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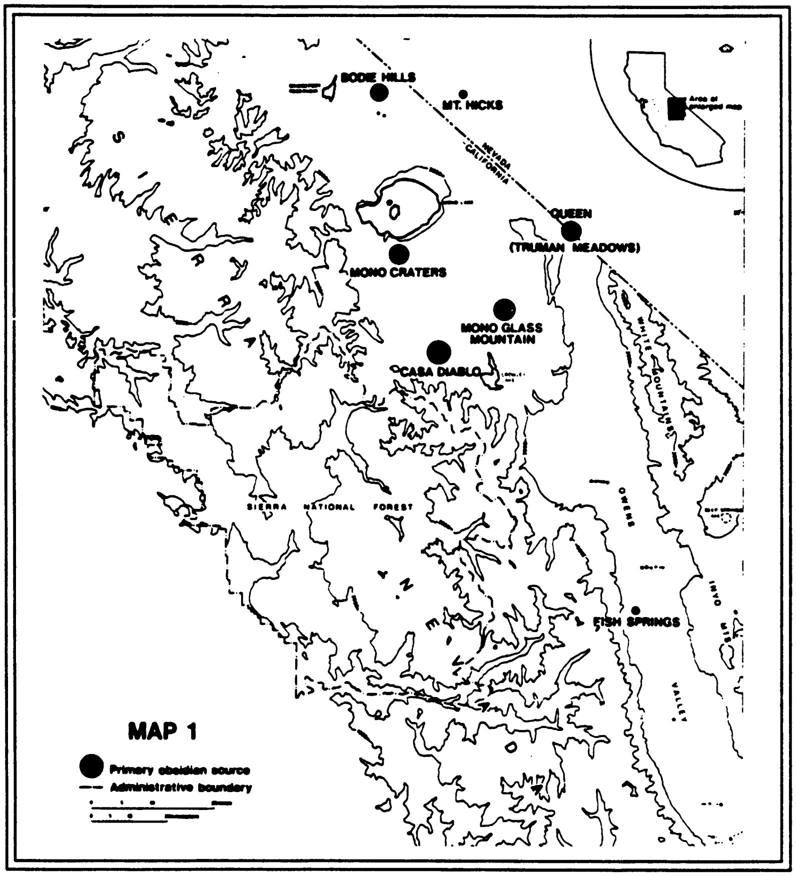

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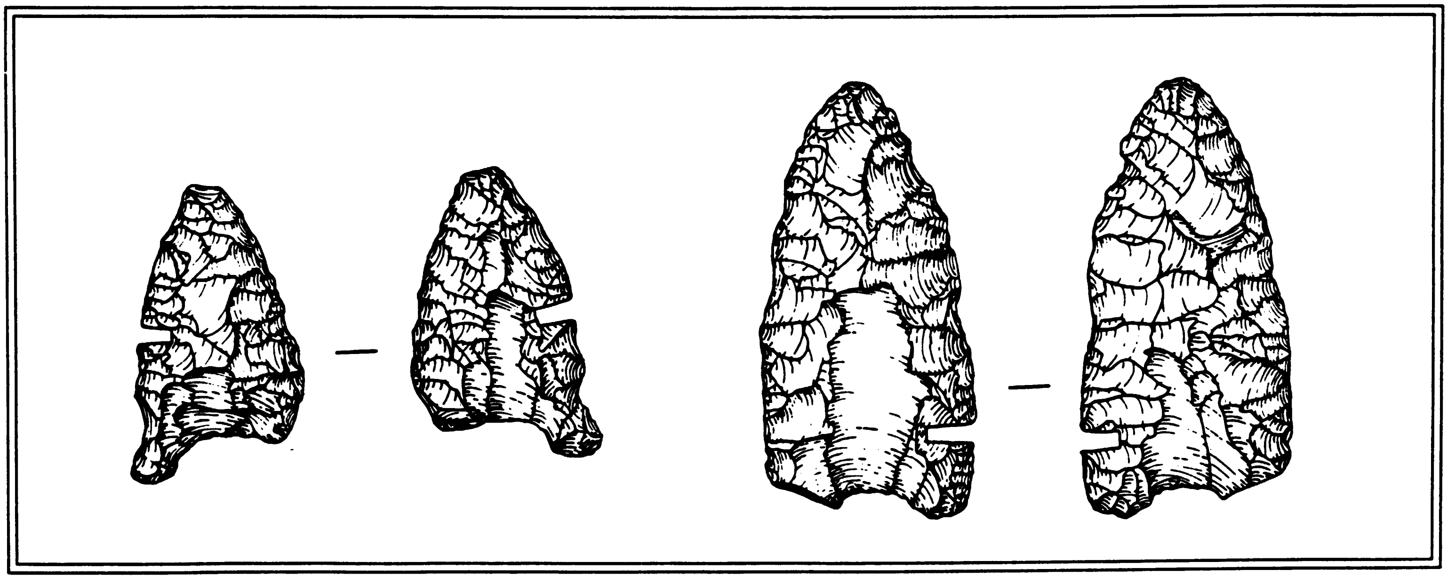

CONTRIBUTIONS
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UNIVERSITY OF CALIFORNIA
ARCHAEOLOGICAL RESEARCH FACILITY

Number 45 June 1984

OBSIDIAN STUDIES IN THE GREAT BASIN

Edited by

Richard E. Hughes

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Preface to Second Printing

Ten years ago I would have been skeptical if someone had told me that there would be an interest in reprinting *Obsidian Studies in the Great Basin.* Regardless, the volume, originally published in a run of 400 copies in June 1984, has been out-of-print for more than five years, and the Archaeological Research Facility has received a steady stream of requests for it.

On reflection, the call to make Contribution 45 again available is, I think, a tribute to the burgeoning interest in obsidian studies worldwide. In 1982, when I organized the symposium at the 18th Great Basin Anthropological Conference in Reno, Nevada at which most of the papers in this volume were first presented, obsidian studies in western North America were scarcely a decade old. Although pioneering work in obsidian characterization began during the middle 1960s, little of that work reached a wider audience until several years later. Because so much obsidian work has been completed in the Great Basin over the past decade, it is easy to forget that until the early 1980s, only three studies had been published specifically focusing on Great Basin obsidian characterization (Jack and Carmichael 1969; Condie and Blaxland 1970; Nelson and Holmes 1979), although somewhat greater attention had been devoted to obsidian hydration (e.g. Michels 1969; Layton 1972a, b; 1973).

Over the last ten years archaeological research employing chemical characterization and hydration rim measurement has increased by an order of magnitude; a citation list of such studies would run several pages. However, since many of the themes of contemporary obsidian studies have changed little during this time, the research strategies applied, and general concerns voiced, by the authors of papers in Contribution 45 are as appropriate today as they were when they were first published.

Richard E. Hughes
Geochemical Research Laboratory
December 1, 1994

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EDITOR'S PREFACE

Most of the papers in this volume were presented in preliminary form at a symposium I organized and chaired at the 18th Great Basin Anthropological Conference, held in Reno, Nevada, September 30, 1982. Two manuscripts (by Bettinger, Delacorte and Jackson and by Stross) were solicited for publication following the conference.

I thank John Graham (Coordinator, University of California Archaeological Research Facility) for making a place for this volume in the *Contributions* series, and Suzanne Sundholm (Archaeological Research Facility) for assistance in seeing the manuscripts through to publication.

R.E. Hughes
July 26, 1984

OBSIDIAN SOURCE ANALYSIS

OBSIDIAN SOURCING STUDIES IN THE GREAT BASIN: PROBLEMS AND PROSPECTS

Richard E. Hughes

Introduction

During the past few years there has been an ever increasing demand for obsidian sourcing studies in archaeological research. The reasons for this demand are obvious: accurate and replicable matches between parent geological sources and obsidian artifacts are prerequisite to establishing source-specific obsidian hydration rates and to determining prehistoric trade and exchange relations.

Archaeologists have eagerly submitted artifacts for analysis, and obsidian sourcing studies have generated tremendous quantities of data. Up to this point, however, there has not been a corresponding enthusiasm for critical evaluation of the accuracy and replicability of these source assignments, and I think it would be fair to say that the results of most sourcing studies are accepted on faith. Uncritical acceptance of the results of sourcing studies occurs, for the most part, because archaeologists typically are unable to evaluate the methods and techniques applied by specialists to assign artifacts to sources. Because of this, incorrect source assignments rarely are detected.

This paper has three purposes: first, to consider some of the methods commonly used by specialists to identify sources and to assign artifacts to them, second, to offer a critical appraisal of application of these methods and, third, to offer suggestions about some of the ways incorrect source assignments can be detected.

The common denominator underlying all sourcing studies is that there exists unique combinations of constituent elements in obsidian which, when considered together or in various subsets, allow distinctions to be made between obsidian sources. Once these distinctions have been made, obsidian artifacts are assigned membership in one or another of the sources on the basis of how closely they resemble the source profiles.

Ternary Diagrams

These source profiles were depicted early on in California obsidian sourcing studies by the use of ternary, or triangular, diagrams. Plots for sources and artifacts were determined in the same way: counts on three elements (usually Rb, Sr and Zr) were summed, then divided into Rb, Sr and Zr values individually to determine the relative percentages for plotting on intersecting axes of the diagram. This method is simple, straightforward and easy to compute and it served admirably in early studies (i.e. Stross et al. 1968; Jack and Heizer 1968) where there existed relatively pronounced differences in trace element composition between sources.

However, there are two basic difficulties with the ternary diagram method of presentation which limit its effectiveness. First, it is quite difficult to distinguish between sources with overlapping plots. As depicted in Figure 1, the cluster of dots represent artifacts from the Humboldt Lakebed site, Nevada (Ch-15) analyzed by Robert Jack (unpublished data). The dots of immediate concern here fall for the most part within the Rb, Sr and Zr variation depicted for the Casa Diablo source (Jack 1976: 211), located in the Mono Basin. Based solely on this ternary diagram plot, many of these artifacts probably would have been assigned to the Casa Diablo source. However, subsequent to Jack's Humboldt Lakebed artifact analysis, a source of artifact quality obsidian has been located near Majuba Mountain in northwestern Nevada, and the ternary diagram plot for this source overlaps with Casa Diablo. Recent analyses of artifacts from Lovelock Cave (Ch-18), located only a few hundred meters from the Humboldt Lakebed site, indicates that many of the specimens that fall within the Casa Diablo range of variation on the ternary diagram in fact were manufactured from parent obsidian of the Majuba Mountain geochemical type (Hughes unpublished data; see Figure 1). This separation could not have been made solely on the basis of Rb, Sr and Zr plots.

The second difficulty arises from the fact that specimens from the same source will not plot in the same place on the ternary diagram if different elemental measurement units are employed. Diagram plots based on parts per million (ppm) trace element concentrations will not necessarily overlap with those based on peak intensity counts. Figure 2 shows that ternary diagram plots derived from peak intensities of Casa Diablo source specimens (Jackson 1974: Figure 15), although generally similar, do not correspond with plots for the same trace elements generated from ppm estimates (Jack, unpublished data). In addition, ppm plots for Queen and Mt. Hicks both fall outside the range of rapid scan peak intensity plots for these same sources. In fact, Queen ppm plots fall within the range of peak intensity plots for Mono Craters, Mono Glass Mountain, Coso Hot Springs and Fish Springs. An equally dramatic contrast can be drawn by considering specimens from the Cougar Butte source in the Medicine Lake Highland of northeast California (Figure 3). The filled circles in Figure 3 depict specimens analyzed in 1978 using the rapid scan technique (Hughes 1978: 62), while the open circles represent specimens from the same source computed from ppm concentrations (Hughes 1983a). Even though six of ten specimens are common to both studies, comparision of these two plots likely would lead one to the conclusion that two different sources were represented. As a final example, Green (1982) has argued on the basis of ternary diagram correspondences that the Hawkins-Malad-Oneida locality in southeastern Idaho was the primary source employed in the manufacture of obsidian artifacts at Danger and Hogup Caves in Utah. However, comparisons of the Rb, Sr and Zr ppm values for Danger Cave and Hogup Cave artifacts published by Condie and Blaxland (1970: 280) with these same values for the assigned source (see Table 3 herein) indicate that this attribution likely is in error.

In historical perspective, difficulties with ternary diagrams were held to a minimum because nearly all the x-ray fluorescence analyses of archaeological collections between about 1967 and 1974 were done at the same laboratory, with the same machine, under the same set of analytical conditions. Thus, the work was internally consistent. Within the last five years, however, more laboratories have become involved in x-ray analysis of western North American archaeological specimens, and the issue of inter-laboratory comparison has become significant. One way around the problem of inter-lab comparison using ternary diagrams is to convert peak intensities into ppm estimates. Properly done, this conversion overcomes machine-specific differences in count rates that result in non-comparable plots; thus, when expressed in ppm, ternary diagrams can be compared directly between laboratories.

Discriminant Analysis

Recognition of the limitations of the ternary diagram method, coupled with the newfound capabilities of semi-automated energy dispersive x-ray fluorescence machines to conduct non-destructive analyses on many elements simultaneously, led some researchers to turn away from presentation of results using ternary diagrams and to explore multivariate statistical techniques.

Discriminant analysis was among the first of the multivariate techniques to be applied to western North American obsidians (Ericson 1981: 9), and later applications to obsidians in this region (i.e. Nelson and Holmes 1979) yielded positive results. Indeed, discriminant analysis appeared ideally suited to assist in obsidian characterization, since "the basic problem of (the technique) is to assign an observation, or case, of unknown origin to one of two (or more) distinct groups on the basis of the value of the observation" (Lachenbruch 1975: 1). Two different, but clearly related aims of discriminant analysis can be pursued. The first, which could be called descriptive, simply derives allocation rules to characterize the differences between obsidian sources on the basis of major, minor, trace or rare earth elements. Once this step has been accomplished, discriminant analysis can be employed to classify cases of unknown origin (these are usually obsidian artifacts) on the basis of allocation rules derived from the analysis of known sources. This latter aim is concerned with predicting source membership for ungrouped cases (cf. Habbema and Hermans 1977).

However appealing discriminant analysis might seem, there are several statistical requirements that must be satisfied before the results of the analysis can be considered reliable. Among the most important are: 1) equality of group covariance matrices, which can be assessed using Box's M statistic, and 2) multivariate normality. Even though multivariate normality is sometimes difficult to assess in the aggregate, on a univariate basis it can be monitored by inspection of ranges, means and standard deviations of each element contemplated for use as a discriminating variable. If measurement of a particular trace element, for example, yields a large standard deviation and coefficient of variation and this element does not vary significantly between sources, it should not be used in the analysis. Inclusion of poorly measured, weak, or redundant variables in discriminant analysis can actually increase the number of misclassifications (cf. Klecka 1980).

While it is commonly believed that the inclusion of larger numbers of variables in discriminant analysis results in a "better" classification, in fact this is not necessarily the case. The goal of a stepwise analysis is to find an optimal set of discriminating variables (in this case, trace and rare earth elements) which, in combination, work as well or better than the full set. Some researchers (Dunn and Varady 1966) have found that for small sample sizes, the use of many variables results in an increase in the misclassification rate when the program is asked to assign unknown cases to their known groups.

With this background in mind, let's consider the output options available with the SPSS discriminant analysis program (Klecka 1975) which have been used by some analysts (e.g. Sappington 1981a, 1981b) to measure classification validity and reliability. These are, first, F-statistics, second, classification results (or "percent correctly classified") tables, and third posterior probabilities for group membership.

The F-statistic is the test for statistical significance of the amount of separation between groups, under the assumption of multivariate distribution. The problem with using this statistic as a "true" measure of the difference between groups is that it considers absolute group sample size. In other words, comparisions between larger groups with more cases will be given more weight in the computation than comparisons between smaller groups. The net result is that these statistics tend to exaggerate differences between source pairs that contain large numbers of cases. In short, "the F-statistic is not directly related to classification performance, but is only in a vague sense connected with measuring discrimination" (Habbema and Hermans 1977: 491). It is definitely not the case that "The larger the F values, the more probable the autonomy of the pairs of groups" (Sappington 1981a: 136). Because of sample size limitations, F-statistics should be interpreted with caution.

The classification results table is essentially a vehicle for presenting information on how well the program classified cases with known group membership and, again, the results in these tables often are taken as a true indication of the reliability of the classification procedure (cf. Sappington 1981a: 137). As it turns out, however, the "percent correctly classified" procedure nearly always overestimates the apparent accuracy because "the validation is based on the same cases used to derive the classification functions" (Klecka 1980: 51). Consequently, it should come as no surprise that a remarkably high percentage of specimens of known group membership will be correctly classified because the allocation rules are applied post-hoc to classification of the very same cases from which they were generated!

So far, this discussion has been limited to consideration of problems associated with discriminant analysis classification of specimens with known group membership; that is, obsidian source standards. However, when attention shifts to classification of cases of unknown origin; that is, obsidian artifacts, one should become much more concerned about the possibility of misclassification. When classifying cases with known group membership, misclassifications could be easily assessed because the true probability of a case being from a particular obsidian source was known. In considering assigning artifacts to sources the question now becomes, "How likely is it that this artifact was manufactured from obsidian from a particular source?" The answer involves discussion of two related issues -- how probability estimates are derived in discriminant analysis, and how to interpret and evaluate them.

Two probability estimates are provided with SPSS discriminant analysis output. P(G/X) is the probability that the object in question is a member of the assigned obsidian source group, while P(X/G) is the probability that a specimen from the assigned source group would be as far from the group centroid as the particular artifact being classified. The first probability, P(G/X), sometimes termed the posterior probability, has been most widely employed in western North American obsidian studies because it appears to be the most straightforward measure of how confident one can be in the artifact-to-source assignment (cf. Nelson and Holmes 1979; Sappington 1981a, 1981b; Nelson, this volume). If one gets a posterior probability of 1.0, the usual interpretation is that this signals a "perfect" fit between the artifact and that particular obsidian source.

Unfortunately, closer inspection of the statistical assumptions underlying the computation of this posterior probability reveal that this estimate is, in fact, quite poorly suited for use in obsidian studies. The reason for this takes us back to the assumptions underlying classical discriminant analysis -- that an ungrouped case is in fact a member of one of the groups in the sampling universe (cf. Kendall 1957; Tatsuoka 1971; Klecka 1980). In applications of discriminant analysis to Great Basin obsidian studies, one cannot safely assume that all potential sources of obsidian within a particular region have been included in the sampling universe (cf. Ward 1977; Hughes 1982). Because the posterior probability is computed on the basis of the assumption that complete information exists about the sampling universe, and further that the ungrouped artifact must be a member of one of these groups, this probability estimate can be completely misleading. The allocation rules in discriminant analysis dictate that a match must be made to one of the sources in the sampling universe regardless of how poorly the elemental measurements of the artifact match the measurements for the source to which it is assigned. Simply stated, the posterior probability, when considered in isolation, is of little utility in assigning artifact to sources, and it is extremely ill-equipped to detect errors in source assignment because of the assumption that the artifact must be a member of one of the known groups.

To illustrate this point, consider the data in Table 1. This table presents trace element concentrations for the Horse Mountain obsidian source in southcentral Oregon, along with trace element ppm values for a projectile point excavated from the King's Dog site (CA-Mod-204) in Surprise Valley, northeast California. When these data were analyzed using the SPSS discriminant analysis program (see Hughes 1983a), the King's Dog artifact was assigned a posterior probability (P G/X) of 1.0, indicating what appeared to be a convincing match to the Horse Mountain source.

Unfortunately, the assignment was dead wrong. As can be seen when the actually ppm values for Horse Mountain and the King's Dog artifact are compared, the correspondence is not all that great. However, since it is the best match within the universe of sources included in the study, the program was completely consistent in assigning this artifact such a high posterior probability of being a member of the Horse Mountain source group.

Detecting Misclassifications

Given these limitations, how can one detect incorrect source assignments in discriminant analysis and identify artifacts that may not belong to any of the sources in the sampling universe? A useful way to do this is to determine the dispersion of Mahalanobis D^2 values around each obsidian source group mean, and then to establish tolerance limits for these D^2 distances on a source-by-source basis. These D^2 distances can be understood as the multivariate distances of an individual artifact (or case) to each of the obsidian source group centroids. Cases are classified into a particular group on the basis of the smallest D^2 distance. High D^2 values, compared to the observed dispersion of D^2 values for source standards to which the artifact is assigned, can profitably be used to detect an artifact that may not be a member of any source included in the sampling universe (cf. Luedtke 1979).

