the geographic location was not yet known in the 1980s. One of these

Table 2  
Sources represented among flakes and summary size statistics by time period for LA-ICP-MS sample

Source	Distance	Newberry					Marana				
		No.	Avg. length	CV length	Avg. width	CV width	No.	Avg. length	CV length	Avg. width	CV width
Coso: W. Cactus Peak	50	0	—	—	—	—	10	7.2	0.37	8.1	0.90
Queen Imposter	55	1	10.8	—	7.9	—	14	8.9	0.49	6.8	0.42
Saline Valley	55	0	—	—	—	—	3	8.2	0.55	7.1	0.61
Coso: Sugarloaf	55	3	7.9	0.60	7.1	0.09	46	7.0	0.36	6.7	0.40
Coso: West Sugarloaf	55	59	9.8	0.41	8.5	0.38	108	7.6	0.47	6.8	0.44
Coso: Joshua Ridge	59	6	8.3	0.35	10.3	0.35	2	7.7	0.18	5.1	0.20
Fish Springs	60	1	9.8	—	4.6	—	14	11.3	0.54	9.2	0.45
Casa Diablo	140	19	7.8	0.33	6.8	0.25	20	6.2	0.30	5.8	0.31
Mono Glass Mtn.	145	0	—	—	—	—	3	5.3	0.29	5.3	0.24
Mono Craters	155	1	10.8	—	7.8	—	0	—	—	—	—
Queen	160	0	—	—	—	—	6	6.3	0.18	4.5	0.26

Distance given in kilometers. All other measurements in millimeters.

(Unknown 4) has subsequently been identified as the “Queen Imposter” source, which is found in Saline Valley (Johnson et al., 1999). Unfortunately, we did not have access to all the original XRF-analyzed projectile points for reanalysis using LA-ICP-MS. Nor were the original raw data on which XRF source identifications were made published (Basgall and McGuire, 1988). Thus, we were unable to determine the provenance of the other two XRF unknown sources, though we suspect one of these is the Saline Valley geochemical type. A second issue is that many of the XRF specimens were only assigned to the more general Coso source, and not specific subsources within Coso. Based on previous analyses, it is likely that a significant fraction (ca. 80–90%) derive from the West Sugarloaf and Sugarloaf sources (Eerkens and Rosenthal, 2004). But again, we did not reanalyze the projectile points to determine specific subsources for these samples. Finally, a third incongruity is that the projectile points come from a wider range of site contexts than the debitage sample, which comes only from house floors. If we were to restrict the tool sample to house floor contexts only we would have an extremely small sample not suitable for statistical analysis.

Each time period encompasses two different projectile point types. Elko points define Newberry assemblages. Humboldt points are less temporally definitive regionally, but the excavators reported that all but one were confidently associated with Newberry contexts (Basgall and McGuire, 1988), thus we group them together here. Marana assemblages are defined by two point types Desert Side-Notched (DSN) and Cottonwood (Bettinger and Taylor, 1974). Table 3 shows the results of the projectile point XRF geochemical analyses.

As Tables 2 and 3 show, Coso obsidian is by far the dominant source present in both periods for both artifact types, comprising 76% of flakes and 53% of points in the Newberry period, and 74% of flakes and 85% of points in the Marana period. This likely stems from a number of factors, primarily the proximity of the Coso Volcanic Fields, the ease in accessing the source, as well as the high quality of the obsidian there. Unlike Saline Valley and Queen Imposter which are also close

(as the crow flies), one does not need to cross a mountain chain to access the Coso sources from CA-INY-30. Similarly, although Fish Springs is approximately the same distance as Coso and crossing a mountain chain is not necessary, this obsidian is generally of poorer quality than Coso and may have been under greater territorial control (Bettinger, 1982). The dominance of Coso obsidian was expected, and has been noted in other southern Owens Valley assemblages (e.g., Basgall and McGuire, 1988; Delacorte, 1999; Eerkens, 2003; Gilreath and Holanda, 2000). Although there are slight differences in the distribution of different Coso subsources between the two periods, West Sugarloaf is most common in both time periods, followed by Sugarloaf, and then Joshua Ridge and West Cactus Peak. These subsurface patterns were expected and have been documented in other studies (e.g., Eerkens and Rosenthal, 2004).