In some packaged discriminant analysis programs (i.e. SPSS) D^2 values are not one of the available output options. In this instance, the P(X/G), the second probability mentioned above, can be used as a rough approximation of D^2 distances. A low P(X/G) probability value likely signals that the artifact in question lies far from the assigned obsidian source group centroid, and therefore that this artifact would be associated with a high D^2 value.

To provide an illustration of how D^2 distances can be used to assess artifact-to-source assignments, let's return to consideration of the data in Table 1. The lower portion of this table presents the range, mean and standard deviation of the D^2 values determined for source specimens from Horse Mountain. Above these data is the D^2 value determined for the King's Dog projectile point. As is apparent, the observed D^2 value for this artifact lies about 80 standard deviations from the mean of the Horse Mountain source even though it was assigned to this source with a posterior probability (P G/X) of 1.0! The large D^2 value for this artifact, relative to the dispersion of D^2 values for the source group, indicates that in fact the artifact lies far from the Horse Mountain group centroid. Additional examples could be cited, but this one illustrates how the use of D^2 values on a source-by-source basis can make it possible to identify artifacts which do not belong to any of the sources in the sampling universe. It should be emphasized that this misclassification could not have been identified solely on the basis of posterior probability (P G/X) interpretation.

Detecting Measurement Errors

Recall that it was stated earlier that one of the requirements of discriminant analysis was that the discriminating variables (in this case, trace and rare earth elements) should conform to a multivariate normal distribution. Although multivariate normality is not readily assessed, it can be monitored in a general way by inspection of the means and standard deviations of the individual elements contemplated for use as discriminating variables. If elemental measurements are highly variable, this usually signals that either the element is not measured well by the particular analytical system, or that there is a great deal of trace element variability present in the parent geological source material.

To see how one might assess whether particular trace and rare earth elements should be used in discriminant analysis classification, refer to the data in Table 2. This table presents the means and standard deviations for ten elements measured by R.L. Sappington at the Idaho Bureau of Mines and Geology, University of Idaho (Green 1982: Tables 2-7) on obsidian source specimens from Idaho. The measured intensities for these ten elements were said to be "ideally quantifiable for the application of statistical procedures" (Sappington 1981a: 135, 139) and all ten were employed as discriminating variables in SPSS discriminant analysis. Because no U.S.G.S. or other international standard rocks apparently were analyzed, it is not possible at this stage to assess the accuracy of these measurements. Consequently, the data in Table 2 must be evaluated in terms of precision -- that is, how uniform the measurements are for particular elements within and across sources. Elements that are not well measured should be excluded from consideration in geochemical characterization studies (see Bowman, Asaro and Perlman 1973: 312; Deutchman 1980: 124; Hughes 1982: 176-178; 1983b: 402).

Because of the marked differences bewteen mean values apparent in Table 2, it is not possible to compare standard deviations directly to determine how well particular elements were measured. To do this, coefficients of variation (CV%)[1] were computed for each element from each source to facilitate comparisons between groups with very different means (cf. Blalock 1972: 88). Put another way, the coefficient of variation provides a good indication of the homogeneity of source-specific elemental variation. Using the guidelines proposed by Thomas (1976: 84):

> "...most CV (measured upon biological variables, at least) should lie between 4 and 10 percent, with 5 and 6 percent being good average values. Observed values much below this range often indicate that the group selection was inadequate to represent the overall variability of the variable. Groups showing values greater than 10 percent or so probably are unpure, possibly because the underlying distribution is bimodal."

The CV percentage values for obsidian source standards measured at the University of Idaho indicate a considerable amount of intra-element variability. Assessed on the basis of CV percentages, Ba, Zr and Rb appear to be the elements best measured by this system, while the other seven (Fe, Sr, Y, Nb, Sn, La and Ce) are much more variable and probably would not be good candidates for inclusion as discriminating variables in discriminant analysis.

Although most of these inter- and intra-element measurements appear too mutable to be used in discriminant analysis, one cannot decide on the basis of these data whether there may be high measurement error in the x-ray fluorescence measurement procedure, or whether these elements are, in fact, as inherently variable in these sources as indicated in Table 2. In order to resolve this issue, a random sample of obsidian source standards from the Hawkins-Malad-Oneida

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[1] Also referred to as the "coefficient of variability" (Friedman 1972: 104-105) and the "coefficient of relative variation" (Ott, Mendenhall and Larson 1978: 126).

(cf. Sappington 1981a: "Oneida"; Nelson, this volume, "Malad") obsidian source was analyzed, and these data were compared to a sample from the same source analyzed at Brigham Young University (see Table 3; also Nelson, this volume, source #31). Analytical conditions associated with the U.C. Berkeley measurements appear in Hughes (1983a, 1983b); those employed at Brigham Young University appear in Nelson (this volume) and Nelson and Holmes (1979).

It is immediately apparent from inspection of Table 3 that the analyses conducted at U.C. Berkeley and at Brigham Young University are in exceptionally close agreement (see Hughes, Hampel and Nelson n.d.) and it is correspondingly clear from comparison of CV percentages in Tables 2 and 3 that the University of Idaho system evidences significantly greater measurement fluctuations on specimens from the same source. In most cases, University of Idaho measurements are <u>at least</u> twice as variable as those conducted at the other two laboratories. This table suggests that while the University of Idaho system is comparatively stable for Ba and Zr measurement, Rb, Sr, Y, Nb and Ce values are not measured with acceptable precision. To the degree that the magnitude of measurement variability apparent in Table 2 is represented in other obsidian sources in Sappington's (1981a; 1981b) sampling universe [2], one would be compelled to suggest that these poorly measured elements should not have been included as variables in discriminant analysis.

Summary

Without thorough consideration of some of the pitfalls of discriminant analysis applications in obsidian sourcing studies it is difficult to determine, for any particular analysis, whether one of four outcomes has resulted:

First, one could get the wrong result because of improper use of the method. In this case, an incorrect artifact-to-source assignment may have been accepted by the analyst due to unperceived violation of assumptions, poor measurement of discriminating variables (trace elements), or the possibility that too much "noise" (redundant or unnecessary variables) was included in the analysis.

Second, one could get the wrong result even though the method was used properly. In this instance, an incorrect assignment of artifact-to-source was made and no statistical assumptions were violated. This may happen because the analyst erroneously accepts a high posterior probability (P G/X) value as indicating a "correct" assignment. As discussed above, the use of D^2 values can help detect this kind of error.

Third, the correct result could be obtained even though the method was used improperly. In this case, a correct classification of an artifact-to-source would be made in spite of violation of statistical assumptions, poor element measurement, or inclusion of redundant variables in the analysis. This usually means that the elements measured on both the artifact and the assigned source are in such close, unique correspondence that the correct assignment will be made no matter what the analyst does.

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[2] This is not possible to determine from the published reports (Sappington 1981a, 1981b) because the raw data on obsidian source standard measurement are not presented.

Fourth, one can obtain the right result using the method properly. This happens, of course, when an artifact is correctly assigned to source and all statistical requirements and measurement criteria have been met. I should caution that a "correct" assignment does not mean that the assignment is correct in any ultimate sense (see Hughes 1983a) — just correct insofar as program requirements and optimization procedures have been satisfied within the framework of probability estimates fundamental to the operation, and interpretive limitations, of the technique.

As is probably clear by now, there are numerous ways to unknowingly get the wrong answer using discriminant analysis. Discriminant analysis classifications often are difficult to troubleshoot even by specialists in multivariate statistical analysis because of the complex interaction among discriminating variables, the multiplicity of statistical assumptions that must be addressed, and the translation of elemental values into slightly alien classification functions and discriminant scores.

Conclusions

At the beginning of this study, I said that this paper had three purposes: to consider some of the methods used to identify obsidian sources and to assign artifacts to them; to offer a critical appraisal of the applications of some of these methods; and to offer some suggestions about some of the ways incorrect source assignments can be detected. Up to this point, I have devoted most attention to the first two, but the third is perhaps the most important to the archaeological community because archaeologists rely on the results of obsidian sourcing studies to provide the substantive data base required to test and refine extant interpretations and reconstructions of prehistoric exchange relationships in the Great Basin. Because of this it is necessary to take a close and critical look at the methods and techniques employed to identify the sources of obsidian artifacts. This is not to say that to do this, archaeologists must re-tool and become multivariate statisticians. I do suggest, however, that archaeologists expend the effort to obtain basic information from any geochemical characterization analysis, so that even if they do not feel competent to assess the work, enough information will be available for others to do so (cf. Ives 1975).

First, it is important to know how the data were generated; this includes machine specifications, whether or not any U.S.G.S. or other international rocks were analyzed as standards, as well as specification of data reduction procedures and overlapping peak stripping routines (see Hughes 1983a: 25-30; Nelson and Holmes 1979: 67-68; Hampel, this volume). It is also important to know whether the resulting data are reported in quantitative units (ppm values) or in semi-quantitative fashion (elemental intensities, peak height amplitudes, or ratios of these) for reasons discussed earlier. Probably most important, it is imperative that the elemental values (whether quantitative or semi-quantitative) be presented for each artifact analyzed along with values measured in comparable units for each of the obsidian sources to which the artifacts are assigned. Given the variable interpretations possible when quantitative and semi-quantitative modes are mixed, the importance of this requirement is by now probably obvious. There are other technical details pertinent to discriminant analysis classifications that should be required (see Hughes 1983a: 53-78), but these will be discussed elsewhere.

Finally, it should be stressed that obsidian studies in the Great Basin are in their infancy, and this places sharp emphasis on taking first things first. No matter how sophisticated the data manipulation, the results will only be as good as the fundamental measurements they are based on. Garbage in, garbage out. Before interpretive studies can effectively be completed, the strengths and weaknesses of the techniques used to identify sources and to assign artifacts to them should be scrutinized. Unless accurate and replicable geochemical characterizations of obsidian sources and artifacts can be made, it will be impossible to develop a broad comparative data base from which convincing arguments about the social consequences of prehistoric obsidian distributions can be advanced.

Acknowledgements

I thank Michael Miller, Statistical Laboratory, University of California Davis, for discussions and constructive comments on this paper; Jeanette L. Blomberg for suggestions that improved content; Joachim Hampel for technical support and assistance; James P. Green for providing obsidian source specimens from Malad, Idaho; and Robert N. Jack for generously allowing me to present the results of some of his unpublished analyses.

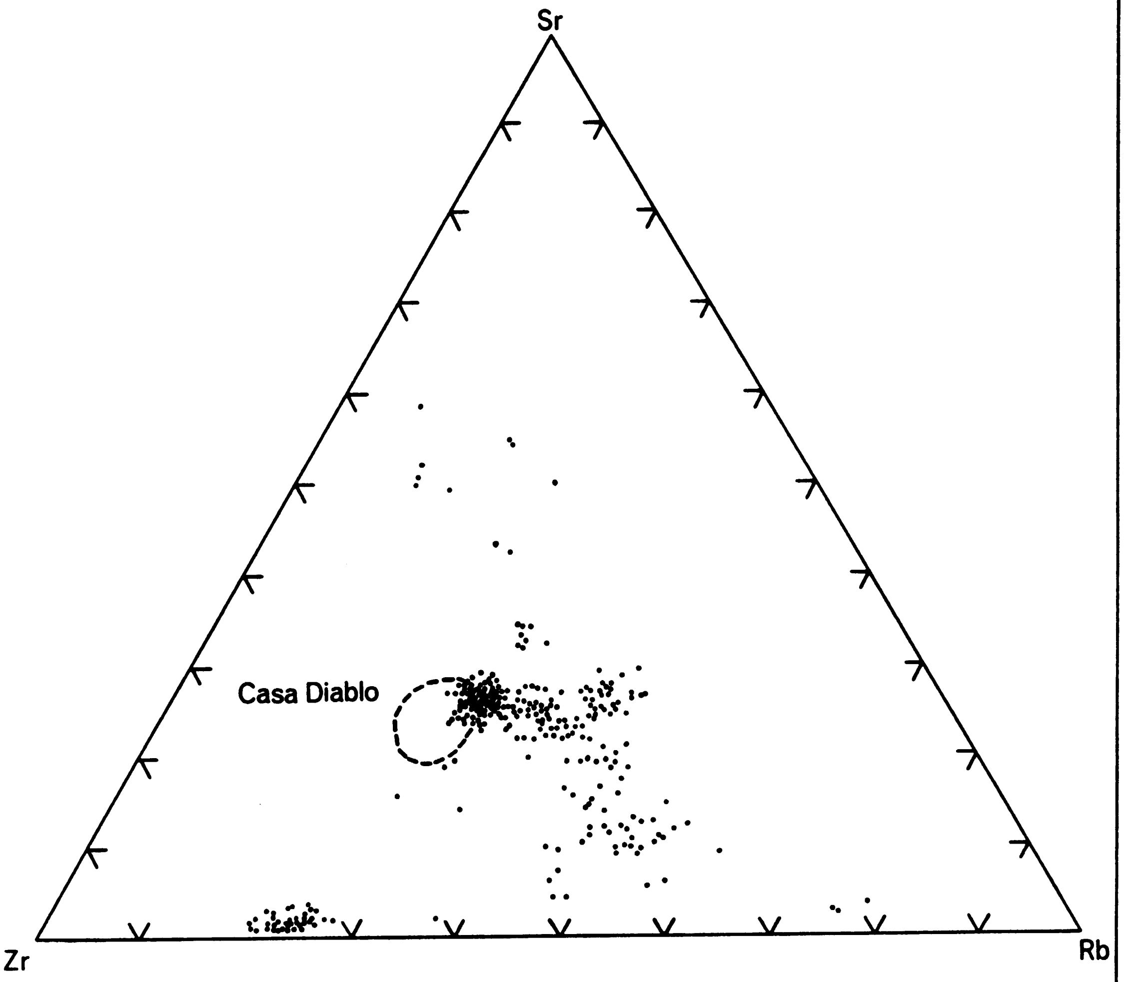

Figure 1. Ternary diagram plot for Humboldt Lakebed (NV-Ch-15) artifacts, with composite plot for Casa Diablo obsidian source specimens in dashed line. Plots for Casa Diablo source specimens and Ch-15 artifacts determined on the basis of rapid scan wavelength dispersive x-ray fluorescence analysis (see Jack and Heizer 1968); Ch-15 artifact plots courtesy of R.N. Jack.

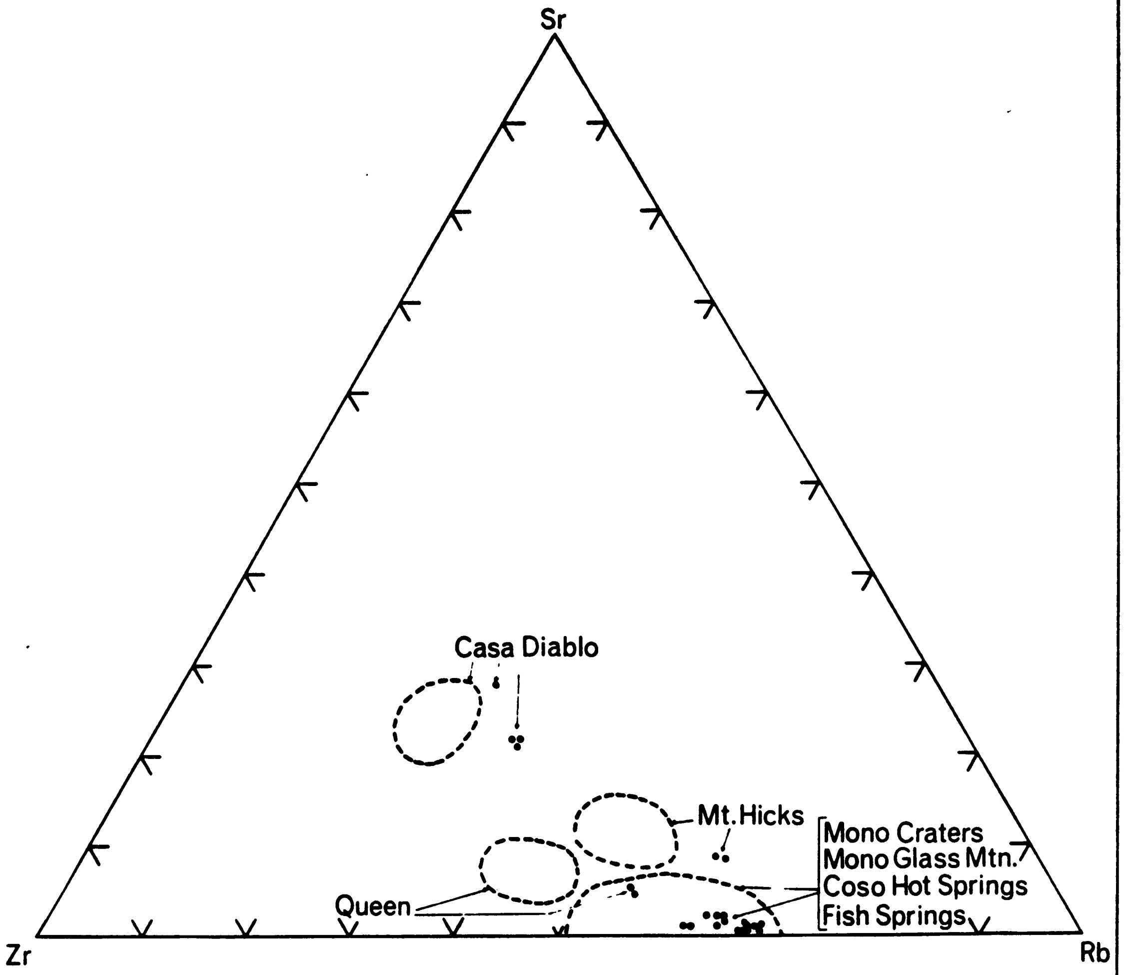

Figure 2. Ternary diagram plots for some obsidian sources in the Mono Basin and western Great Basin. Dashed lines delimit composite plots for source specimens analyzed by rapid scan wavelength dispersive x-ray fluorescence (from Jackson 1974 and Jack 1976). Dots represent plots for source specimens derived from quantitative analysis (in parts per million) using wavelength dispersive x-ray fluorescence (from R.N. Jack, unpublished data).

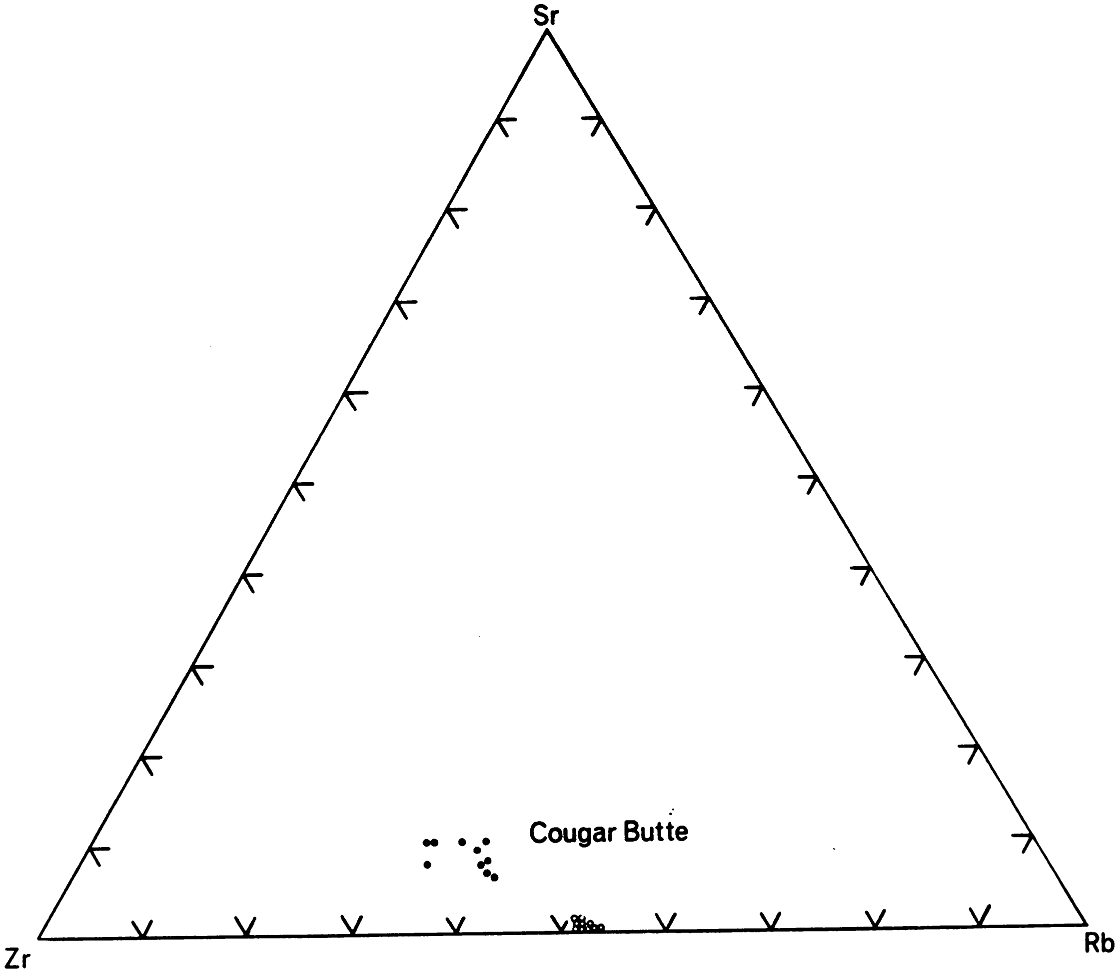

Figure 3. Ternary diagram plot for obsidian source specimens from Cougar Butte, Medicine Lake Highland, northeast California. Dots depict specimens analyzed using the rapid scan wavelength dispersive technique, while open circles represent plots for specimens computed from parts per million concentrations using energy dispersive x-ray fluorescence.

Obsidian Source		Trace Element Concentrations (ppm)				
		Rb	Sr	Y	Zr	Nb
Horse Mtn. (n=20)	$\bar{x}$	141.8	0.1	115.4	706.7	29.7
	s.d.	6.1	.6	5.3	23.4	3.4
King's Dog (Mod-204) projectile point (1-228122)		204.0	0.0	120.5	705.2	80.7

Mod-204 projectile point $P(G/X) = 1.0000$

Mod-204 projectile point $D^2 = 355.13$

Horse Mtn. D^2 statistic range = 0.30 - 14.22

$\bar{x} = 5.05$

s.d. = 4.06

Table 1. Trace element concentration values for obsidian from Horse Mountain, Oregon, and an obsidian projectile point from the King's Dog site in relation to Mahalanobis D^2 values.

		Obsidian Source					
Elements		Hawkins-Malad-Oneida (n=50)	Smith Creek (Chesterfield) (n=24)	Big Southern Butte (n=32)	Camas-Dry Creek (n=21)	Owyhee-Brown's-Castle (n=25)	Timber-Squaw Butte (Webb Creek) (n=10)
Fe	$\bar{X}$	389.6	941.9	920.6	748.8	439.2	84.7
	S.D.	78.5	117.9	191.8	81.7	93.5	96.3
	CV%	20.1	12.5	20.8	10.9	21.3	113.7
Rb	$\bar{X}$	135.3	103.5	391.1	205.1	255.7	209.9
	S.D.	28.6	38.7	59.1	28.7	34.8	48.1
	CV%	21.1	37.4	15.1	14.0	13.6	22.9
Sr	$\bar{X}$	64.8	325.4	1.4	24.7	10.4	2.8
	S.D.	23.8	47.6	4.5	21.3	14.3	5.9
	CV%	36.7	14.6	317.0	86.1	41.3	210.7
Y	$\bar{X}$	63.1	78.1	601.3	124.9	74.4	93.8
	S.D.	23.3	29.9	72.6	27.2	19.6	28.3
	CV%	36.9	38.3	12.1	21.8	26.4	30.1
Zr	$\bar{X}$	278.9	609.8	1002.6	896.5	315.0	140.7
	S.D.	40.4	71.3	90.9	68.7	78.1	47.0
	CV%	14.5	11.7	9.1	7.7	24.8	33.4
Nb	$\bar{X}$	117.0	101.0	1303.3	264.9	92.2	191.7
	S.D.	27.2	33.3	124.2	33.1	18.8	37.3
	CV%	23.3	33.0	9.5	12.5	20.4	19.5
Sn	$\bar{X}$	19.1	28.5	411.3	67.7	92.1	65.9
	S.D.	22.0	30.4	45.7	26.8	38.5	40.3
	CV%	115.1	106.7	11.1	39.6	41.8	61.2
Ba	$\bar{X}$	27696.5	25147.7	0	11875.1	4312.3	323.1
	S.D.	2195.3	2219.2	0	1883.7	2333.4	80.6
	CV%	7.9	8.8	0	15.9	54.1	25.0
La	$\bar{X}$	0	0	17.1	0	0	4.0
	S.D.	0	0	27.0	0	0	12.7
	CV%	0	0	158.4	0	0	316.3
Ce	$\bar{X}$	62.4	150.9	1092.9	694.7	258.5	0.5
	S.D.	72.4	143.1	362.8	142.6	115.5	1.6
	CV%	116.1	94.8	33.2	20.5	44.7	316.0

Table 2. Elemental intensity means ($\bar{X}$), standard deviations (S.D.) and coefficients of variation (CV%) for ten elements from six Idaho obsidian sources. Measurements made at the Idaho Bureau of Mines and Geology; computed from data in Green (1982: Tables 2-7).

Elements		U.C. Berkeley (R.E. Hughes, analyst)	Brigham Young University (F.W. Nelson, analyst)
		n=20	n=7
Rb	$\bar{X}$	119.2	127.2
	S.D.	10.9	3.0
	CV%	9.1	2.4
Sr	$\bar{X}$	68.2	77.1
	S.D.	6.2	2.5
	CV%	9.0	3.2
Y	$\bar{X}$	30.1	9.2
	S.D.	5.0	7.6
	CV%	16.7	82.6
Zr	$\bar{X}$	93.9	86.1
	S.D.	9.3	6.2
	CV%	9.9	7.2
Nb	$\bar{X}$	16.5	7.2
	S.D.	2.1	3.8
	CV%	12.6	52.8
Ba	$\bar{X}$	1614.4	1628.9
	S.D.	72.7	12.4
	CV%	4.5	0.8
La	$\bar{X}$	31.2	n.m.
	S.D.	6.4	
	CV%	20.6	
Ce	$\bar{X}$	62.9	n.m.
	S.D.	7.6	
	CV%	12.0	

n.m. = not measured

Table 3. Trace element concentrations (in parts per million) for obsidian source specimens from Malad, Idaho. Mean ($\bar{X}$) and standard deviation (S.D.) values in parts per million. Source specimens for U.C. Berkeley analysis were selected at random from those in Hawkins-Malad-Oneida column in Table 2.

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TECHNICAL CONSIDERATIONS IN X-RAY FLUORESCENCE ANALYSIS OF OBSIDIAN

Joachim H. Hampel

This paper discusses the application of x-ray fluorescence (XRF) to archeological research, specifically to the study of the chemistry of obsidians. Recent technological advances in XRF analysis have emphasized the effectiveness of the technique as well as the need to adhere to specific basic procedures. The XRF laboratory at the Department of Geology and Geophysics at the University of California at Berkeley has participated in the chemical analysis of archeological obsidians from throughout the Americas since 1965.

XRF utilizes a primary x-ray beam to displace electrons, generally from the K, L, and M shells. These electrons are replaced by electrons from outer shells producing secondary or fluorescent x-rays. Each element displays a characteristic x-ray spectrum that can be detected and measured, enabling the various elements in a given sample to be identified and quantified.

There are two basic types of XRF detection systems: energy dispersive and wavelength dispersive. Energy dispersive XRF systems generally utilize low power x-ray tubes (40 to 60 watts) to produce the primary x-ray beam, and a lithium drifted, silicon, semi-conductor to detect the fluorescent x-rays (Woldseth 1973). This detection system discriminates between x-rays with different energies. Wavelength dispersive systems utilize higher power X-ray tubes (2000+ watts) to produce the primary beam, and fluorescent x-rays are discriminated by diffraction off of crystals in the detection system that are set to be wavelength-specific according to Bragg's Law (Jenkins 1974; Jenkins and DeVries 1975). In both systems the detected x-rays may be displayed graphically, or the data may be reduced by computer into numerical form.

Hughes (1983: Figure 2-2) illustrates the basic features of the energy dispersive system; the wavelength dispersive system appears in Nelson (this volume). The greater distance between the sample and the detector in the wavelength system, in combination with the decrease in beam intensity that accompanies diffraction, requires that the wavelength system has a higher power x-ray tube. The following discussion pertains to energy dispersive systems similar to the United Scientific Spectrace 440 system in use in the Geology Department at Berkeley.

There are two basic methods of preparing samples for XRF analysis: destructive and non-destructive. The destructive method consists of grinding the sample to minus 400 mesh, and pressing the resulting powder into a pill at approximately 20,000 psi. This technique allows the investigator to accurately analyze for elements with characteristically low energy x-rays, i.e., those elements in the sodium to iron section of the Periodic Table. Although this technique provides a more complete characterization of a given sample, it is often not suitable for archeological specimens. Non-destructive analysis consists of putting the intact specimen into the XRF unit for analysis. This method eliminates time consuming sample preparation, allows the sample to be preserved, and although the scope of the analysis is somewhat limited, it often is sufficient for the archeologist.

It is often desirable to define an "average" composition of source material for artifacts. Either method can be used to define an average composition. The average can be determined by either grinding a number of samples from an obsidian source, mechanically blending the resulting powders, and then analyzing a number of intact specimens and taking the numerical average of the analyses.

Figure 1 is a graphic respresentation of an XRF scan of the U.S.G.S. BCR-1. Notice that the K-beta peaks of rubidium, strontium, and yttrium interfere respectively with the k-alpha peaks of yttrium, zirconium, and niobium. This interference effectively increases the area of the K-alpha peaks, and since the area of each peak is considered to be a function of the concentration of the element in the sample, these interferences must be subtracted before the concentration can be calculated (see Schamber 1977). The problem of overlapping peaks is resolved by stripping, a process that involved subtracting that part of the peak area contributed by interfering elements by comparing the spectrum of interest with pure element reference spectra (see Figure 2).

Figure 2 is an XRF scan of an intact obsidian flake from the Fish Springs source located in Owens Valley, Inyo County, California. Figure 3 is an XRF scan of a Fish Springs obsidian sample that has been pulverized and pressed into a pill. Note that the peak heights of the elemental and Compton scatter peaks differ from those in the previous figure, due in part to differences in the smoothness and the size of the illuminated surfaces. However, since the Compton peak serves as a scale factor, the calculated concentrations are approximately equal regardless of the absolute number of x-rays detected. Table 1 shows the results of analyzing an intact flake and a powder of the same specimen.

The Compton peak technique works satisfactorily for elements with atomic numbers in the range of 27-41 (Franzini, Leoni and Saitta 1976), and is particularly applicable to elements in the range 37-41 when analyzing archeological samples. It is also possible to analyze for elements in the 55-60 range if a high energy source (such as the Americium 241 source at Berkeley) is available.

This technique is not applicable to elements with atomic numbers less than 27, since the Compton peak does not fall within the energy range of the x-rays produced by these elements. When analyzing for these elements standards must be used for comparison. The standards should resemble the unknowns as much as possible in terms of composition so that the effects of matrix absorption and fluorescence will be minimal in data reduction. Elements within this range may be analyzed only in samples that have been pressed into pills.

The archeologist is generally concerned with keeping his artifacts intact, and is therefore limited to the analysis of trace and light rare earth elements, and it is these values that are generally reported in the literature. It is extremely important that both the method of analysis and the results of an analysis of an international rock standard be included in each report. The inclusion of this information helps analysts in other laboratories evaluate the accuracy of the data included in the report (see Stross et al. 1983). Without such comparative data no such evaluation is possible, and therefore the validity of conclusions based on these data cannot be determined.

Trace element	Unmodified Obsidian flake (ppm)	Pressed Powder (ppm)
Rb	208.3	206.6
Sr	11.5	11.2
Y	34.9	31.9
Zr	95.7	87.6
Nb	38.1	35.2

Table 1. Comparison of trace element concentration values (in ppm) between an unmodified flake and a pressed powder sample from the Fish Springs obsidian source (cf. Jack 1976: Table 11.5).

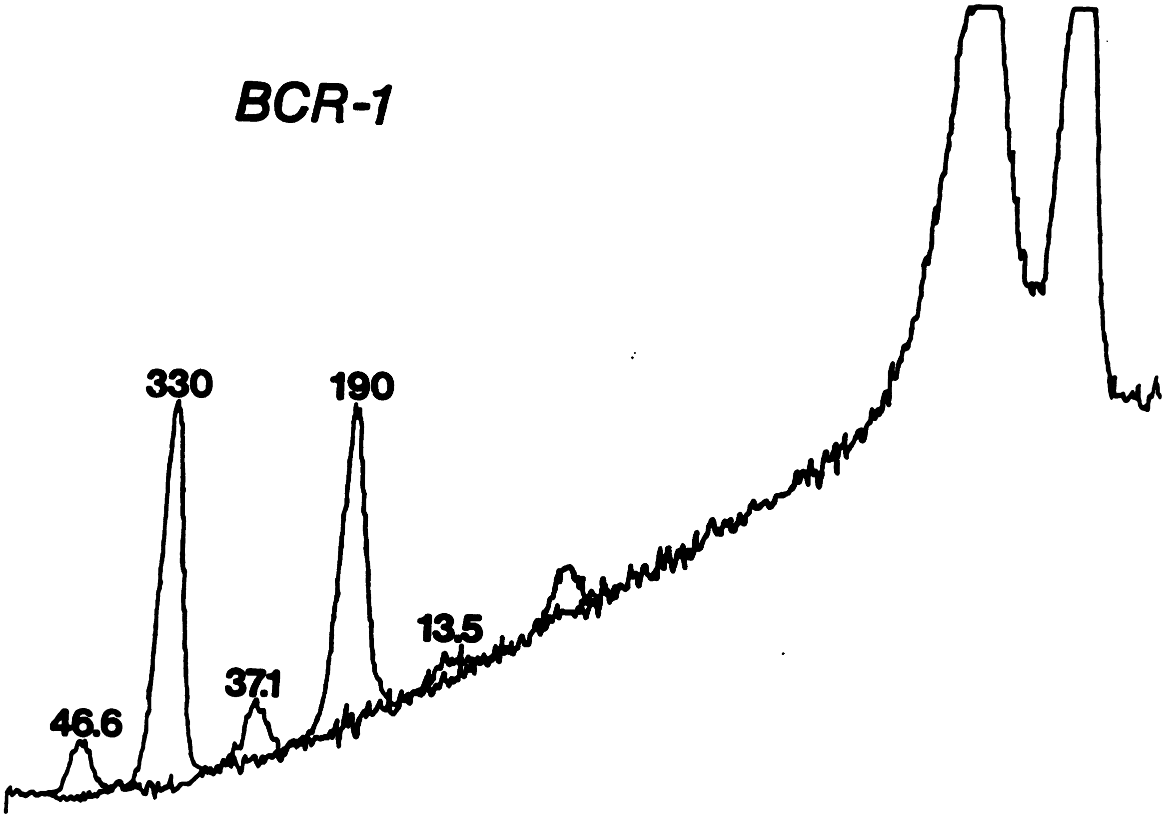
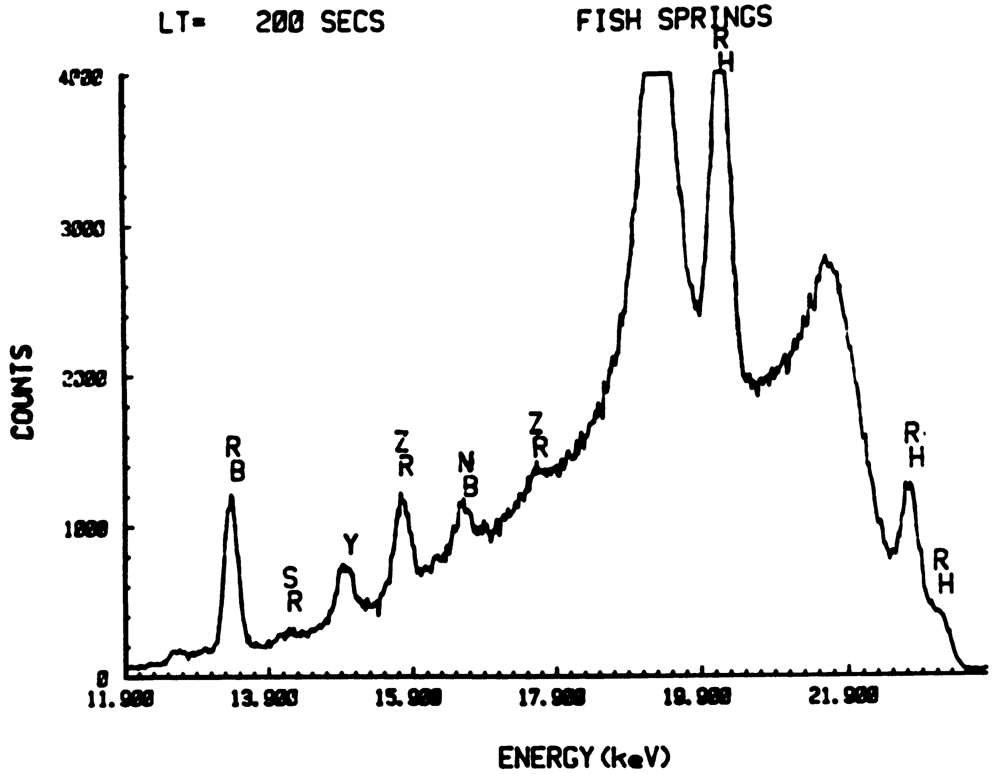


Figure 1. Energy dispersive x-ray fluorescence scan of the 12-20 keV region of the energy spectrum in the U.S. Geological Survey BCR-1 rock standard. Numbers above energy peaks are concentrations in parts per million for Rb (46.6), Sr (330), Y (37.1), Zr (190) and Nb (13.5).



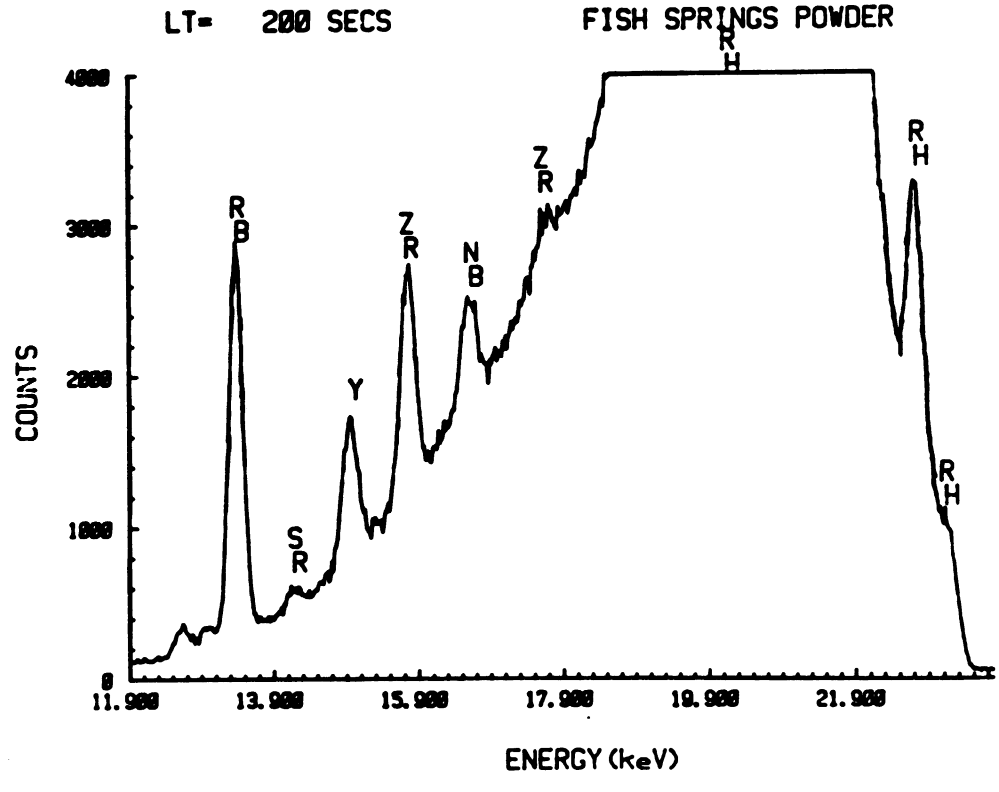


Figure 2 (top). Energy dispersive x-ray fluorescence scan of an unmodified obsidian flake from Fish Springs.