### 5.1. Comparison to predictions from model

Prediction #1, that the average distance to source would be higher in the Newberry period is borne out in both the flake and projectile point samples. The average distance moved for the Newberry period is over 10% further for flakes (74.4 vs. 66.4 km) and 7% further for points (62.0 vs. 57.7 km). This is due to the high frequency of the distant Casa Diablo source among the Newberry flakes and both Queen and Casa Diablo among the Newberry points. Interesting also is the greater average distance of flakes vs. points in both time periods, suggesting that these two artifact categories record mobility patterns and obsidian acquisition in different ways. Also in line with prediction #1, when we plot the frequency of different geochemical types against their distance, we see more gradual fall-off curves (i.e., distant sources more frequent) in the Newberry period for both flakes and points than in the Marana period. Fig. 5 shows these trends.

Prediction #2, that Newberry flakes from more distant sources should be both larger and more variable than Marana flakes, also holds. Fig. 6 plots the average length and width of flakes for each geochemical type against distance from CA-INY-30. Several patterns are evident. First, Newberry period flakes are larger than their Marana counterparts irrespective of distance. This is in keeping with the larger projectile points, bifaces, and other flaked stone tools Newberry peoples made. Second, and more interesting, there is virtually no difference in flake length or width with distance in the Newberry period. As seen in the top two frames, flakes do not seem to get significantly smaller with distance from the source. On the other hand, Marana flakes decrease in both length and width with increasing distance from the source mostly as a result of the small average size of the three more distant sources.

Moreover, as seen in Table 2 there is structure in the variation of flake length and width as measured by the coefficient of variation (CV; standard deviation divided by average). There is little patterning in CV values with distance during the Newberry period, indicating that flakes from distant sources (primarily Casa Diablo) are just as variable and include the same range of flake sizes (small pressure to larger percussion) that

Table 3  
Provenience data from previously analyzed projectile points

	Newberry			Marana		
	Elko	Humb.	Total	DSN	Ctwtd	Total
Coso: W. Cactus Peak		1	1	1	1	2
Queen Imposter				1		1
Coso: Sugarloaf	1	4	5	2	2	4
Coso: West Sugarloaf	2	6	8	11	10	21
Coso: Joshua Ridge		1	1			
Fish Springs	1	1	2	1	3	4
Casa Diablo	3	1	4		1	1
Mono Glass Mtn.		1	1			
Queen	2	2	4	1		1
Unknown 2	2		2			
Unknown 1		2	2	1		1
Coso		2	2	8	10	18
Total	11	21	32	26	27	53

Elko includes all subtypes (e.g., Corner-Notched, Eared, etc.); Humboldt (both Concave Base and Basally-Notched); DSN, Desert Side-Notched; Ctwtd, Cottonwood.