Figure 3 (bottom). Scan of a pressed powder obsidian sample from Fish Springs.

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X-RAY FLUORESCENCE ANALYSIS OF SOME WESTERN NORTH AMERICAN OBSIDIANS

Fred W. Nelson, Jr.

Introduction

The elemental composition of several geologic sources of obsidian in Arizona, California, southern Idaho, Nevada, northern New Mexico, Oregon, western Utah, and north western Wyoming has been determined using X-ray fluorescence spectrometry (Figure 1). The results of analyses of several obsidian artifacts from archaeological sites in this area also are reported and compared to the analyses of the obsidian sources. Some of the sources reported in a previous study (Nelson and Holmes 1979) have been reanalyzed; several new sources have been analyzed, and two new trace elements (yttrium and niobium) have been added to the analyses.

In addition to reporting the trace element composition of the obsidian sources and artifacts, the methods used to conduct the analyses also will be described. The statistical procedures used to distinguish between the geologic sources of obsidian and to correlate the archaeological obsidian artifacts to the geologic sources also will be explained. After the results of analysis of the obsidian geologic sources and artifacts have been presented, the artifacts will be assigned to their probable geological obsidian source by statistical and graphical means.

Obsidian is useful for this type of study because: 1) most of the geologic sources are homogeneous; that is, the elemental composition usually does not vary significantly from one area of the source to another (see Bowman, Asaro, and Perlman 1971, 1973a, 1973b; Zeitlin 1979 for possible exceptions); 2) there are a limited number of sources; 3) each source appears to have its own unique trace element composition; and 4) the properties of obsidian are not changed during the manufacture of the artifacts.

In addition to source analysis, it has been demonstrated that it is possible to study the economics of obsidian use and exchange rather thoroughly from extraction to final discard (Clark 1981; Clark and Lee 1981). Clark (1981) suggests that source analysis of obsidian should only be a small part of the study of obsidian artifacts and that source analysis, replication studies, functional analysis, and careful excavation are all basic to understanding obsidian use and exchange among prehistoric peoples. However, in this paper only the analysis of obsidian for its trace element composition is described.

Methods of Analysis

The method employed here for the analysis of obsidian is x-ray fluorescence spectrometry and wavelength dispersive detection. This method uses x-rays from a chromium or tungsten x-ray tube to furnish the energy necessary to cause the electrons in the atoms to jump from one energy level to another less stable level. As the electrons in the less stable energy levels fall back into their more stable levels, fluorescent x-rays are emitted. The energy or wavelength of these fluorescent x-rays is unique for each element. Therefore, by determining which wavelengths or energies are emitted the elements in the sample can be identified. The intensity of the fluorescent x-rays allows one to determine the quantity of the element present in the sample.

The detection of the fluorescent x-rays was accomplished in this study using wavelength dispersive methods. This detection system uses diffraction crystals to disperse the fluorescent x-rays of various wavelengths so that the detector can measure each one of them. This is done by setting the diffraction crystal to the proper two theta (2^{θ}) angle (Figure 2) as described by the Bragg equation ($n\lambda = 2d \sin \theta$). The elements present in the sample can then be identified. This method offers advantages in resolution because each element is measured separately using the appropriate two theta angle setting for that specific element. However, because the analysis of each element must be done separately -- a major disadvantage of this method is the length of time required to analyze each sample.

The analyses were performed using a Philips PW 1410 vacuum path x-ray fluorescent spectrometer equipped with a high-precision five-position diffraction crystal changer and a semi-automatic programmable goniometer controller. Power to the x-ray tube is supplied by an ultra stable three kilowatt Philips 1140 generator. Table 1 lists the instrumental settings used for the analysis of each element. The analyses were performed in three groups: 1) rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), niobium (Nb), and manganese oxide (MnO); 2) ferric oxide (Fe_2O_3), titanium dioxide (TiO_2), and barium (Ba); and 3) sodium oxide (Na_2O).

Measured intensities were corrected for counter deadtime, background, instrumental drift and, where necessary, spectral overlap (Norrish and Chappell 1977; Hutchison 1974: 527). The corrected net peak data were then interpreted using two computational procedures: 1) a linear calibration of concentration to net peak intensity was used for Na_2O, TiO_2, MnO, Fe_2O_3, and Ba and 2) a linear calibration of concentration to the ratio of net peak intensity to the intensity of coherently scattered radiation from the tungsten (W) $L_{\gamma 1}$ tube line was used for Rb, Sr, Y, Zr, and Nb (Norrish and Chappell 1977; Jenkins and DeVries 1969; Bertin 1970). The accuracy of these methods is shown in Table 2 which compares the results of analysis of several international rock standards (G-2, GSP-1, AGV-1, GA, GH, NIM-G, GM, RGM-1, and QLO-1) to the reported values of Flanagan (1973, 1976), Fabbie and Espos (1976), and Steele (1979).

The samples were prepared for analysis by crushing 1.2 grams of obsidian in a Plattner's alloy tool steel percussion mortar and pestle to minus 40 mesh and then pulverizing the resultant chips in an agate vial using a Spex 5100 mixer/mill. The chips were ground for 15 minutes to a powder of approximately 400 mesh. Pellets were made by pressing 0.500 grams of obsidian powder under a pressure of 1,170 Kg per cm^2 using a Fabbi-type die and a Spex

B-25 hydraulic press (Fabbi 1970). Whatman CF-11 cellulose powder was used for the backing and shoulders of the pellet.

Correlation Of Artifacts To Sources

Two methods are used to correlate the artifacts to the obsidian sources --- graphical and statistical. The graphical method involves comparing the relative concentrations of three elements and plotting the results on a three coordinate (ternary) graph. This can be done for any combination three elements -- however this laboratory has used Rb, Sr, Zr; $Fe_2O_3/10$, TiO_2, MnO; and Ba, TiO_2, MnO. Once the range of variation for the sources has been determined and plotted, the artifacts are assigned to a particular source if they fall within the range of variation for that source.

A computer program has been developed to calculate and plot the relative concentrations of each of the sets of three elements. This program was written by the author, and utilizes a software package entitled *Plot79, Release 1.5* (Beebe 1979). Figures 3, 4, 5, and 6 are examples of the graphs produced by this method and illustrate the range of variation for the geologic sources of obsidian analyzed in this study.

The statistical validity of the correlation of the artifacts to their geologic sources is tested by the statistical method of discriminant analysis. This is done by using the computer program SPSS subprogram DISCRIMINANT (Nie et al. 1975: 434-467). Discriminant analysis combines the discriminating variables in a stepwise fashion in such a manner that the variables are used in the order of their highest value as discriminating functions. In this way the groups are forced to be as statistically distinct as possible.

The method used for controlling the stepwise selection of discriminant functions is the minimum Wilks's Lambda. Because the magnitude of variation between the values reported for the different elements is large, a logarithmic (base 10) transformation was used to normalize the values. Table 3 shows that for this project, iron is the single best discriminating variable and that the next best discriminating variable in combination with iron is barium, then titanium, etc. The relative discriminating power of these elements is not constant and will depend upon their relative concentrations and variations within a given suite of samples (Nelson and Holmes 1979: 68).

In addition to constructing discriminant functions for samples of known provenience the SPSS subprogram DISCRIMINANT can also be used to classify unknown samples and to calculate the probability that a given sample belongs to a given source. The program also reports the second most probable group to which a sample may be assigned (Nelson and Holmes 1979: 69). Therefore, once the geologic obsidian sources have been grouped and the groups verified, the obsidian artifacts then can be added to the program. They are then assigned to the geologic source from which they came.

Recently Hughes (1983) has identified and described several potential problems that may be encountered when the statistical procedures of discriminant analysis are used with obsidian data. Therefore, when using discriminant analysis, one must be aware of these potential problems and critically review the results one obtains before accepting them.

Obsidian Geologic Sources

Tables 4, 5, 6, 7, and 8 present the results of analysis of the obsidian sources. In each case the location of the source, the number of samples analyzed, the average values for each element, and the standard deviation are given for each element. Figures 3, 4, 5, and 6 represent graphically the range of values for each obsidian source by comparing the ratios of three sets of three elements. The validity of each of the groups illustrated in Figures 3, 4, 5, and 6 has been checked and confirmed using discriminant analysis as described above.

Several sources are very close to each other geographically and some of these are also similar in trace element composition, while others are quite distinct. Compare for example, the four obsidian sources from the Mineral Mountain Range, Beaver County, Utah (Table 4 and Figure 3; Sources 1, 2, 3, and 4). One explanation for the difference in trace element composition between sources very close geographically may be a "...temporal variability of this local volcanic event..." as explained by Hughes (1982: 180). Sources 1, 2, 3, and 4 are all within a few kilometers of each other and the only difference in trace element composition between Sources 1 and 2 is in the concentrations of rubidium and zirconium present (see Table 4 and Figure 3). In Figure 3 this difference is illustrated by the Rb, Sr, Zr ratio whereas the ratios of the other two sets of elements show that they are identical. It is interesting that Sources 3 and 4 — although they are located very close to Sources 1 and 2 — are quite different in elemental composition (Table 4 and Figure 3). The discriminant analysis computer program shows that there is enough difference in elemental composition to discriminate and differentiate between each of the four sources. Even though the discriminant analysis program sometimes reports the 2nd Highest Probability to be quite high for sources very close geographically (see Table 9, Sample 630), it has never done so for sources from different areas. For example this has never happened between sources from the Mineral Mountain Range and Topaz Mountain or the Black Rock Desert.

Other examples of the ability of discriminant analysis and the graphical program to distinguish between sources that are very close geographically appear in Table 4 and Figure 3 for the Topaz Mountain Sources (Sources 5, 6, and 7) and the six sources from the Black Rock area (Sources 8, 9, 10, 11, 12, and 13). This ability to distinguish between obsidian sources that are very close geographically allows one to study in detail procurement trends and differences between different archaeological sites, areas, and time periods (Hurtado de Mendoza and Jester 1978). This is one of the great advantages obsidian studies offer when studying exchange and procurement patterns.

Archaeological Obsidian Artifacts

Once the trace element composition of the obsidian sources has been determined and the groups plotted and statistically verified it is possible to compare the trace element composition of the obsidian artifacts to the sources in order to determine the geologic source of origin of the obsidian used in their manufacture (Tables 9, 11, and 12 and Figure 7). The artifact samples are prepared and analyzed in exactly the same way as the source samples. The results of analysis are then plotted and the graphs are compared to the graphs representing the range of variation of the geologic sources of obsidian (Figures 3, 4, 5, and 6). In this way a tentative identification of the geologic obsidian source of each artifact is determined. This identification is checked by adding the trace element composition data of the artifacts to that of the geologic sources of obsidian and statistically determining which group or geologic source each artifact belongs to by discriminant analysis. In this procedure each obsidian source sample is labelled according to source or source group, but the data from the artifacts is labelled as ungrouped. Therefore the artifacts are assigned to the source to which they belong only because the discriminant analysis statistic program can recognize the similarity of the trace element composition of the artifact to an obsidian source.

As an example of the results of this procedure the trace element data from several obsidian artifacts from different archaeological sites have been included. Table 9 and Figure 7 illustrate the data from three archaeological sites in Utah County, Utah (see Figure 1 for their location). Table 9 lists the Highest Probable Group and 2nd Highest Probable Group assignment according to the SPSS subprogram DISCRIMINANT. As can be seen in Table 9 various obsidian sources are represented, and source use appears to vary by archaeological site and time period. A summary of the obsidian used in the manufacture of artifacts is given in Table 11 to illustrate how they differ from site to site and from one archaeological period to another.

As can be seen in Tables 4 and 10, it appears that during earliest times obsidian was entering Utah Valley from the two closest sources -- the Topaz Mountain area and the Black Rock area. During Sevier times this continued to be the case except that obsidian from the Malad area, Idaho was also coming in from the north to Spotten Cave. Goshen appears to have received all its obsidian from the Black Rock area. During Shoshone times most of the obsidian coming into Utah Valley came from the north -- from the Malad source (56%) and from an unidentified source, possibly located in Yellowstone National Park (Source 47) (22%). Samples of obsidian from the geologic source corresponding to Source 47 have not been identified but because of the similarity of the trace element composition of Source 47 to some of the published values of the Yellowstone National Park sources it is possible that this is the area from which the obsidian for these artifacts came (Ferison et al. 1968; Griffin, Gordus and Wright 1969; Gordus, Griffin and Wright 1971).

Table 11 lists the results of analysis of obsidian artifacts from southwestern Utah and northwestern Arizona. Figure 7 illustrates how these compare graphically to the range of values of the sources. As can be seen the majority of the obsidian came from the Modena area -- the closest area -- with smaller amounts coming from the Mineral Mountain Range. One artifact is from an unidentified source -- possibly from southern Nevada.

Table 12 shows the data from the analysis of obsidian artifacts from the Fillmore area, Millard County, Utah, and from southeastern Utah and western Colorado. Figure 7 illustrates how these compare graphically with the sources. All of the obsidian analyzed from the Fillmore area comes from the Black Rock

Rock area — which is very close. It appears the inhabitants could see no reason to transport obsidian over long distances when it was in their "back yard." However, there are presently no local obsidian sources known in southeastern Utah, so the obsidian apparently had to be transported over longer distances. From the results listed in Table 10, it appears that at least some of the obsidian came from the Jemez Mountain area of New Mexico and the Government Mountain area in Arizona. However, of the three artifacts analyzed, one is from an unknown source.

Discussion

The results of analysis of several obsidian geologic sources in the Great Basin area have been presented along with the trace element composition of obsidian artifacts from several archaeological sites. The methods used to analyze the obsidian have been described and the procedures used to correlate the artifacts to the obsidian sources have been explained. As can be seen in Table 3, it is possible to determine the trace element composition quite accurately using x-ray fluorescence spectrometry and wavelength dispersive methods for detection. Tables 4, 5, 6, and 7 show that the trace element composition of geologic sources of obsidian can be used to distinguish and "fingerprint" the sources. By comparing the trace element composition of obsidian artifacts to the geologic sources it is possible to determine from which source the obsidian artifact came — even though the artifact may have been found hundreds of miles from the source. The comparison of artifacts to the obsidian sources has been done using a computer plot program and the statistical program SPSS subprogram DISCRIMINANT.

Table 13 also shows that it is possible to correlate the results of analyses of obsidian sources undertaken at different laboratories. This table compares the data reported in the present study to that reported by Jack (1971, 1976), Jack and Carmichael (1969) and Hughes (1983) for several sources. Even though there are some differences between analyses the overall agreement is quite good. This illustrates the advantages of reporting data in part per million and/or weight precent (and for specifying the instrumental parameters used in the analyses) instead of only assigning artifact to sources or reporting relative values for the elements (cf. Hughes, this volume). When one reports absolute values the data are much more useful to others.

The reason archaeologists are interested in going to all the trouble and expense of analyzing obsidian is because the source of the obsidian for the artifacts can be located quite precisely — sometimes to within a square kilometer. When artifacts located hundreds of kilometers from an obsidian source can be shown to have originated at a particular source it provides evidence that procurement in some manner or exchange with the distant area was taking place. As these data are combined with other archaeological data, archaeologists will be in a better position to study economic patterns of exchange and procurement.

This study suggests that prehistoric peoples usually obtained obsidian from the closest source -- probably for economic reasons. However, for one reason or another this was not always the case. For example, the Williamson site at the northern end of Utah Lake, received most of its analyzed obsidian from the Malad, Idaho and possible from a Yellowstone National Park source during the Shoshone Period. It is the archaeologist's job to explain why they did not follow the normal pattern and obtain obsidian from a closer source such as Topaz Mountain. In this case the reason may be that Shoshone who migrated between Idaho and northern Utah picked up and brought obsidian with them as they travelled from Idaho to Utah. It may not have been a matter of trade but a matter of transporting what they had obtained and used while in Idaho. It is hoped that the data presented in this report will be useful in helping archaeologists to solve these kinds of problems.

Acknowledgements

I wish to thank the following individuals for providing samples of obsidian from the geologic sources: Department of Geology, Brigham Young University, for most of the source samples from Utah; Vaden G. Stickley, Bureau of Land Management, Winnemucca, Nevada, for many of the Nevada source samples; R. Lee Sappington for most of the Idaho source samples; Catherine M. Cameron for obsidian samples from New Mexico; Roderick A. Hutchinson, Park Geologist, Yellowstone National Park for obsidian samples from Yellowstone; and John Clark and Wayne Howell for obsidian from the Malad, Idaho source.

Alan C. Spencer provided artifacts from Spotten Cave and the Williamson site; Richard A. Thompson, Southern Utah State College, provided the artifacts listed in Table 9; and Don Forsyth and Wayne Howell provided the artifacts listed in Table 10.

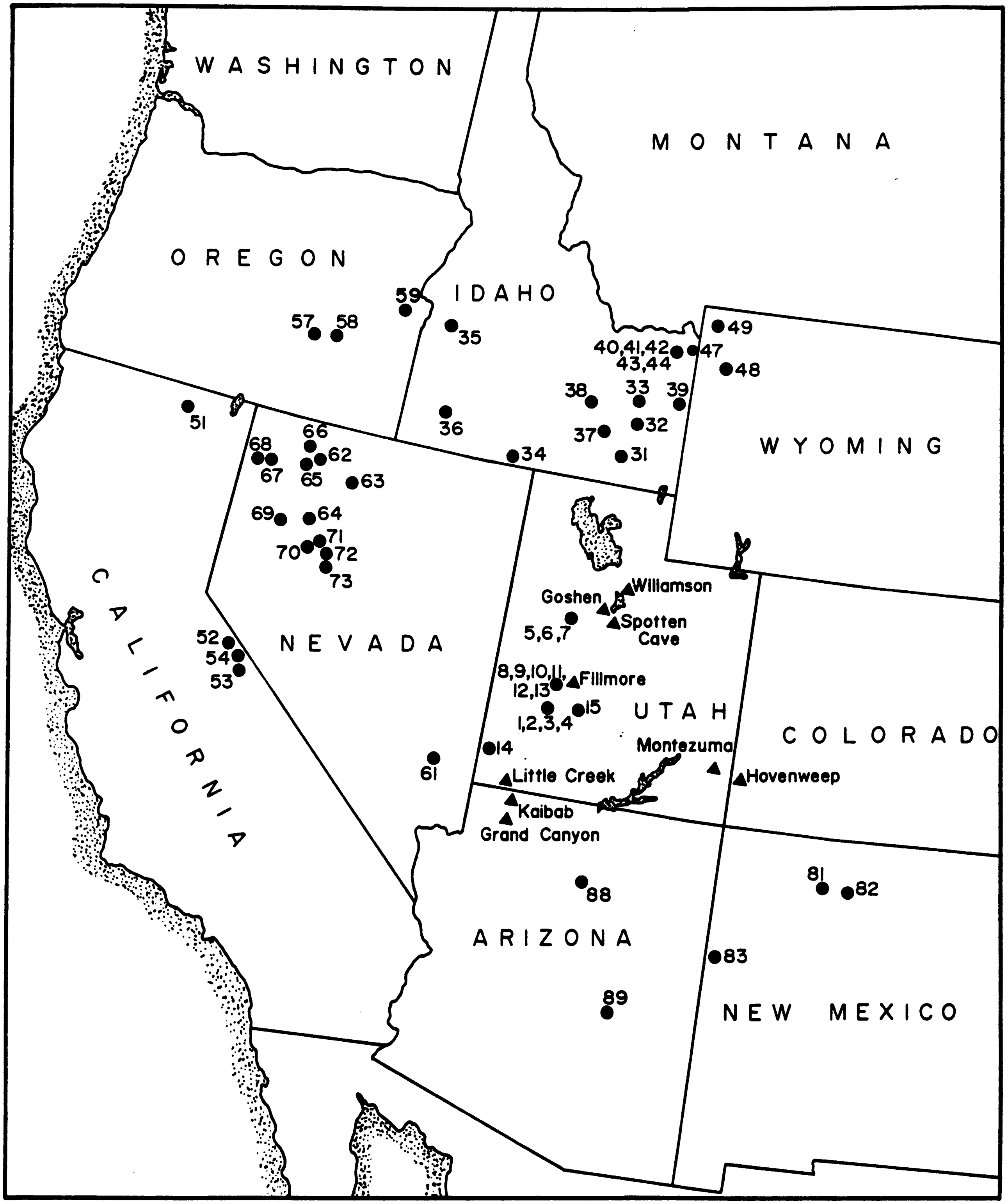

Figure 1. Map showing the approximate location of the geologic sources of obsidian and the archaeological sites from which obsidian has been analyzed. The numbers refer to the geologic sources of obsidian listed in Tables 4 - 8.