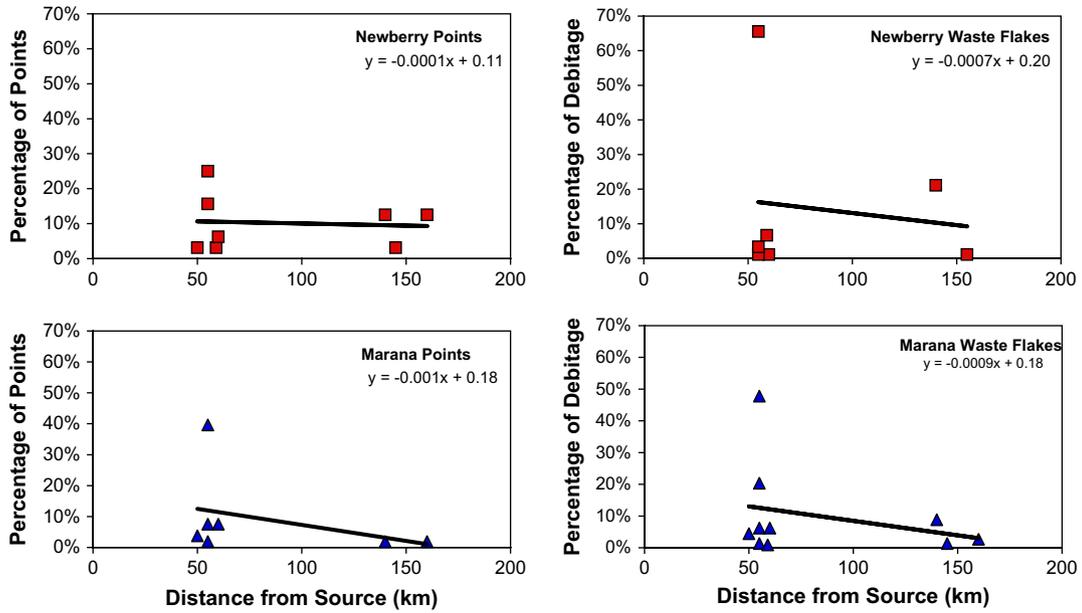


Fig. 5. Fall-off curves for geochemical types with distance.

closer sources such as West Sugarloaf include. By contrast, variation in flakes decreases noticeably with distance in Marana assemblages. Thus, not only are more distant Marana flakes smaller, they are consistently smaller because they represent primarily pressure refinishing and tool rejuvenation debris.

Both of these findings (i.e., average size and variation in size) are directly in keeping with Prediction #2. The complete lack of relationship between size and distance evident in Fig. 6 during the Newberry period was unexpected. This finding indicates that Newberry groups were so mobile that the raw material they brought back to CA-INY-30 was basically in the same stage of reduction (resulting in similarly sized debitage), regardless of whether it came from 140–160 km away or 50–

60 km. Marana obsidian coming from long distances, on the other hand, was already in a greatly reduced state, resulting only in the deposition of small resharpening flakes at CA-INY-30. We note further, that this pattern of decreasing size with distance does not hold for projectile points in either time period. The Newberry point sample is small with many broken pieces, but the limited data that are available do not give any indication of a reduction in size with distance, in either length or width. Similarly, the DSN and Cottonwood points are the same size regardless of whether they came from Coso (avg. length  $\times$  width = 20.3  $\times$  11.3 mm), other sources within 60 km (avg. length  $\times$  width = 23.2  $\times$  11.7 mm), or sources over 120 km away (avg. length  $\times$  width = 19.5  $\times$  12.7 mm).