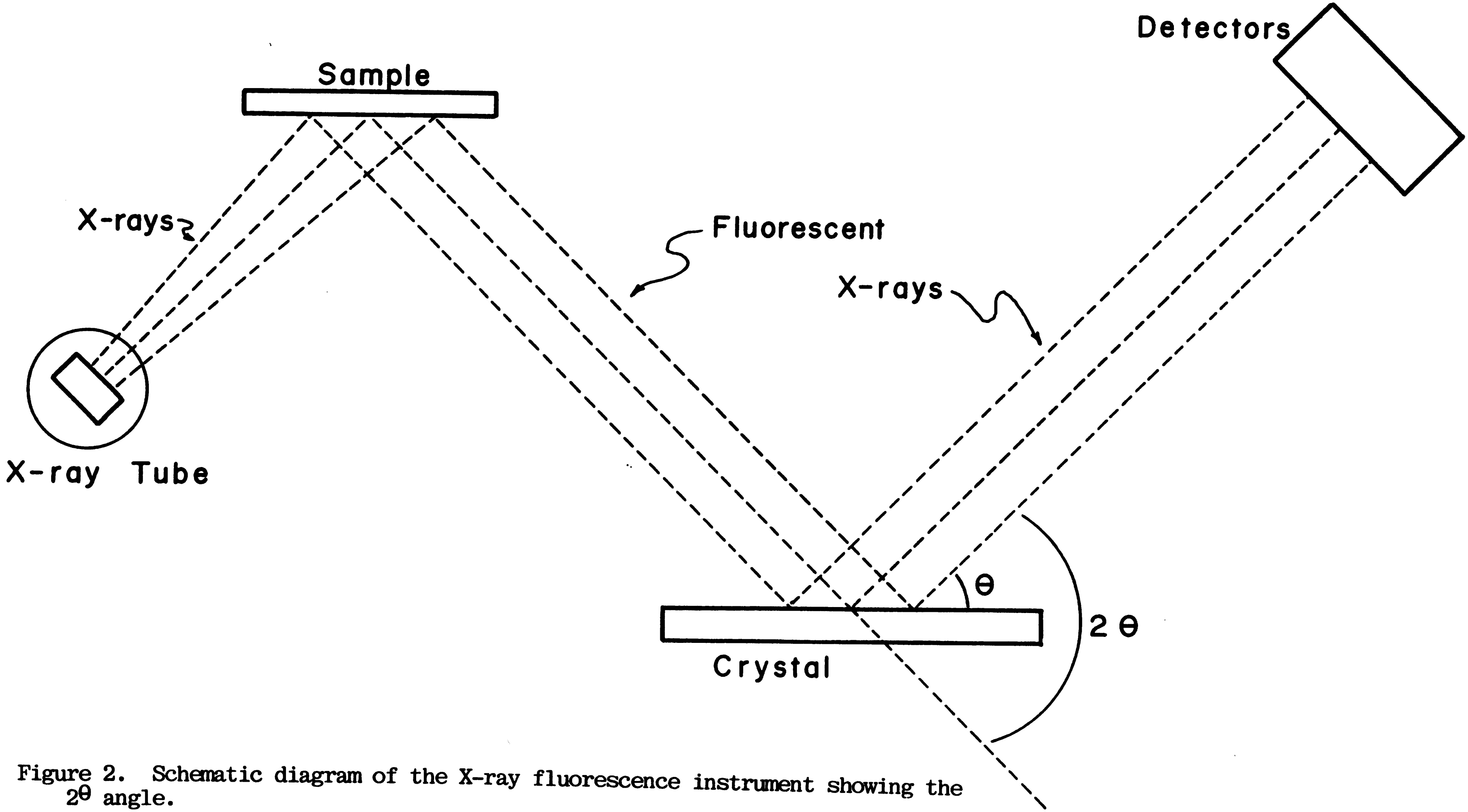

Figure 2. Schematic diagram of the X-ray fluorescence instrument showing the 2θ angle.

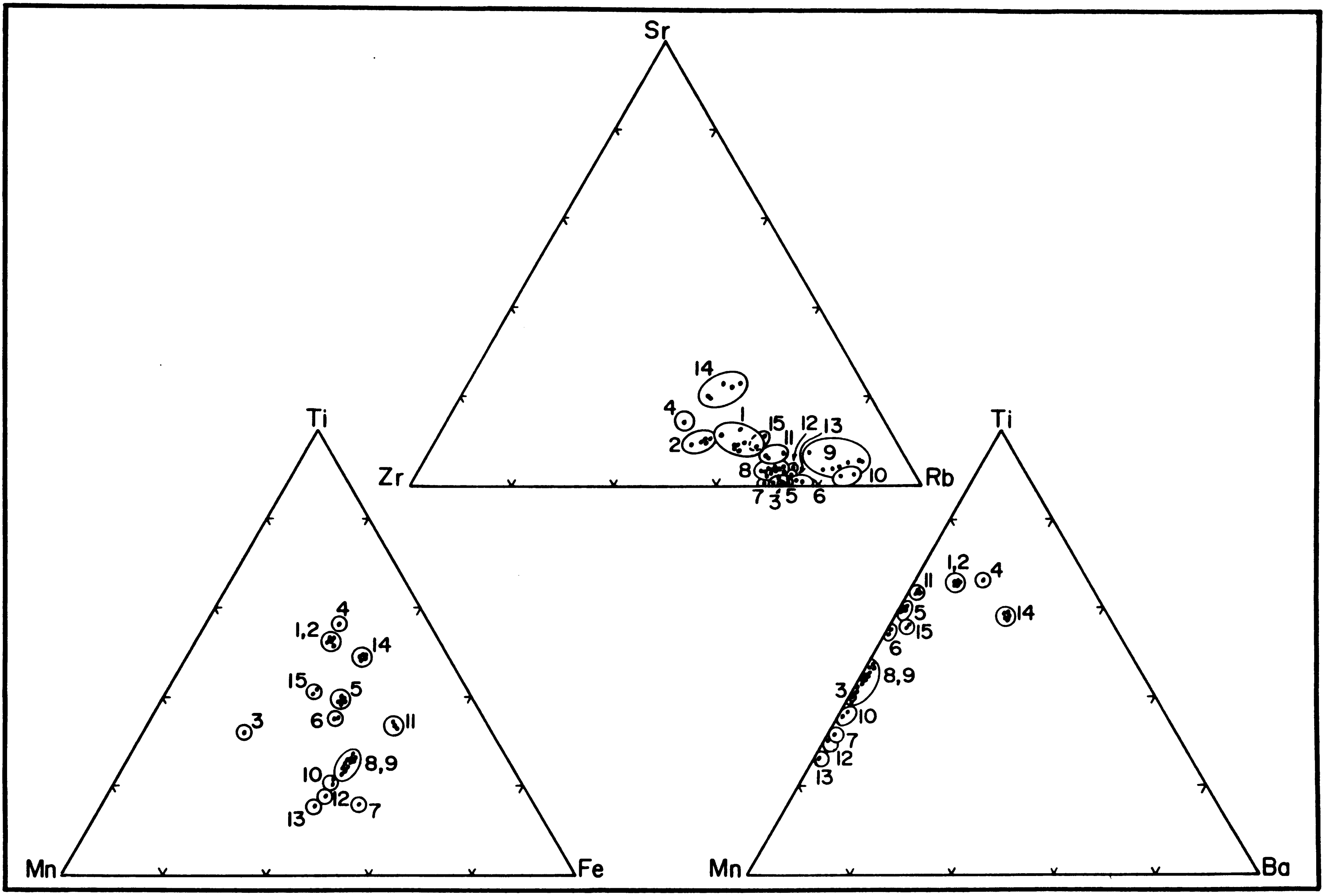

Figure 3. The range of values of the relative concentrations of Rb, Sr, Zr; Fe/10, Ti, Mn; and Ba, Ti, Mn for the Utah obsidian sources. The numbers refer to the geologic sources of obsidian listed in Table 4.

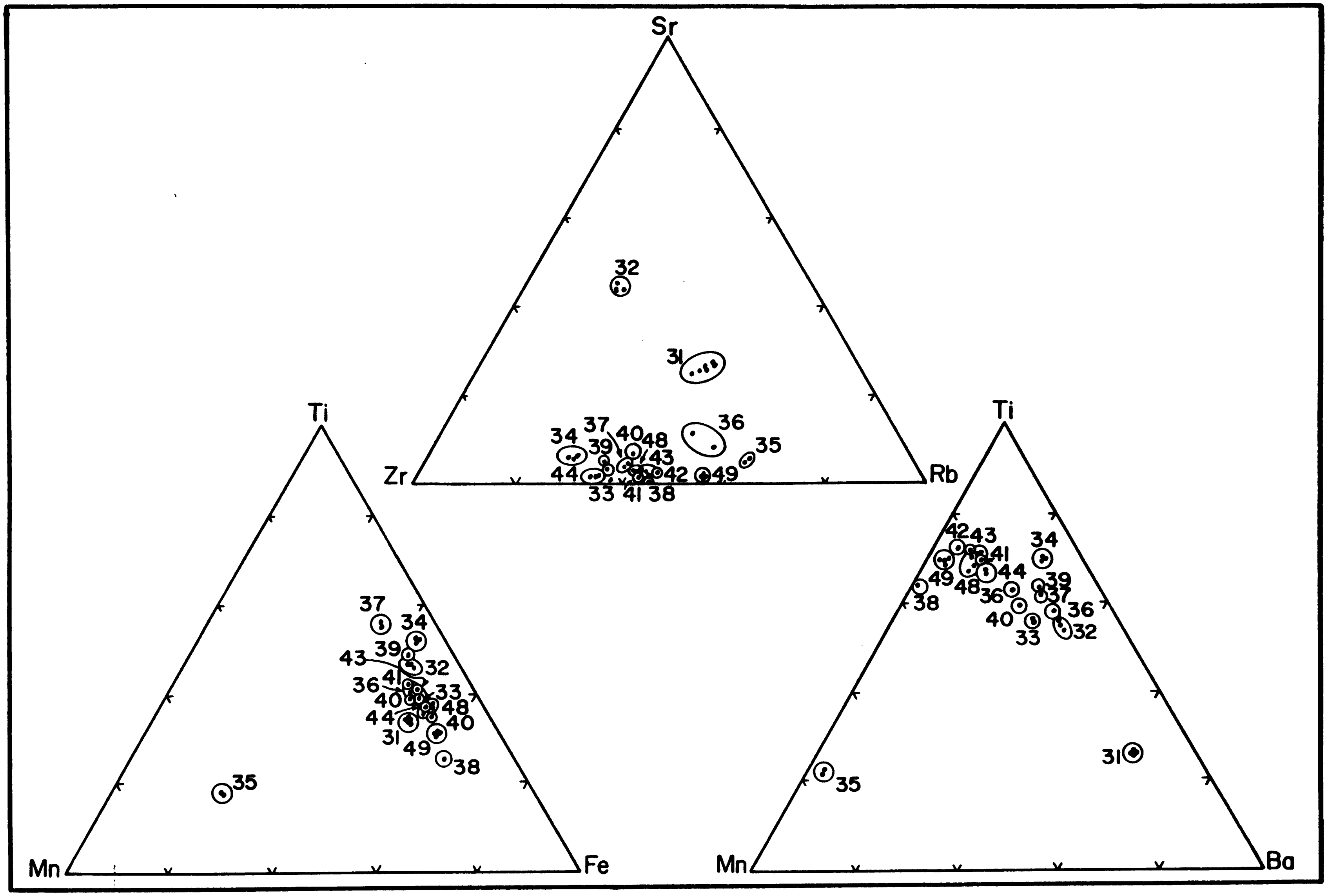

Figure 4. The range of values of the relative concentrations of Rb, Sr, Zr; Fe/10, Ti, Mn; and Ba, Ti, Mn for the Idaho and Wyoming obsidian sources. The numbers refer to the geologic sources of obsidian listed in Table 5.

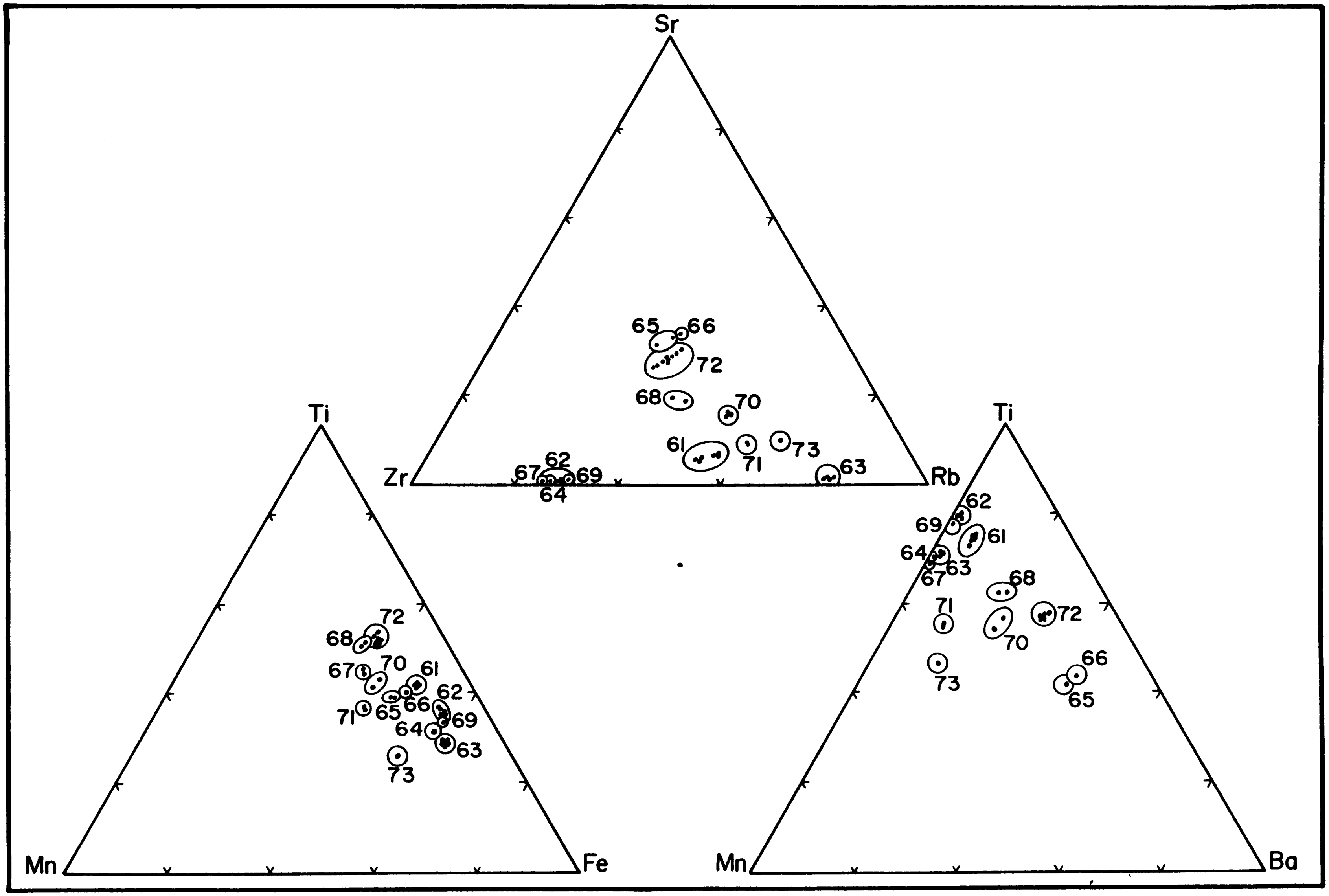

Figure 5. The range of values of the relative concentrations of Rb, Sr, Zr; Fe/10, Ti, Mn; and Ba, Ti, Mn for the Nevada obsidian sources. The numbers refer to the geologic sources of obsidian listed in Table 6.

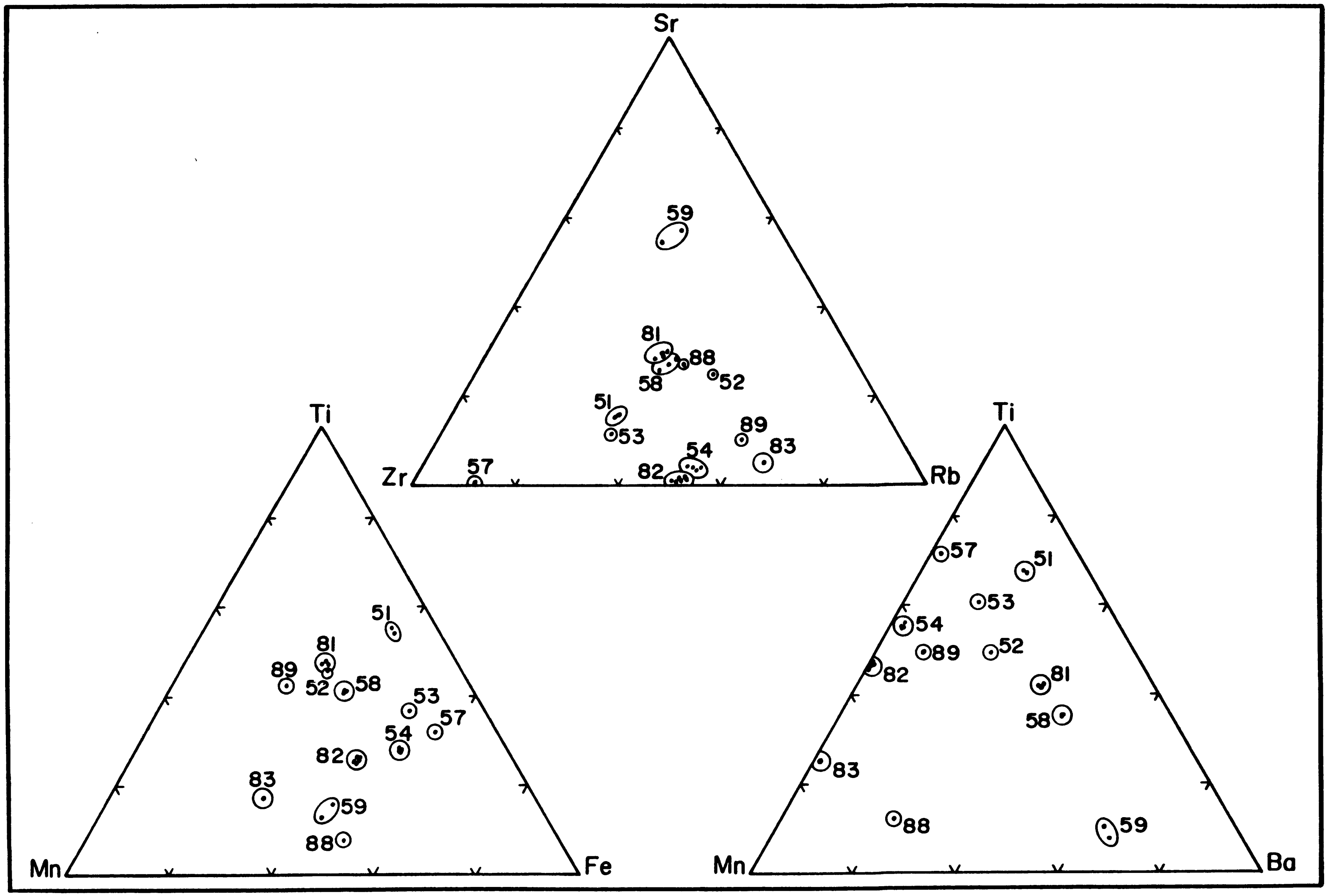

Figure 6. The range of values of the relative concentrations of Rb, Sr, Zr; Fe/10, Ti, Mn; and Ba, Ti, Mn for the Arizona, New Mexico, California, and Oregon obsidian sources. The numbers refer to the geologic sources of obsidian listed in Tables 7 and 8.