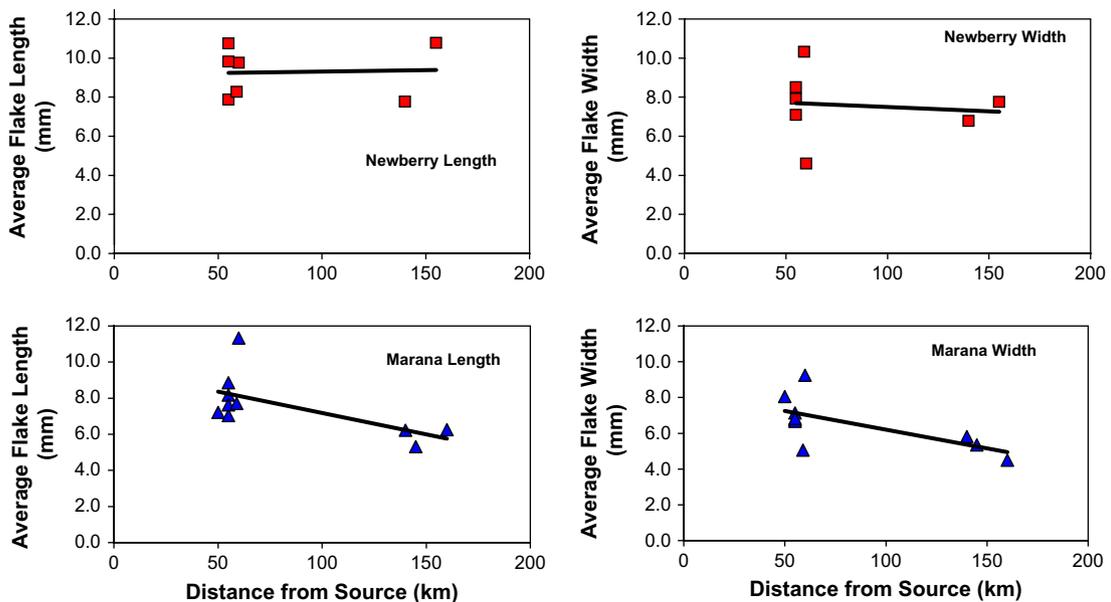


Fig. 6. Flake length and width vs. distance from source.

While the first two predictions were confirmed, Prediction #3, that Newberry obsidian includes a greater diversity of geochemical sources, was not. There is some support for this prediction if we consider the projectile points only. There, we see that the 32 Newberry points represent at least 10 geochemical types, while the 53 Marana points include only 8 types. Thus, in spite of a greater sample size, there are fewer geochemical sources represented in the Marana sample. However, to be fair, over a third of the Marana points were not assigned to individual Coso subsources, and the absence of Joshua Ridge is surely attributable to this factor. As well, we must also assume that the two “unknown” sources documented in the Newberry period represent distinct geochemical types not present in the Marana sample.

On the other hand, if we consider the debitage sample, we obtain the opposite result. Newberry flakes include seven geochemical types among 90 flakes, while Marana flakes include ten among 226. If we bootstrap the Marana flakes to make the samples sizes equivalent, that is, repeatedly and randomly sample only 90 of the 226 flakes, we obtain an average of 8.3 geochemical sources among the Marana flakes, still higher than the Newberry sample. Not only is the absolute diversity (i.e., richness) of Marana geochemical sources higher, but the evenness is higher as well. All of the geochemical sources are represented by more than one piece, most by multiple pieces, and the Saline Valley sources (e.g. Saline Valley and Queen Imposter) are well represented. On the other hand, outside of Casa Diablo and the Coso subsources, geochemical types in the Newberry assemblage are represented by single specimens only.

## 6. Discussion

The results of our analysis speak to important differences in how obsidian technologies were organized in Owens Valley and how toolstone was being differentially acquired, moved and reduced through time. Although a reduction in residential mobility explains many of the patterns, there are several trends that were unexpected based on the predictions derived by the model outlined in the beginning of the paper. We summarize the findings below by time period.

### 6.1. Newberry patterns

The Newberry obsidian assemblage appears much as we would expect of a highly residentially mobile society. Relative to the less mobile Marana families, tools and flakes are from further away on average, flakes from more distant sources are in a less-reduced state, and projectile points are more diverse geochemically.

Unexpected, though still in line with that of a mobile group, is the apparent lack of decrease in flake size with distance. Instead, it appears that distant sources were essentially at the same stage of reduction as more proximal ones. This suggests an extreme degree of mobility, so high that the time it took to travel 120–140 km resulted in little additional reduction than the time it took to travel 50–60 km (i.e., apparently raw

material was not used during transport to residential bases such as CA-INY-30). The lack of such a distance–decay pattern among waste flakes is not unknown, and has been noted elsewhere (e.g., Close, 1999). We know that Newberry groups produced large bifaces (ca. 10–20 cm long), which some archaeologists have interpreted as functional cores (e.g., Delacorte, 1999). Indeed, caches of such bifaces have been found at sites in the region, including CA-INY-30 (e.g., Basgall and McGuire, 1988; Garfinkel et al., 2004). Geochemical analyses show that such biface–core caches often include items fashioned from glass with different geochemical signatures. Such caches imply some degree of toolstone curation, with anticipated future use at these particular points on the landscape. Indeed, Elston (1982) has argued that rates of curation in the western Great Basin were high before 1500 BP and relatively low thereafter. Such high rates of curation are also in keeping with high mobility.