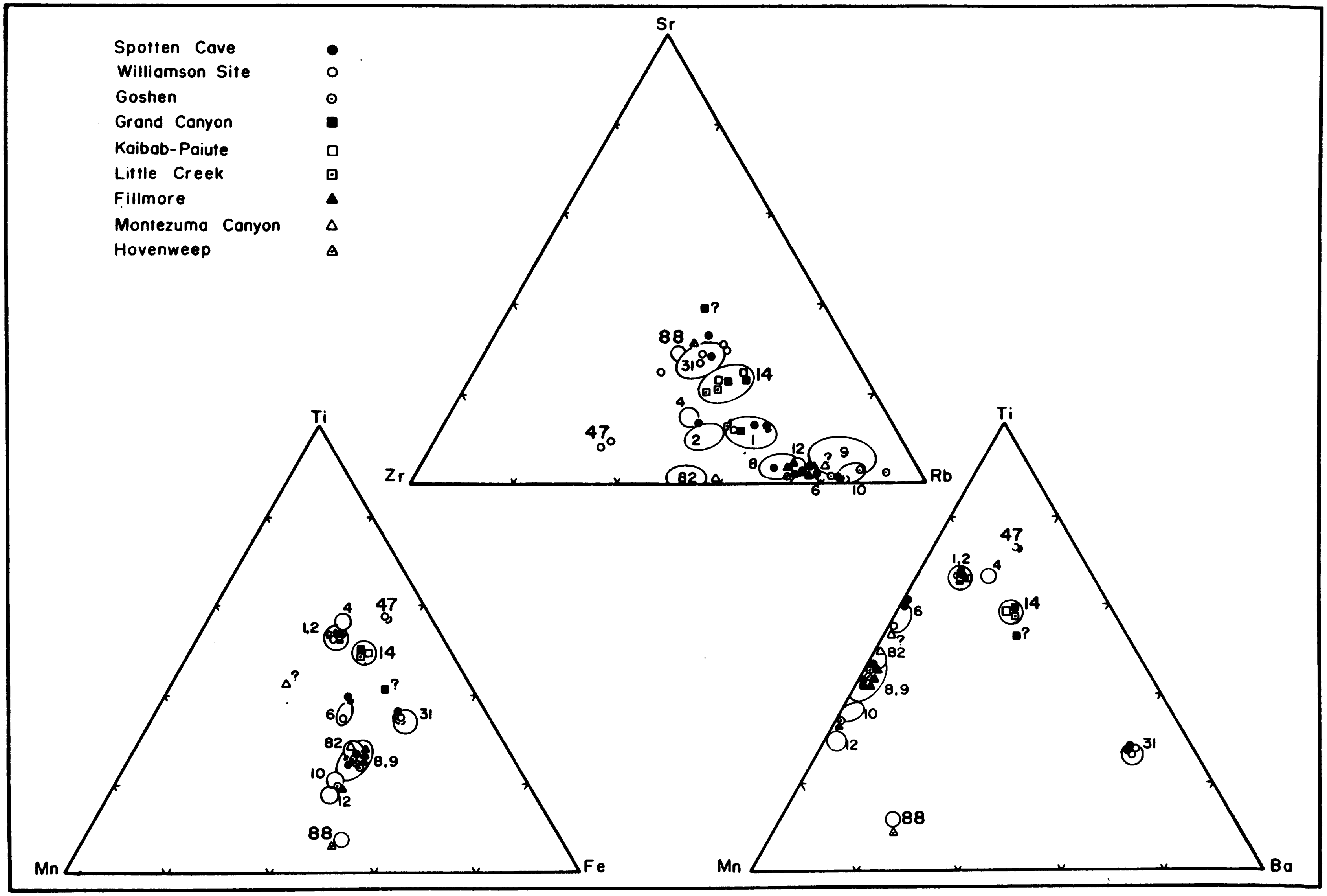

Figure 7. The relative concentrations of Rb, Sr, Zr; Fe/10, Ti, Mn; and Ba, Ti, Mn for obsidian artifacts from the sites listed in Tables 9, 11 and 12. The numbers refer to the geologic sources of obsidian listed in Tables 4 - 8.

Table 1. Instrumental settings used for the analysis of obsidian sources and artifacts.

Element	Analytical Line	2θ	Analyzing Crystal	X-ray Tube	Generator Kv	Generator mA	Counting Time
Rb	K_α	26.62	LiF200	W	50	20	40 sec
Sr	K_α	25.15	LiF200	W	50	20	40 sec
Y	K_α	23.80	LiF200	W	50	20	40 sec
Zr	K_α	22.55	LiF200	W	50	20	40 sec
Nb	K_α	21.40	LiF200	W	50	20	40 sec
MnO	K_α	62.97	LiF200	W	50	20	40 sec
Fe_2O_3	K_α	57.52	LiF200	Cr	50	20	40 sec
TiO_2	K_α	86.14	LiF200	Cr	50	20	40 sec
Ba	L_α	87.17	LiF200	Cr	50	20	40 sec
Na_2O	K_α	54.38	RAP	Cr	40	60	100 sec

Table 2. Comparison of the results of X-ray fluorescence analysis of international geologic standards to their reported values.

Geological Standard	Source of Data	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %
G-2	XRF	170	480	12	301	13	.033	2.65	.465	1865	4.08
G-2	Flanagan 1973: 1976	168	479	12	300	14	.034	2.65	.50	1870	4.07
GSP-1	XRF	253	233	28	532	21	.037	4.03	.615	1249	2.82
GSP-1	Flanagan 1973; 1976	254	233	30	500	29	.042	4.33	.66	1300	2.80
AGV-1	XRF	69	655	13	182	5	.097	6.80	1.044	1207	3.95
AGV-1	Flanagan 1973; 1976	67	657	21	255	15	.097	6.76	1.04	1208	4.26
GA	XRF	172	298	28	134	15	.092	2.72	.436	826	3.40
GA	Flanagan 1973; 1976	175	305	18	140	13	.09	2.83	.38	850	3.55
GH	XRF	383	11	89	171	78	.055	1.43	.080	27	3.82
GH	Flanagan 1973	390	10	70	160	85	.05	1.34	.08	22	3.85
NIM-G	XRF	322	12	146	303	48	.021	2.13	.090	118	3.43
NIM-G	Steele 1979	325	20	147	300	53	.021	2.00	.090	120	3.36
GM	XRF	261	132	45	170	34	.049	1.94	.201	334	3.87
GM	Flanagan 1973	250	133	26	145	17	.04	2.02	.21	328	3.76
RGM-1	XRF	155	107	21	248	12	.041	2.02	.287	833	3.92
RGM-1	Fabbi & Espos 1976	154	117	--	212	--	.037	1.95	.293	827	3.92
QLO-1	XRF	76	338	--	178	—	.095	4.59	.647	1375	4.15
QLO-1	Fabbi & Espos 1976	68	329	--	175	--	.097	4.42	.635	1392	4.07

Table 3. Results of the stepwise selection of the discriminating functions and their relative value in classifying the obsidian samples into groups.

Discriminating Functions	Eigenvalue	Percent of Variance	Wilk's Lambda	Chi-square
Fe_2O_3	884.04521	55.57	0.0000000	4026.4
Ba	328.54849	20.65	0.0000000	3151.1
TiO_2	251.77478	15.83	0.0000000	2403.2
MnO	79.13015	4.97	0.0000021	1689.5
Rb	29.27066	1.84	0.0001644	1124.0
Zr	11.73152	0.74	0.0049766	684.09
Sr	4.18452	0.26	0.0633599	355.90
Na_2O	2.04422	0.13	0.3284912	143.61

Table 4. Results of analysis of obsidian sources in Utah.

	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	NaO_2 %
Mineral Mountain Range, Beaver County, Utah										
Source #1. School Mine Area: T27S, R9W, Sections 1, 2, 11, 34 USGS Adamsville, Utah 15' quadrangle. 1958 n=2										
$\bar{X}$	233.4	37.7	0.4	119.8	16.7	.054	.67	.137	170.0	3.48
S.D.	28.1	2.9	.9	14.7	8.1	.001	.03	.003	5.5	.14
Source #2. Wild Horse Canyon Area: T27S, R9W, Sections 2, 22 USGS Adamsville, Utah 15' quadrangle. 1958 n=5										
$\bar{X}$	193.6	37.5	19.9	137.0	25.5	.054	.67	.138	171.0	3.52
S.D.	4.6	.6	8.4	7.8	4.0	.001	.01	.001	4.0	.04
Source #3 Kirk Canyon Area: T27S, R9W, Section 27 USGS Adamsville, Utah 15' quadrangle. 1958 n=1										
X	360.7	2.2	8.3	133.1	43.0	.110	.45	.074	7.0	4.11
Source #4. Pumice Hole Mine Area: T28S, R9W, Section 2 USGS Adamsville, Utah 15' quadrangle. 1958 n=1										
X	181.3	57.2	18.7	150.1	22.7	.051	.76	.163	328.0	3.44
Topaz Mountain Area, Juab County, Utah										
Source #5. T12S, R11W, Sections, 28, 39, 31 USGS Topaz Mountain 15' quadrangle. 1953 n=8										
$\bar{X}$	443.9	6.0	38.8	164.0	53.7	.067	.91	.103	10.3	3.48
S.D.	8.9	1.9	7.8	9.7	4.5	.001	.02	.002	2.0	.16
Source #6. T12S. R11W, Section 29 & T13S, R11W, Section 6 USGS Topaz Mountain 15' quadrangle. 1953 n=2										
$\bar{X}$	484.5	5.6	31.7	148.7	54.6	.073	.91	.909	9.7	3.75
	9.9	.9	4.8	7.1	3.2	.001	.03	.002	2.0	.03

Table 4. Continued

	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %
Source #7. T13S, R11W, Section 19 & T13S, R11W, Section 6 USGS Topaz Mountain 15' quadrangle. 1953 n=1										
X	372.9	3.8	109.7	154.5	57.7	.068	1.00	.032	13.8	3.89
Black Rock Area, Millard County, Utah										
Source #8. T24S, R9W, Section 11 USGS Antelope Spring, Utah, 7.5'quadrangle. 1973; T23S, R8W, Section 31 & T24S, R9W, Section 3 USGS Cruz, Utah 7.5' quadrangle. 1973; T24S, R10W, Section 10 USGS Black Rock, Utah 7.5' quadrangle. 1973 n=15										
$\overline{X}$	264.6	13.7	36.4	101.6	18.6	.065	.89	.052	9.6	3.83
	9.3	1.6	10.6	9.5	5.6	.002	.02	.004	1.6	.18
Source #9. T24S, R9W, Section 14 USGS Antelope Spring, Utah 7.5' quadrangle 1973; T23S, R9W, Sections 2, 35 & T23S, R8W, Section 21 USGS Cruz, Utah 7.5' quadrangle. 1973; T23S, R7W, Section 17 USGS Tabernacle Hill, Utah 15' quadrangle. 196s; T24S, R8W, Section 10 USGS Cove Fort, Utah 15' quadrangle. 1962 n=7										
X	259.0	16.1	---	42.6	---	.065	.90	.053	13.7	3.78
S.D.	7.7	4.7	---	14.5	---	.002	.03	.003	4.2	.36
Source #10. T23S, R9W, Section 26 USGS Cruz, Utah 7.5' quadrangle. 1973; T24S, R9W, Section 35 USGS Antelope Spring, Utah 7.5' quadrangle. 1973. n=2										
$\overline{X}$	291.5	8.5	---	44.5	---	.073	.85	.042	11.0	4.02
S.D.	3.5	.7	---	7.8	---	.001	.01	.001	4.2	.03
Source #11. T22S. R6W, Section 11 USGS Fillmore, Utah 15' quadrangle. 1962 n=3										
$\overline{X}$	303.7	32.5	---	152.5	---	.079	2.09	.146	35.6	4.12
S.D.	.9	6.5	---	52.4	---	.002	.02	.006	2.0	.05
Source #12. T23S. R9W, Section 35 USGS Cruz, Utah 7.5 quadrangle. 1973 n=1										
X	331.1	14.8	---	107.7	---	.077	.83	.035	9.1	4.19

Table 4. Continued.

	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %
Source #13. T23S, R9W, Section 35 USGS Cruz, Utah 7.5 quadrangle. 1973										
n=1										
$\bar{X}$	348.2	8.8	---	114.7	---	.079	.77	.029	7.9	4.15
Source #14. Modena Area, Iron County, Utah: T35S, R19W, Section 12 USGS Modena, Utah 7.5 quadrangle. 1972										
n=5										
X	198.2	85.4	3.3	109.9	5.5	.045	.91	.133	497.9	3.43
S.D.	2.2	4.0	4.5	18.0	6.7	.001	.02	.004	6.9	.07
Source #15. Marysvale Area, Piute County, Utah: T27S, R4W, Section 24 USGS Mount Brigham, Utah 7.5' quadrangle. 1980										
n=2										
$\bar{X}$	311.5	52.1	0.0	135.8	18.8	.091	.88	.127	74.0	3.85
S.D.	20.1	5.6	0.0	9.8	11.6	.001	.03	.006	7.1	.06

Table 5. Results of analysis of obsidian sources in Idaho and Wyoming.

	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %
Source #31.	Malad (Elk Horn County), Oneida County, Idaho Source: T11S, R35E, Section 26 USGS Wakley Peak, Idaho 7.5' quadrangle. 1968									
n=7										
$\bar{X}$	127.2	77.1	9.2	86.1	7.2	.032	.97	.068	1628.9	3.57
	3.0	2.5	7.6	6.2	3.8	.001	.02	.001	12.4	.12
Source #32.	Chesterfield, Bannock County, Idaho Source: T7S, R37E & R38E USGS Portneuf, Idaho 15' quadrangle. 1948									
n=3										
$\bar{X}$	84.4	210.1	9.7	175.8	8.2	.050	2.15	.232	1421.7	4.01
S.D.	3.6	7.4	8.1	6.5	5.5	.002	.10	.012	9.1	.14
Source #33.	Kelly Canyon, Jefferson County, Idaho Source: T4N, R41E, Section 28 USGS Heise, Idaho 7.5' quadrangle. 1951									
n=2										
$\bar{X}$	173.5	20.8	83.9	293.5	53.6	.048	1.96	.161	785.2	3.72
S.D.	3.0	0.0	.7	4.5	.5	.001	.01	.004	2.2	.04
Source #34.	Brown's Bench, Twin Falls County, Idaho Source: T12S, R13E, Section 11 USGS Tuanna Butte, Idaho 7.5' quadrangle. 1979; T14S, R14E, Section 30 USGS Brown Bench South, Idaho 7.5' quadrangle. 1977									
n=4										
$\bar{X}$	200.0	46.5	64.5	464.2	38.6	.037	2.76	.339	1108.7	2.88
	4.4	2.7	5.6	16.4	3.4	.002	.08	.013	42.3	.01
Source #35.	Timber Butte, Gem County, Idaho Source: T10N, R1E, Section 35 USGS Ola, Idaho 7.5' quadrangle. 1970									
n=2										
$\bar{X}$	179.2	16.6	54.1	90.7	39.8	.113	.40	.034	49.6	4.34
S.D.	1.3	1.2	1.1	1.3	1.1	.000	.00	.001	.3	.06
Source #36.	Owyhee (Toy Pass), Owyhee County, Idaho Source: T6S, R2W, Section 14 USGS Triangle, Idaho 15' quadrangle. 1965									
n=2										
$\bar{X}$	195.7	38.7	29.0	144.4	15.0	.024	1.12	.104	452.3	3.22
	12.1	8.4	2.3	9.3	.9	.001	.03	.017	226.9	.12

Table 5. Continued.

	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %
Source #37. American Falls, Power County, Idaho Source: T8S, R31E, Section 6 USGS American Falls SW, Idaho 7.5' quadrangle. 1971										
X	182.8	23.2	66.9	259.5	43.5	.045	1.41	.234	971.5	3.49
S.D.	2.4	1.1	7.2	7.5	.5	.001	.03	.000	8.3	.02
Source #38. Big Southern Butte, Butte County, Idaho Source: T1N, R29E, Section 11 or 14 USGS Big Southern Butte, Idaho 7.5' quadrangle. 1972										
n=1										
X	281.1	1.4	240.0	333.1	232.6	.047	2.07	.086	11.5	3.96
Source #39. Pack Saddle, Teton County, Idaho Source: USGS Packsaddle Lake, Idaho 7.5' quadrangle. 1965										
n=1										
X	175.7	25.8	37.6	301.1	25.7	.040	1.88	.217	866.0	3.46
Source #40. Reas Pass, Fremont County, Idaho Source: T14N, R45E, Section 6 USGS West Yellowstone, Idaho 15' quadrangle. 1958										
n=1										
X	171.4	32.2	42.3	233.9	40.5	.041	2.07	.140	549.0	3.61
Source #41. Bign Springs Fire Tower, Fremont County, Idaho Source: T14N, R44E, Section 34 USGS West Yellowstone, Idaho 15' quadrangle. 1958.										
n=1										
X	187.9	11.6	---	230.0	---	.045	1.69	.158	242.5	3.22
Source #42. Upper Fish Creek Road, Fremont County, Idaho Source: T12N, R45E, Section 33 USGS Buffalo Lake, Idaho 15' quadrangle. 1957										
n=1										
X	209.8	12.2	55.2	236.3	36.0	.043	1.64	.136	87.9	3.40
Source #43. Partridge Creek, Fremont County, Idaho Source: T11N, R45E, Section 26 USGS Warm River Butte, Idaho 15' quadrangle. 1957										
n=2										
X	198.9	11.5	57.1	238.9	37.1	.041	1.61	.140	157.5	3.42
S.D.	.2	1.5	17.2	20.7	9.8	.001	.05	.004	10.0	.02

Table 5. Continued.

	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %
Source #44.	South Partridge Creek and Lower Fish Creek Road, Fremont County, Idaho Source: T11N, R45E, Sections 17, 19 USGS Buffalo Lake, Idaho 15' quadrangle. 1957									
n=4										
$\bar{X}$	179.4	12.6	73.2	326.5	48.9	.046	2.11	.152	293.7	3.57
S.D.	2.2	1.5	4.7	11.4	3.1	.001	.02	.003	7.5	.02
Source #48.	Grassy Lake Area, Teton County, Wyoming Source: USGS Grassy Lake Reservoir, Wyoming 15' quadrangle. 1956									
n=3										
$\bar{X}$	209.5	16.3	66.6	275.5	49.1	.041	1.89	.131	184.5	3.52
S.D.	5.8	.8	3.6	16.2	3.7	.005	.06	.005	3.1	.14
Source #49.	Obsidian Cliff, Obsidian Creek, & Crystal Creek Area, Yellowstone National Park, Wyoming Source: USGS Mammoth, Wyoming 15' quadrangle. 1958									
n=4										
$\bar{X}$	250.7	9.0	65.7	188.6	33.3	.029	1.35	.075	38.1	3.70
S.D.	1.3	1.4	4.4	1.5	1.8	.0001	.01	.002	10.1	.04

Table 6. Results of analysis of obsidian sources in Nevada.

	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %
Source #66. n=1	Source 21, Humboldt County, Nevada; T44N, R27E, Section 1 USGS Railroad Point, Nevada 15' quadrangle. 1965									
X·	145.5	137.8	0.0	127.3	0.0	.046	1.59	.139	1331.5	3.82
Source #67. n=2	Sources 29, 39, Humboldt and Washoe County, Nevada; T45N, R24E, Section 5 USGS Catnip Mountain SE, Nevada 7.5' quadrangle. 1966 and T43N, R23E, Section 34 USGS Nut Mountain, Nevada 7.5' quadrangle. 1966									
$\bar{X}$	218.4	2.0	66.2	625.7	18.1	.129	2.38	.299	33.3	4.40
S.D.	6.8	1.3	6.9	0.0	4.6	.00	.06	.002	7.6	.01
Source #68. n=2	Sources 23, 31, Washoe County, Nevada: T43N, R21E , Section 34; T43N, R22E, Section 21 USGS Massacre Creek 7.5' quadrangle. 1966									
$\bar{X}$	187.3	82.2	0.0	169.3	4.1	.062	1.26	.196	581.9	3.99
S.D.	.4	6.7	0.0	16.3	5.7	.003	.01	.001	54.0	.42
Source #69. n=3	Dolly Varden Basin #1, Washoe County, Nevada: T35N, R22E, Section 7 USGS Lovelock, USA quadrangle 1:250,000 series. 1955									
$\bar{X}$	167.4	4.0	24.1	395.8	4.2	.047	2.93	.178	9.8	4.46
S.D.	2.2	.6	12.4	6.3	5.8	.003	.06	.004	2.2	.08
Source #70. n=2	Seven Troughs Range, Pershing County, Nevada: T31N, R29E, Section 4 USGS Lovelock, USA quadrangle 1:250,000 series. 1955									
$\bar{X}$	195.9	56.7	0.0	111.6	0.0	.048	1.04	.110	418.9	3.54
S.D.	5.1	2.5	0.0	2.7	0.0	.005	.01	.002	2.3	.07
Source #71. n=2	Source 8, Pershing County, Nevada: T32N, R30E, Section 17 USGS Lovelock, USA quadrangle 1:250,000 series. 1955									
X	208.3	31.5	0.0	104.5	3.3	.051	.88	.081	147.9	3.45
S.D.	.1	.5	0.0	1.6	.1	.000	.07	.001	2.4	.01

Table 6. Continued.

	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %
Source #72.	Poker Brown Wash and Sources 9, 10, 11, 12, Pershing County, Nevada: T31N, R31E, Section 27 USGS Poker Brown, Nevada 7.5' quadrangle. 1971; T31N, R30E, Sections 4, 25; T31N, R31E, Section 5 USGS Lovelock, USA quadrangle 1:250,000 series. 1955; T31N, R32E, Section 11 USGS Rye Patch Reservoir, Nevada 7.5' quadrangle. 1971									
n=9										
$\overline{X}$	155.6	121.2	0.1	159.4	1.7	.052	1.36	.204	1042.2	3.74
S.D.	2.7	2.8	.4	14.0	2.9	.003	.04	.002	14.2	.08
Source #73.	Source 13, Pershing County, Nevada: T28N, R32E, Section 11 USGS Oreana, Nevada 15' quadrangle. 1956									
n=1										
X	238.4	35.0	0.0	82.7	1.8	.044	1.02	.051	146.4	3.61

Table 7. Results of analysis of obsidian sources from New Mexico and Arizona.

	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %
Source #81. Jemez Mountains, Sandoval County, New Mexico: T18N, R4E, Section 31 USGS Redondo Peak, New Mexico 7.5' quadrangle. 1970										
n=3										
$\overline{X}$	101.5	87.3	0.0	111.2	9.4	.083	.88	.154	1352.4	4.39
S.D.	1.0	2.4	0.0	8.1	4.2	.003	.02	.001	3.4	.05
Source #82. Jemez Mountains, Sandoval County, New Mexico: T18N, R5E, in Capulin and Alamo Canyons USGS Bland, New New Mexico 7.5' quadrangle. 1953										
n-7										
$\overline{X}$	198.3	3.9	33.1	183.0	73.5	.082	1.20	.072	7.1	4.44
S.D.	2.2	1.4	7.7	9.1	4.4	.001	.01	.001	.7	.06
Source #83. Red Hill, Catron County, New Mexico: T3S, R18W USGS Saint Johns, USA quadrangle 1:250,000 series. 1970										
n=1										
$\overline{X}$	162.6	12.5	14.2	72.1	36.6	.098	.56	.033	16.5	4.22
Source #88. Government Mountain, Coconino County, Arizona. USGS Parks, Arizona 7.5' quadrangle. 1974										
n=1										
X	105.0	72.3	14.4	90.3	44.9	.090	1.08	.017	301.5	4.46
Source #89. Superior, Pinal County, Arizona. USGS Picketpost Mountain, Arizona 7.5' quadrangle. 1949										
n=1										
X	106.8	18.0	---	55.4	---	.086	.54	.103	195.6	4.17

Table 8. Results of analysis of obsidian sources from California and Oregon.

	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %
Source #51. Stoney Rhyolite Core, Medicine Lake, Siskiyou County, California. USGS Medicine Lake, California 15' quadrangle. 1952										
n=2										
$\bar{X}$	141.1	73.4	25.6	238.8	13.2	.040	1.69	.254	736.0	3.91
S.D.	1.56	.42	.28	.57	1.84	.00	.007	.0021	3.96	.035
Source #52. Bodie Hills, Mono County, California. USGS Bridgeport, California 15' quadrangle. 1958										
n=1										
X	182.4	94.5	3.7	115.5	14.4	.062	.69	.109	501.3	3.71
Source #53. Inyo Craters, Mono County, California. USGS Mono Craters, California 15' quadrangle. 1953										
n=1										
X	158.3	53.9	23.1	270.4	21.9	.058	1.92	.143	346.4	4.23
Source #54. Mono Craters, Mono County, California. USGS Mono Craters, California 15' quadrangle. 1953										
n=4										
$\bar{X}$	181.4	12.0	29.8	149.5	30.9	.051	1.24	.067	29.4	3.89
S.D.	2.98	1.42	2.74	4.26	2.10	.0015	.044	.0029	1.99	.099
Source #57. Burns, Harney County, Oregon. USGS Baker, USA quadrangle 1:250,000 series. 1974										
n=2										
$\bar{X}$	98.2	5.7	---	735.4	---	.068	3.22	.182	50.0	4.36
S.D.	.85	.57		11.67		000	.014	.0007	.78	.028
Source #58. Glass Butte, Lake County, Oregon. USGS Crescent, USA quadrangle 1:250,000 series. 1970										
n=2										
$\bar{X}$	106.5	79.4	---	107.4	---	.056	.76	.092	1140.9	3.76
S.D.	1.93	2.32		10.13		000	00	.0010	14.17	.021
Source #59. Sugarloaf Butte, Malheur County, Oregon. USGS Jamieson, Oregon 15' quadrangle. 1950										
n=2										
$\bar{X}$	64.2	157.2	---	60.1	---	.091	.95	.031	2267.1	3.74
S.D.	3.54	2.40		11.31		.0028	.042	.0057	107.55	.042

Table 9. Results of analysis of obsidian artifacts from Spotten Cave (42Ut104), the Williamson Site (42Ut477), and Goshen (42Ut416) in Utah County, Utah (Alan C. Spencer, personal communication; Dale L. Berge, personal communication)

Sample Number	Cultural Association	Rb ppm	Sr ppm	Zr ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %	Highest Probability			2nd Highest Probability	
										Group	P(X/G)	P(G/X)	Group	P(G/X)
						SPOTTEN CAVE (42Ut104)								
616	Desert Archaic	193	41	74	.056	.72	.146	183	3.69	1	.0000	0.9996	2	0.0003
617	Sevier	109	90	67	.035	.95	.073	1690	3.76	31	.0000	1.0000	---	
618	Sevier	284	6	73	.067	.89	.049	12	3.90	9	.0000	0.9343	10	0.0656
619	Sevier	150	41	113	.056	.73	.145	189	3.75	2	.0000	0.9992	4	0.0008
620	Late Sevier	113	74	69	.036	.97	.068	1659	3.67	31	.0074	1.0000	---	
621	Late Sevier	507	7	102	.068	.97	.104	17	3.80	6	.0000	1.0000	---	
622	Late Sevier	250	12	100	.065	.92	.053	10	3.92	8	.7434	1.0000	---	
623	Late Sevier	288	5	95	.066	.90	.049	13	3.99	8	.0000	0.9993	10	0.0004
624	Late Sevier	495	7	96	.067	.94	.105	15	3.74	6	.0000	1.0000	---	
625	Sevier	191	42	72	.056	.72	.141	179	3.67	1	.0000	0.0078	2	0.0021
626	Desert Archaic	269	9	80	.064	.91	.055	10	3.85	8	.2060	1.0000	---	
627	Sevier	197	46	86	.056	.74	.147	185	3.83	1	.0000	0.9927	4	0.0072
						WILLIAMSON SITE (42Ut477)								
628	Shoshone	533	3	104	.072	.94	.088	12	3.78	6	.0000	1.0000	---	
629	Shoshone	178	43	315	.048	1.86	.307	700	3.64	*47	.0000	?	---	
630	Shoshone	189	39	104	.056	.73	.145	193	3.66	4	.0004	0.5481	2	0.4351
631	Shoshone	174	47	285	.049	1.87	.315	720	3.64	*47	.0000	?	---	
632	Shoshone	113	77	58	.035	.97	.069	1664	3.70	31	.0030	1.0000	---	
633	Shoshone	99	68	105	.036	.97	.069	1663	3.74	31	.0000	1.0000	---	
634	Shoshone	116	79	78	.035	.94	.066	1629	3.60	31	.0116	1.0000	---	
635	Shoshone	116	73	81	.035	.96	.068	1651	3.42	31	.0334	1.0000	---	
636	Shoshone	116	74	57	.035	.97	.070	1676	3.72	31	.0072	1.0000	---	

Table 9. Continued.

Sample Number	Cultural Association	Rb ppm	Sr ppm	Zr ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %	Highest Probability Group	P(X/G)	P(G/X)	2nd Highest Probability Group	P(G/X)
							GOSHEN (42Ut416)							
797	Sevier	295	7	20	.066	.97	.051	11	4.04	9	.0000	0.8921	10	0.1079
798	Sevier	279	10	36	.065	.91	.052	10	3.95	9	.0330	1.0000	—	
799	Sevier	329	5	70	.074	.87	.038	8	4.15	10	.0000	1.0000	—	
800	Sevier	285	5	102	.065	.93	.052	10	3.97	8	.0000	1.0000	—	

* Source 47. Possibly the Buffalo Lake, Yellowstone Source.

Table 10. Geologic sources for obsidian artifacts from Spotten Cave, the Williamson site and Goshen.

Archaeological Period	Number of Samples	Source Identification	Percent
		SPOTTEN CAVE	
Desert Archaic	1	1	50%
	1	8	50%
Sevier	1	31	20%
	1	9	20%
	1	2	20%
	2	1	40%
Late Sevier	1	31	20%
	2	6	40%
	2	8	40%
		WILLIAMSON SITE	
Shoshone	5	31	56%
	1	6	11%
	1	4	11%
	2	47?	22%
		GOSHEN	
Sevier	2	9	50%
	1	10	25%
	1	8	25%

Table 11. Results of analysis of obsidian artifacts from southwestern Utah and northwestern Arizona (Richard Thompson, personal communication 1980).

Sample Number	Provenience	Rb ppm	Sr ppm	Zr ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %	Highest Probability			2nd Highest Probability	
										Group	P(X/G)	P(G/X)	Group	P(G/X)
					GRAND CANYON NATIONAL PARK, ARIZONA									
818	GC-663 962-95	198	84	85	.047	.91	.135	513	3.44	14	.6156	1.0000	---	
821	GC-663 107-10	182	82	103	.047	.93	.132	509	3.50	14	.4854	1.0000	---	
822	GC-782 126-1	186	40	107	.056	.73	.142	183	3.67	2	.0002	0.8249	4	0.1747
823	GC-800 181-25	112	114	69	.070	1.74	.171	847	3.83	?	---	?	---	
					KAIBAB-PAIUTE RESERVATION, ARIZONA									
819	KPR-6 506-10	188	82	113	.047	.92	.133	502	3.42	14	.9016	1.0000	---	
824	KPR-47 547-3	195	88	82	.047	.92	.128	489	3.41	14	.2544	1.0000	---	
					LITTLE CREEK MOUNTAIN, WASHINGTON COUNTY, UTAH									
820	42Ws940 1103-4	194	82	134	.047	.91	.135	513	3.46	14	.4612	1.0000	---	
825	42Ws945 1105-2	186	83	103	.047	.90	.130	503	3.43	14	.5888	1.0000	---	
826	42Ws1077 1220-2	193	40	105	.056	.73	.141	175	3.61	2	.0000	0.4799	1	0.4034

Table 12. Results of analysis of obsidian artifacts from the Fillmore Area, Millard County, Utah; Montezuma Canyon, San Juan County, Utah and Hovenweep National Monument, Montezuma County, Colorado.

Sample Number	Cultural Association	Rb ppm	Sr ppm	Zr ppm	MnO %	Fe_2O_3 %	TiO_3 %	Ba ppm	Na_2O %	Highest Probability			2nd Highest Probability	
										Group	P(X/G)	P(G/X)	Group	P(G/X)
		FILLMORE AREA, MILLARD COUNTY, UTAH												
892	Sevier	317	7	92	.073	.87	.037	9	4.03	12	.0000	1.0000	---	
893	Sevier	261	14	126	.064	.99	.057	11	3.89	8	.0007	1.0000	---	
894	Sevier	275	10	80	.066	.99	.051	11	3.90	9	.0000	0.5515	8	0.4485
895	Sevier	282	6	93	.066	.95	.051	12	3.95	8	.0000	0.9999	9	0.0001
896	Sevier	275	11	74	.064	.97	.053	12	3.82	9	.0000	0.9875	8	0.0125
897	Sevier	264	12	82	.060	.97	.059	15	3.85	8	.0000	1.0000	---	
		MONTEZUMA CANYON, SAN JUAN COUNTY, UTAH--42SA2756, 42SA2096												
816	Basket Maker III	144	7	34	.068	.42	.079	21	4.13	?	---		---	
817	Pueblo I	207	0	143	.086	1.19	.073	9	4.51	82	.0000	1.0000	---	
		HOVENWEEP NATIONAL MONUMENT, HACKBERRY GROUP MONTEZUMA COUNTY, COLORADO												
902	Pueblo III	93	74	70	.087	.94	.011	305	4.66	88	.0000	1.0000	---	

Table 13. A comparison of the results of analyses reported in this paper to those reported by Jack (1971, 1976), Jack and Carmichael (1969) and Hughes (1983).

Reference	Rb ppm	Sr ppm	Y ppm	Zr ppm	Nb ppm	MnO %	Fe_2O_3 %	TiO_2 %	Ba ppm	Na_2O %
Government Mountain, Coconino County, Arizona										
Source 88, Table 7	105	72	14	90	45	.090	1.08	.017	302	4.46
Jack (1971)	113	78	13	77	52	.085		.031	308	
Stoney Rhyolite Core, Medicine Lake, Siskiyou County, California										
Source 51, Table 8	141	73	26	239	13	.040	1.69	.254	736	3.91
Hughes (1983)	160.9	80.2	32.0	225.8	9.9				826.6	
	±2.7	±2.3	±2.5	±3.6	±2.1				±13.1	
Bodie Hills, Mono County, California										
Source 52, Table 8	182	95	4	116	14	.062	.69	.109	501	3.71
Jack & Carmichael (1969)	195	93	13	98	13	.063		.106	540	
Jack (1976)	198	96	11	103	14	.063		.109	555	
Inyo Craters, Mono County, California										
Source 53, Table 8	158	54	23	270	22	.058	1.92	.143	346	4.23
Jack & Carmichael (1969)	149	99	23	193	15	.068		.206	620	
Mono Craters, Mono County, California										
Source 54, Table 8	181	12	30	150	31	.051	1.24	.067	29	3.89
Jack & Carmichael (1969)	190	5	27	106	20	.058		.065	16	
Jack (1976)	196	4	25	108	23	.059		.065	17	
Glass Butte, Lake County, Oregon										
Source 58, Table 8	107	79		107		.056	.76	.092	1141	3.76
Jack & Carmichael (1969)	80	30	45	95	10	.052		.087	1300	
Hughes (1983)	92.9	25.5	56.8	93.0	10.5				1205.3	
	±6.6	±2.9	±5.0	±5.8	±2.4				±78.9	
Obsidian Cliff, Yellowstone National Park, Wyoming										
Source 49, Table 5	251	9	66	189	33	.029	1.35	.075	38	3.70
Jack & Carmichael (1969)	250	5	90	170	65	.030		.090	50	

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VISUAL SOURCING OF CENTRAL EASTERN CALIFORNIA OBSIDIANS

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As compared with their counterparts of barely a generation ago, modern archaeologists practice science with the help of a bewildering and ever increasing battery of technical aids. As the direct result of research achievements in physics, chemistry, biology, and electronics and vigorous programs in government, industry, and academia to develop the practical applications of these achievements, a generation of sophisticated technology applicable to virtually every phase of archaeological work, from site survey to report preparation, is now available. Unfortunately, many of these techniques are very expensive, a drawback all too apparent in an era of dwindling funds for research in archaeology that is likely to get worse before it gets better. It would seem prudent therefore, periodically to take stock of the technology considered "state of the art" in archaeology in terms of its performance relative to less expensive alternatives -- perhaps less technical -- but potentially capable of achieving comparable or closely comparable results. In each such instance, the question is whether the differences in results justify the differences in cost.

The specific problem dealt with below is that of obsidian source analysis. The techniques now available for this kind of work include neutron activation and several variations of x-ray fluorescence (cf. Harbottle 1982). It is generally accepted that these chemical methods of sourcing provided the first reliable means for establishing the parent geological source of obsidian artifacts. Prior to their advent, the attribution of archaeological obsidian to specific quarries was based on a combination of visual inspection and common sense, the results of which were rightly considered speculative and seldom put forth with any conviction, although they have proved right (e.g, Bennyhoff 1956; cf. Jack 1976) about as often as wrong (e.g., Goldschmidt and Driver 1940: 120; cf. Hughes 1978: 54).

The reliability of chemical sourcing methods, despite their expense and inaccessibility to many, resulted almost immediately in the development of an entirely new field of obsidian source analysis. The theoretical and methodological naievete evident in the early literature of the field, attributable to its origins in and subsequent emphasis on scientific technique, has evaporated as research has increasingly addressed itself to issues firmly grounded in anthropological theory. Despite this, the nascent field of obsidian source analysis still retains some dubious axioms. Among the most basic of these is the proposition that volcanic glass flows are so variable in their macroscopic physical properties that reliable source identifications can only be made by one of the accepted chemical sourcing methods. Curiously, this proposition has seldom been put to the test.

This would present no problem if source analyses were inexpensive or required of only a few specimens in each instance, but neither condition applies.

The least expensive chemical sourcing methods costs approximately $15 per sample and with increased awareness of sampling as an archaeological problem it is apparent that for a broad range of problems source analysis must be performed on large suits of specimens often numbering into the thousands (cf. Hughes and Bettinger 1984).

In more philosophical perspective, the claim that obsidian sources are never macroscopically distinguishable agrees with neither common sense nor experience; it is no more logical than its alternative, that they can always be distinguished megascopically. Many archaeologists, whatever they are willing to put into print, express confidence in their ability to recognize specific glass sources, though few have any idea as to the degree to which their impressions are correct. [1]

In the following sections, we explore the viability of megascopic obsidian sourcing as an alternative to the more formidable chemical methods available. The term megascopic here refers to unaided visual inspection, and to visual inspection aided only by low power magnification (10x - 30x).

Background

During the course of probabilistic surveys of a large archaeological transect centered near the modern town of Big Pine, California (Bettinger 1975; 1977), it became evident that obsidian exhibiting certain properties of color, texture, banding, inclusions, and iridescence varied in abundance according to location within the transect; it increased in frequency near the known location of the Fish Springs obsidian source (cf. Steward 1933: 262), and decreased with increased distance from that point. By the close of the survey, familiarity with this distinctive obsidian and its pattern of distribution made it appear likely that Fish Springs was the source of this particular glass. In turn, this suggested that Fish Springs produced in some frequency a variety of glass that could be distinguished visually from glass produced by other sources. Local amateurs, far more familiar than we with the welter of archaeological sites in Owens Valley, expressed similar opinions about glass they identified as deriving from the Queen source, in the Truman Meadows area north and east of Big Pine on the California-Nevada border.

To explore further these possibilities, in 1977 two undergraduate students in the Department of Anthropology at New York University were familiarized with the properties of the glass believed to derive from Fish Springs. These two students then identified the frequency of such glass in samples of debitage given to them without provenience from sites located during the probabilistic surveys of the Big Pine transect. The results showed the expected patterning, sites near the Fish Springs source yielding high frequencies of this variety of glass, while sites farther away yielded lower

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[1] Editor's note: workers at Sonoma State University report success rates between 80 - 95% for visual source identifications of Borax Lake, Mt. Konocti, Napa Glass Mountain and Annadel obsidian at archaeological sites in the North Coast Ranges of California (see Origer 1982: 194-197).

frequencies. Further, as previously observed in the field, the frequencies of this type of glass were extremely high near the source (often in excess of 90%) which suggested that the attributes that had been employed to identify Fish Springs obsidian characterized the bulk of the material produced by this source. These findings indicated that for at least some obsidian sources, objective and explicit criteria could be developed to permit reliable magascopic identification of the majority of glass from a single source.