One prediction derived from the model that was not met was higher geochemical diversity among waste flakes in the Newberry period. Instead, we saw heavy use of a few geochemical types (e.g., West Sugarloaf and Casa Diablo) and only sparing presence of others. Interesting in this regard is the absence or near-absence of nearby sources such as Fish Springs, Saline Valley, and Queen Imposter, geochemical sources that were used in much higher frequencies during the ensuing Marana period. As well, sources that are equally distant from CA-INY-30 as Casa Diablo, such as Mono Glass Mountain and Queen, were also sparingly transported. The lack of these sources is puzzling because most lie between CA-INY-30 and the source of the heavily used Casa Diablo obsidian in Long Valley. This is particularly so in the case of Fish Springs, which is directly on the line between these endpoints, nearly halfway between them. The presence of some projectile points at CA-INY-30 made out of these obsidians shows they were exploited at some previous point during the seasonal round. As well, research on the northern end of Owens Valley (Eerkens and King, 2002) shows that Fish Springs obsidian was carried over 50 km north and reduced there, and that Mono Glass Mountain was heavily used in that region. Why would Newberry groups ignore obsidian sources such as Fish Springs on their movements between Long Valley and base camps such as CA-INY-30?

One potential factor in the answer to this question is the quality of Fish Springs obsidian, which is not as high as Casa Diablo or West Sugarloaf. Although there is plenty of workable glass and large bifaces were occasionally fashioned, much of the obsidian available on the surface has impurities that make knapping more difficult. The same can be said of Mono Glass Mountain, but this is not true of Queen and Queen Imposter, both of which contain high-quality glass available as large knappable nodules.

A second and more likely factor relates to how people made use of the landscape. All evidence indicates that the people who occupied CA-INY-30 did not stop to exploit resources, including obsidian, near places like Mono Glass Mountain, Saline Valley, and Fish Springs when returning from higher elevations in Long Valley. Again this suggests extremely

high mobility with specific destinations in mind. Apparently people were moving and encountering high-quality obsidian so often that retooling at other obsidian sources on their way to CA-INY-30 was not necessary. From a foraging perspective, this also suggests that food resources available around these ignored obsidian sources were of much lower return rates than those available in Long Valley, where Casa Diablo is, and around Owens Lake, where CA-INY-30 is, at least at the times of the year CA-INY-30 was occupied (apparently most of the year judging by carbonized seeds and migratory bird remains; [Basgall and McGuire, 1988](#)). Overall, Newberry patterns suggest highly targeted extraction and transportation, favoring exploitation only of certain obsidian sources, to the exclusion of others, before returning to CA-INY-30.

To this point in the paper, all of our interpretations have been based on an assumption of direct obsidian procurement within a mobile settlement system. We think the patterns in obsidian support this interpretation, that is, in favor of direct procurement as the primary means of acquiring obsidian. If exchange had been the preferred acquisition method, presumably within a more sedentary residential settlement system, it is difficult to understand why closer sources, such as Saline Valley, Queen Imposter, and Fish Springs are not better represented in the debitage profiles, relative to Casa Diablo. These other sources are present among the projectile points and were thus clearly suitable to produce a range of tool types. If obsidian had been valuable enough such that long-distance exchange of workable obsidian from Casa Diablo was worthwhile, based on economic principles, it would seem likely that people living close to these other sources would also produce bifaces for exchange and consumption at CA-INY-30. Moreover, with exchange as the primary means of acquisition, we would expect that more distant sources would often be acquired in down-the-line trading. If so, we would have expected a stronger negative relationship between flake size and distance.

Our interpretations do not mean that exchange of obsidian was absent during the Newberry period, indeed, trans-Sierran movement of obsidian into the Central Valley, Bay Area, and coast was almost surely by exchange. Similarly, obsidian was surely exchanged (or shared) among individuals in a base camp. We only suggest that within Owens Valley long-distance exchange was not a major means of acquiring obsidian in Newberry times.

### 6.2. *Marana patterns*

By contrast, Marana-period acquisition followed a very different trajectory. Debitage assemblages show a marked pattern of decreasing size with distance. In whatever form Marana obsidian was being moved, upon reaching INY-30 the distant sources appear to have been in a highly reduced state. Reduction of distant sources was confined to small reshaping and/or finishing activities. As well, more distant sources are much less frequent than more proximal ones, resulting in a steeper fall-off curve with distance from source. Such a pattern is consistent with a society that is not very residentially mobile. It is

difficult to state with certainty how such distant obsidian was being acquired, however, we strongly suspect that it was being moved as finished tools, such as projectile points or small knives, likely hafted on arrows or wooden handles. Moreover, we suspect that such movement was largely the product of down-the-line exchange rather than direct procurement.

More local sources were obtained in a less-reduced state, perhaps as bifaces or prepared cores (debitage with cortex is absent), and were used to produce a range of implements. As a result, debitage from local sources tends to be larger on average but also more variable, including both earlier percussion and later pressure debris. Such obsidian may have been traded or directly procured, though the former seems likely given the importance of obsidian exchange in the ethnographic record (e.g., [Steward, 1933, 1938](#); see also [Davis, 1961](#)) and archaeological evidence indicating territorial control over the distribution of obsidian from some sources (e.g., [Bettinger, 1982](#)).

At the same time, a wide range of geochemical types from the north, south, and east were accessed by INY-30 inhabitants during the Marana period. The diversity of sources is just as high as in the Newberry period. If trade was the primary means of acquiring obsidian, as we suspect, this pattern speaks to the wide-ranging trading networks that had developed in the Owens Valley region by the Marana period. Inhabitants at INY-30 seem to have been involved in direct trade with groups in nearly all cardinal directions, and received other more exotic items via down-the-line trading.

### 6.3. *Issues of mixing*

We attempted to examine diachronic change by controlling the context of the analyzed flakes, only taking samples that we felt were confidently associated with discrete house floors. Excavations at INY-30 clearly showed that various parts of the site had been occupied for several thousand years ([Basgall and McGuire, 1988](#)), leaving the possibility that some of the later houses may have been built on older cultural deposits. Thus, it is possible that the association between any individual flake and a floor is spurious in this section we consider possible issues of mixing and contamination.

Another potential means to control for temporal context is to perform obsidian hydration analysis on each flake. Unfortunately, due to the destructive nature of this technique, especially on small pressure flakes, we could not follow this approach. Obsidian hydration was an important component of the original investigations at INY-30. [Basgall and McGuire \(1988, p. 123\)](#) obtained hydration measures on artifacts associated with a range of temporal contexts, including houses from both time periods of interest here. Hydration readings associated with Newberry floors were predominantly within the range expected, and hence, they thought the Newberry contexts to be relatively unaffected by mixing. On the other hand, they rejected over half of the readings on flakes associated with Marana floors because hydration rims were too large to be late prehistoric in age. They attributed this to stratigraphic mixing as well as scavenging of older flakes by Marana peoples.

Although mixing of temporal contexts may be a potential problem for the Marana houses, several factors suggest these processes are more limited in extent, especially in the sample we selected for analysis. First, while a significant proportion of the flakes from Marana houses contain aberrant hydration readings, 8 of 12 projectile points recovered from Marana house contexts are of the correct type (i.e., Cottonwood and Desert Side-Notched; with two Little Lake and two Rose Springs points out of context). Moreover, none of the four aberrant point types was found directly on a house floor. All were found stratigraphically above the floors (10–40 cm) in the fill zone. Thus, there is much less evidence for stratigraphic mixing among the projectile points.

Second, it is likely that the method of selecting flakes for hydration analysis contributed to a larger number of aberrant readings versus our geochemical sourcing sample. Among the debitage in particular, the hydration sample was comprised mainly of artifacts large enough to also be analyzed by XRF (generally greater than 8 mm in diameter and thicker than 1.5 mm). If house cleaning was a regular activity in prehistory, it is likely that larger flakes would have been differentially removed from their primary house-floor context. Any larger flakes currently associated with the floors are more likely to be due to depositional processes, such as post-occupation infilling of house depressions. Since our sample comprised mainly small pressure flakes, we believe a better case can be made for their correct association with the floors. We hope to test this notion in the future by analyzing a sample of the smaller flakes by hydration.

Third, the original hydration sample included a number of artifacts within the more general “fill zones” of houses, contexts that are more likely to include contaminants. This is not a fault of the excavators, as they attempted to get source-specific hydration readings from flakes in as best a context as possible. However, given the sampling strategy this may have required them to include larger flakes from slightly further away from the actual house floors. By contrast, our sample comprises mainly flakes lying directly on the floors, providing a firmer association between living surface, radiocarbon date, and artifact.

Finally, if mixing is a problem for the Marana contexts, it is clear that these flakes are not derived from earlier Newberry contexts. As shown, Newberry and Marana flake profiles are unlike one another, the latter including significant numbers of geochemical types not represented in the Newberry sample. If the Marana houses were dug into older cultural deposits and those older deposits are contributing significant numbers of artifacts to our geochemical analyses, those deposits are clearly not Newberry in age. An alternative source of contamination could be older Lake Mojave (ca. 9000–6000 BP) and Little Lake (ca. 6000–3500 BP) components. However, many of the geochemical types represented in the Marana sample are also uncommon in the earlier deposits. Moreover, the spatial location of Lake Mojave and Little Lake deposits (in the northern and south-central areas) are not in close proximity to the majority of Marana houses (in the north-central and southeastern sections), again limiting the likelihood that these deposits are significantly skewing our results.

Inevitably, a section like this comes off sounding defensive about our sample selection. Our intention is not to be defensive, but to critically examine our analyses for potential sources of bias. The original excavators clearly attempted to evaluate the same criterion. We feel that the issues discussed above support the notion that mixing, contamination, and/or scavenging is not a significant problem for our study. Although there may be a small number of intrusive flakes in our sample, especially the Marana houses, the patterns among and between houses are robust enough to show marked and consistent differences between different time periods. If mixing was a pervasive problem, we would expect greater homogeneity among our samples.

## 7. Conclusions

Our analyses largely support previous settlement models proposed for the Owens Valley (e.g., [Basgall, 1989](#); [Bettinger, 1999a,b](#); [Delacorte, 1999](#)). Newberry groups appear to have been quite mobile, much more so than Marana groups, and had ample access to obsidian, including some sources at great distance from base camps such as CA-INY-30. Marana groups appear to have been much more sedentary, but still accessed obsidian from a range of sources. However, our analyses highlight important details of these settlement patterns that have not previously been discussed in great detail.

In particular, we were surprised at the high degree of mobility suggested by the Newberry debitage assemblages. People acquiring obsidian during this period appear to have moved so quickly that the amount of reduction in toolstone en-route was the same for movements of 50–60 km as it was for 120–140 km. As well, they often ignored smaller intermediary sources where the glass is often of poorer quality. To us, this looks like rapid “jumps” across the landscape to reach very specific target destinations. Use of smaller and perhaps inferior sources of obsidian was not necessary, likely because knappers knew they would be on the move again soon and could embed obsidian procurement within those activities. Based on studies by [Bamforth \(1986\)](#), such a pattern should correlate with low tool maintenance & little recycling of tools. Additional research is necessary to fully explore this issue, but preliminary technological studies of Newberry flaked stone assemblages support this prediction (e.g., [Basgall, 1989](#); [Delacorte, 1999](#); [Eerkens and King, 2002](#)).

Of course, it is not necessary that the entirety of Newberry society was highly mobile and moved simultaneously. Thus, it is possible that Newberry residential bases may have been relatively stable (i.e., semi-sedentary) and that only some segments of the population were making these extreme and rapid movements, for example, young men on hunting expeditions. This line of reasoning would explain why the small number of Newberry dwellings that have been excavated, including those at INY-30, often appear to be heavily used and invested with substantial labor (e.g., semi-subterranean). Such houses would be expected of groups expecting to spend a significant amount of time in a particular region (e.g., [Binford, 1980](#); [Kelly, 1983](#); [Kent, 1992](#); [Yellen, 1977](#)).

Indeed, a scenario involving highly mobile groups of young male hunters associated, but not always living, with more residentially sedentary women and children is consistent with several models that have been proposed in nearby regions (e.g., Broughton, 2004; Zeanah, 2004). More specifically, Hildebrandt and McGuire (2002) and McGuire and Hildebrandt (2005) have recently suggested that the hunting of large game for prestige was an important activity for young men during the Newberry period. Such expeditions may have taken men from base camps like INY-30 to distant hunting grounds in Long Valley, where Casa Diablo obsidian is found. Because the population levels in Owens Valley may have already been fairly high, hunting territories near places like Fish Springs may have been either hunted out or controlled by local groups. The lower human population levels in Long Valley and attendant higher densities of game may have enticed Owens Valley hunters to make the long trek, but to do so quickly without stopping along the way to retool. Once in Long Valley, hunters may have made quick trips to the Casa Diablo obsidian quarry to retool before returning home, again, a quick journey with few stops and/or opportunities to reduce obsidian before reaching INY-30.

As well, our analyses of Marana obsidian support existing models (e.g., Basgall, 1989; Bettinger, 1982, 1999b; Delacorte, 1999), but again highlight details that expand our understanding of settlement patterns and exchange relations in this time period. We expected the dominance of local obsidian sources in debitage and tool assemblages. However, we were surprised at the diversity of geochemical types represented in the debitage assemblages, indicating a wide range of exchange relations with nearly all neighboring regions. Whether the goal of such exchange relations was merely the acquisition of obsidian, or whether obsidian was merely a component of a wider range of goods that were moved, or whether obsidian merely served as a symbolic token of broader political and social alliances (e.g., gifts), is still unknown, though we certainly suspect one of the latter two given ethnographic descriptions (see Davis, 1961). In any case, it is apparent that Marana groups expended considerable effort moving obsidian across the landscape in a range of directions.

Most interestingly, our results nearly mirror those of McGuire (2002) in northeastern California. In an analysis of a large dataset of both projectile points and flakes across several distinct environmental zones, he found Middle Period (equivalent to our Newberry Period) obsidian acquisition to be characterized by a focus on just a few sources (i.e., low diversity), often to the exclusion of closer sources. He attributed this to higher logistical mobility to intensively exploit just a few key obsidian sources (McGuire, 2002, p. 97). By contrast, Late Period (overlapping with our Marana Period) people had access to a greater range of sources, a pattern he attributed to greater rates of exchange. Unfortunately he did not examine fall-off patterns for flake size against distance over time, thus we could not compare that aspect of our research with his, but such an analysis would be extremely interesting. In any case, that we found essentially the same diachronic patterns as McGuire (2002), suggests that these processes involving obsidian acquisition are applicable to broad spatio-temporal contexts.

In sum, we hope to have shown that detailed geochemical analyses of large numbers of obsidian artifacts, combined with technological analyses and careful control of temporal context, can reveal important information about a range of prehistoric behaviors, including mobility patterns, the organization of lithic technologies, and exchange relations. Moreover, techniques such as LA-ICP-MS facilitate rapid and non-destructive analysis of large samples of artifacts, large and small, to help reveal these patterns.

### Acknowledgements

We thank Kelly McGuire, Robert Yohe and JAS reviewers for commenting on earlier drafts, Mark Basgall and Kelly McGuire for generating the CA-INY-30 assemblage, Lisa Deitz and Robert Bettinger for providing access to collections, Michael Glascock and Tim Carpenter for providing source samples, and the University of California Davis for funding the analyses. We also thank Robert Bettinger for conversations and input regarding interpretation of the data.

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