Building on this assumption, quarry specimens and chemically sourced samples of obsidian debitage were inspected and a series of criteria were developed as a basis for the visual identification of obsidian from four major obsidian sources, three located in eastern California and one in western Nevada. These sources were: Casa Diablo, Mount Hicks, Truman Meadows (Queen), and Fish Springs. Since the initial work, Bodie Hills has been added to this list.

Between 1980 and the present, the identification criteria for these glasses has been refined and the reliability of visual identification has been tested in three different instances.

Procedures

In all cases the techniques for megascopic identification have been the same. Specimens, either debitage or tools, are first inspected without magnification and candled to ascertain color and translucency. Each is then examined under a 10x-30x variable power binocular dissecting microscope with movable high intensity light source held in various positions to reveal inclusions, color, texture, and other salient attributes. It has been our practice to have two individuals, each similarly equipped with a binocular microscope and light source, work side by side examining the same specimen in turn, identifying its source independently. The identifications are compared and in the case of discrepancies the specimen is reexamined to resolve the differences.

As the technique has been perfected, there has been a conscious effort to produce a specific source identification for each specimen and to minimize the frequency of specimens left unattributed to source. The reasoning here is that rigorous adherence to objective identification criteria in these tests, rather than more subtle intuitive impressions, alone will result in the isolation of traits that permit replicable results with visual sourcing. If a particular piece exhibits traits that satisfy the criteria specified for a particular source, e.g., in opacity, it is always identified as belonging to that source, regardless of whether it resembles in other respects the balance of specimens visually identified as belonging to that source or whether the identifier genuinely believes it to be from that source. The point is that in visual sourcing, the gross megascopic variability observed in glass from a particular location is reduced to a few key traits which it is assumed to display invariably and which at the same time others are assumed never to display. The empirical utility of the traits selected in any given instance can only be ascertained if the logical consequences of this assumption for identification are adhered to strictly. In this scheme, the only specimens that are left unidentified are those that exhibit none of the traits or a combination of traits that identify the sources encompassed in the research and are hence presumed to be from other sources. The distinguishing traits currently used to identify the five glass sources within the Inyo-Mono region now considered potentially susceptible to megascopic sourcing are described in some detail below.

Casa Diablo. This is the largest source in eastern California and certainly the one with the widest distribution when frequency is considered (Ericson 1981). The trait taken to distinguish this source is its near-uniform opacity. All except the thinnest pieces permit the passage of little or no light. The degree of light transmission may vary between or within pieces of this glass but it is never more than faintly translucent. Some of this obsidian shows a deep silky sheen that approaches chatoyance. On the basis of earlier tests neither texture, which varies from very waxy to coarse grained, nor color, which varied from black to red and brown, are considered reliable in identifying this source.

Fish Springs. This small source is located near the modern town of Big Pine. As discussed elsewhere (Bettinger 1982), there are two distinguishing attributes of this source: 1) much of it is green; and 2) it displays feathery brown inclusions that show an iridescent play when struck by low-angle light. All except the smallest pieces exhibit some heterogeneity in the transmission of light, which may vary from near-transparent to near-opaque, the transition from one to the other occurring in the form of sharply defined and typically contorted flow bands. The clearer material contains abundant black and white phenocrysts that are most obvious only upon microscopic examination. Also characteristic are white-gray streaks or thin bands of what appear to be volcanic ash. Minor fractions are brilliant red or exhibit a silky silver sheen produced by elongated vesicles; neither of the latter two are considered definitive traits.

Queen (Truman Meadows). The distinguishing trait of Queen obsidian is its translucency and lack of minor inclusions. Much of this glass is clear almost to the point of transparence, usually with a distinct gray or golden brown cast. Minute phenocrysts are very sparse. Flow banding is common and occurs as thin, dense planar bands that are almost perfectly parallel to each other. In identifying this source, care must be taken that these planar bands are not viewed from the perpendicular, in which case the glass will appear to be nearly opaque. The only eastern California source with which Queen may be commonly confused is Mt. Hicks.

Mt. Hicks. This source resembles Queen in that a substantial fraction of it is clear and without magnification appears nearly transparent and free of inclusions. Segregation of the two is as follows. First, Mt. Hicks seldom occurs in large pieces, greater than 2 cm. in diameter, without some inclusions in the form of banding or clouding. Second, Mt. Hicks glass exhibits substantial quantities of small phenocrysts readily visible upon magnification. Third, Mt. Hicks does not exhibit the striking parallel planar banding found in Queen glass. The banding is invariably contorted and individual bands frequently intersect each other. The only eastern California source with which Mt. Hicks is generally confused is Bodie Hills.

Bodie Hills. To date, this source has proved the most troublesome to identify megascopically, in part because it constitutes but a very small fraction of the collections with which we have worked. The traits used define two distinct forms. One exhibits contorted, but generally linear, gray-green bands and masses interspersed with much smaller quantities of clear bands and masses containing minute black and white phenocrysts visible under magnification. This form might be confused with Fish Springs except that it lacks the brown and white banding characteristic of that source. The second Bodie Hills form is a mixture of very dense black and, in smaller quantities, red-brown dentritic masses interspersed with much smaller quantities of clear material containing minute black and white phenocrysts.

Quantification of Reliability

The reliability of megascopic source identification is most conveniently tested by comparing these identifications with identifications obtained on the same material by one of the standard chemical characterization techniques (either x-ray fluorescence or neutron activation). It is, of course, assumed that the megascopic identification is done without knowledge of the results of chemical characterization. Consequently, megascopic identification should precede chemical characterization.

The matches and mismatches between chemical identifications, in this study by x-ray fluorescence, and visual identifications can be quantified in several ways. The simplest expresses the number of correct visual identifications as a fraction of the correct and incorrect identifications, combined, for all sources. In general terms, this expresses the overall reliability of visual source identifications and is an appropriate measure of the utility of the procedure in establishing the gross composition of a large assortment of glass from a site or region. The range of archaeological questions to which such data are applicable include patterns of resource acquisition, either by trade or direct procurement, territoriality (e.g. Bettinger 1982), and social ranking (e.g. Hughes 1978) to cite a few examples. In some cases, two or more sources that are difficult to distinguish visually can be meaningfully combined. Thus, until recently in our research Queen and Mt. Hicks sources were merged into a single co-source, which seemed justified on the grounds that they are relatively close together geographically. More drastically, in much earlier central Owens Valley studies, Fish Springs, which is readily identified, was compared against all others, which were then less well known. The extent to which such merging of visually similar sources is useful will depend on the question at hand and the relative location of the sources potentially to be merged with respect to each other and to the remaining sources.

The reliability of visual identification also can be couched in terms applicable to an individual source. Here, as when all sources are considered at once, the number of correct identifications is the total number of pieces from a source correctly identified as belonging to that source. The errors, however, can be of two kinds and hence admit of no simple quantification. In reference to a single source, there are first errors of commission, those in which other sources are wrongly confused with the source in question. In the tabulated test results, in which we adopt the convention of casting x-ray fluorescence identifications as the columns and visual identifications as the rows, these equal the marginal row total less the number of correctly identified pieces.

Still speaking of a single source, there are also errors of omission, those in which specimens of that source are incorrectly attributed to another source. These equal the column total less the number of correct identifications.

It should be obvious that for any collection of pieces subjected to visual sourcing, the number of errors made overall is equal to the total number of errors of omission and, at the same time, the total number of errors of commission. That is, a piece incorrectly attributed is at once an error of commission (with respect to the source to which it was wrongly attributed) and omission (with respect to the source to which it actually belonged). This is not true in the case of the individual source, where an error of omission does not imply an accompanying error of commission -- nor an error of commission one of omission. Consequently, sources may vary according to the degree to which they are subject to errors of commission and, similarly, to errors of omission.

Further, there are at least two senses in which it can be useful to distinguish between errors of commission and errors of omission for individual sources. First, inspection of the errors of omission and commission discloses which specific sources are most commonly confused with each other and, if the distinguishing visual criteria are kept in mind, the basis for that confusion. Thus, errors of commission occur when the traits taken to distinguish the source in question are found in glass from a different source; errors of omission occur when the traits taken to distinguish a source are not present in glass from that source. Careful inspection of such data provides a sound basis for improving identification criteria for future applications.

Second, it is useful to distinguish between errors of commission and errors of omission because in some applications of source information, errors of commission are relevant and errors of omission are not. In these circumstances, visual source identification can provide reliable data for sources infrequently subject to errors of commission regardless of the frequency of errors of omission for that source.

The most recurrent situation of this kind is in relation to source specific obsidian hydration dating. For this purpose, source identification is relevant only for the sample submitted for rind measurement and not the entire population of specimens representing that source. Thus, it need only be certain, or relatively certain, that the specimens visually identified as belonging to a source are from that source, which is to say that the source is not greatly subject to errors of commission.

The same sort of utility would apply to any archaeological question involving only one specimen rather than a suite of specimens. For instance, the ability to determine with, say, 95% reliability that a given specimen is Fish Springs obsidian might be useful in any number of contexts.

It is possible, of course, to minimize errors of commission by being exceptionally conservative in identifications and deferring all questionable identifications to a residual category of unidentifiable specimens. This, however, effectively eliminates the application of the results to broader questions regarding the gross composition of an obsidian collection, for it cannot be assumed that the number of specimens for which visual identifications are quite certain is proportional to the total number of specimens of that source in the collection. Some sources are likely to be more distinctive than others and so exhibit a higher frequency of certain identifications. For these reasons and for the reason that it tends to make the recognition of reliable source traits more ambiguous, we have eschewed this conservative strategy in our visual source identifications.

Results

Tables 1 through 3 report the results of three successive tests in which we have compared visual source identifications of archaeological materials from central Owens Valley (Table 1), Long Valley (Table 2), and western Nevada (Table 3) with chemical source identifications of the same materials. Table 4 summarizes for each test the frequency of overall errors, errors of commission, and errors of omission. In each case it was presumed on the basis of both geographical location and previous source analysis that Fish Springs, Casa Diablo, Queen, Mt. Hicks, and Bodie Hills glass would account for a substantial fraction of the material present. In addition, these sources were considered susceptible to visual identification and at least provisional identification criteria were available for each one.

The visual identification criteria for certain of these sources, however, differed to some degree between the three tests. The currently accepted identifying traits described earlier were used in the most recent test (western Nevada). The identifying criteria for Fish Springs in the first (Owens Valley) and second (Long Valley) tests were the same as those currently accepted.

The identification criteria for Casa Diablo were the same as currently accepted in the Long Valley test but not in the earlier Owens Valley test, in which it was defined by a combination of traits consisting of susceptibility to light transmission (opaque), color (grey/black), and texture (fine-grained).

In the Owens Valley test, Queen was identified on the basis of transparency and Mt. Hicks on the basis of contorted banding and cloudy inclusions. The results of this test showed these criteria to be invalid and in the following Long Valley test Queen and Mt. Hicks were treated as a combined co-source identified by the presence of complete or fractional translucence.

Bodie Hills was identified by the presence of abundant black dendritic masses in both the Owens Valley test and the Long Valley test.

Central Owens Valley. The first test (Table 1) was carried out in 1980 on a sample of 39 projectile points and 15 pieces of debitage selected from sites located in the Big Pine archaeological transect mentioned earlier. In this first trial of visual sourcing, the principal question was whether Fish Springs obsidian, which was defined in this and all subsequent tests in the manner described earlier, could be reliably segregated from other glass occurring on archaeological sites in Owens Valley. At the time we believed it also would be possible to segregate other glasses visually, but our notions about the defining criteria that would apply to these were less certain than for Fish Springs. That is, the identifying traits employed for Casa Diablo, Mt. Hicks, and Queen were neither as well defined nor as well understood as they are at present.

The effects of this differential familiarity are evident in the results from the test. Every piece of Fish Springs glass in the test sample was identified correctly as Fish Springs. However, two additional pieces, one from Casa Diablo and one from Mt. Hicks, were incorrectly identified as Fish Springs. Casa Diablo was correctly identified in 7 of 11 instances and it was not confused with any other source. On the other hand, 4 pieces of Casa Diablo glass were not correctly attributed to this source; 1 was identified as Fish Springs, and the other 3 were considered unidentifiable. Mt. Hicks and Queen were not successfully separated: six pieces of Mt. Hicks were incorrectly identified as Queen, a seventh as Fish Springs, and an eighth was unidentifiable. Queen was not mistaken for any other source, but (as just noted) 6 pieces of Mt. Hicks were wrongly identified as Queen. In addition to these, also unidentified was a single piece of Mono Craters/Mono Glass Mountain, two chemically indistinguishable glass sources, one located east of Long Valley, the other in the Mono Basin. Finally, 5 pieces from an as yet unknown source, probably in Nevada, were correctly identified as deriving from sources outside central eastern California.

<u>Long Valley</u>. A second test of visual source identification was performed in early 1983 on a sample of 57 projectile points collected during surface surveys in Long Valley. At this time it was believed that the Queen and Mt. Hicks sources could not be visually separated with any degree of confidence, so these two sources were lumped together as a single co-source.

The results of the test are indicative of our familiarity with different glass sources at the time and of the distinctive differences between these particular glass sources. Casa Diablo, Queen, and Mt. Hicks are among the most easily and reliably recognized glasses found in eastern California and we had frequently encountered them during previous research in both Owens Valley and Long Valley. Long term familiarity with these glasses, coupled with their dominance in the Long Valley collection, resulted in very accurate visual source identifications for this particular collection. Fifty-one of fifty-seven pieces, or 80%, were attributed to the correct source.

Minimal representation of Fish Springs, Bodie Hills, and Mono Craters/Mono Glass Mountain glass precludes an accurate statistical assessment of success in identifying these sources. The mediocre performance with Fish Springs is probably an aberration of sample size; the poor performance with Bodie Hills and Mono Glass Mountain/Mono Craters, on the other hand, is reasonabily indicative of the limited degree to which they were susceptible to visual identification at the time. Visual identification criteria have yet to be determined for Mono Glass Mountain and Mono Craters. Fortunately, neither source contributes significantly to any archaeological assemblage in central eastern California so far analyzed by x-ray fluorescence.

Nevada. In the most recent test of visual source identifications, a sample of 60 projectile points from Hidden Cave, western Nevada, and Gatecliff Shelter, central Nevada, that had been previously sourced by x-ray fluorescence (Hughes 1983a, 1983b) were examined and attributed to sources on the basis of visual identification criteria described above. On the basis of careful inspection of previously sourced collections, the explicit criteria described earlier were used to distinguish Queen, Mt. Hicks, and Bodie Hills glass.

The results indicate that Queen and Mt. Hicks glasses can be successfully segregated in the vast majority of cases by visual inspection alone: out of a combined total of 37 pieces of Queen and Mt. Hicks obsidian, 31 (89%) were correctly identified, and only 3 of the misidentifications were the result of confusion between these two particular sources; the other 3 errors resulted from Mt. Hicks glass being misattributed to Bodie Hills.

That highly reliable criteria for segregating Bodie Hills from other sources remain to be discovered, if indeed they exist, is shown by the relatively low reliability of visual identifications. Only 7 of 10 specimens were correctly attributed from a group of 11 specimens visually identified as belonging to that source. Moreover, the data in Table 3 clearly indicate that Bodie Hills is likely to resist accurate visual sourcing because it often is confused with two other sources, Casa Diablo and Mt. Hicks, that are themselves visually quite distinct and seldom confused with each other or with other sources. It is the case, therefore, that Bodie Hills must lie between these two sources in terms of its visual characteristics and be sufficiently variable that it is confused with them and they with it. The results of this particular trial indicate that Bodie Hills is confused with Mt. Hicks at roughly the same rate Mt. Hicks is confused with Bodie Hills, i.e. between 14% and 10% of the time. These data also indicate that Casa Diablo glass is never wrongly identified as Bodie Hills, but that much Bodie Hills glass, about 20%, is wrongly identified as Casa Diablo.

When only eastern California sources are considered, the accuracy of visual source identifications in this particular test is 83%. X-ray fluorescence, however, indicated that nearly 18% of the collection in question consisted of pieces attributable to the Majuba Mountain source in northwestern Nevada (Hughes 1983b). We were entirely unaware of the existence of this source since it only recently has been reported in the literature. In addition, Hughes' (1983b) work on this source suggests that it may be difficult to distinguish from Casa Diablo even by x-ray fluorescence unless the proper elements are measured. That this source is likely to be a major problem in attempts at visual sourcing in areas where it is found is shown by the results reported in Table 3. Here, Majuba Mountain is confused with both Queen and Casa Diablo. In this respect it is rather similar to Bodie Hills, which, as just discussed, overlaps with both Mt. Hicks (a "clear" source) and Casa Diablo (an "opaque" source). Given this, it is curious that Majuba Mountain is not as frequently confused with Bodie Hills as might be expected. The obvious implication is that Majuba Mountain is not variable in appearance in the sense that it might be described as grading between clear and opaque. Rather, these data suggest that Majuba Mountain takes on two distinct forms: a dark, opaque form practically identical to Casa Diablo, and a clear form identical or nearly identical to Queen. Reinspection of the pieces in question suggests some dimensions along which it may be possible to segregate Queen from Majuba Mountain, but not that differentiate Majuba Mountain from Casa Diablo.

Conclusions and Implications

As stated at the outset, at issue here is the long standing axiom that obsidian glass sources cannot be reliably identified without recourse to chemical characterization. In operational terms, the question is whether the substantial cost of chemical characterization relative to visual identification is justified by the observed differences in results obtained by these two techniques. Within the range of possible outcomes implied, at one extreme visual identification might be judged so unreliable or misleading that one would conclude that chemical characterization is always worth the cost regardless of the problem under scrutiny. On the other hand, at the other extreme, visual identification might be found to match results obtained by chemical characterization exactly and lead to the conclusion that the cost of the latter is never justified. As one might reasonably have expected, the results of the three tests reported above indicate that at least for the western Great Basin, neither extreme applies and that the actual situation falls somewhere in the middle. Several more concrete conclusions drawn from these data are discussed below.

First, in the most general sense, it is quite clearly the case that many obsidian sources produce glass that can be successfully identified megascopically. More than three-quarters (78%) of all the specimens considered in the three tests were correctly identified using visual identification criteria.

Second, not all eastern California sources can be visually identified with equal success. At present, Fish Springs produces the best results over the widest area. Although it did not appear in the samples from western and central Nevada there is no reason to believe that it would have been missed had it been present as it does not in any respect resemble the other sources represented in those collections. In addition, we suggest that identifications attributed to this source are sufficiently reliable to be used as a basis for source-specific obsidian hydration dating.

Mt. Hicks glass is likewise successfully identified over a large area extending as far east as central Nevada. Nevertheless, Bodie Hills glass and Queen glass are mistaken for Mt. Hicks glass often enough that megascopic identifications of this source are probably unreliable when used as a control for obsidian hydration dating.

The Queen source is so readily confused with the Majuba Mountain source that visual identification is likely to be of limited value in central and western Nevada until the Majuba Mountain source is better known. With respect to assemblages from eastern California, on the other hand, Queen can be readily identified. Further, since other sources are seldom confused with it, with this geographic limitation, identifications obtained visually provide a sound basis for source specific obsidian hydration dating.

Like Queen, Casa Diablo glass is too often confused with Majuba Mountain glass to be consistently identified in western and central Nevada. Further, in eastern California, Bodie Hills obsidian is taken for Casa Diablo obsidian with sufficient regularity (ca. 20%) that in assemblages with substantial quantities of Bodie Hills obsidian, visual identification of Casa Diablo obsidian will be subject to considerable error of commission and therefore not suitable as a control for obsidian hydration dating. Where Bodie Hills is not present in any quantity, as was found to be the case in Long Valley and Owens Valley, for example, visual identification of Casa Diablo glass is quite reliable and p perfectly suitable for use in conjunction with source specific obsidian hydration dating.

Bodie Hills would appear to be the least reliable source for visual identification. It is so frequently taken for the two sources geographically closest to it, Mt. Hicks (ca. 10%) and Casa Diablo (20%), and, in turn, Mt. Hicks is so frequently taken for Bodie Hills (ca. 14%), that visual identification will be of only modest utility for assemblages that contain Bodie Hills glass in any appreciable quantity. Nevertheless, certain kinds of questions, for example territoriality, might be addressed with source information of the accuracy observed for Bodie Hills, though source specific obsidian hydration dating is not among them.

From the specific conclusions above regarding the utility of visual identification of obsidian in eastern California follow certain broader implications for the potential role of visual identification in archaeological investigation.

For one thing, visual identification cannot replace chemical characterization. Chemical characterization is ordinarily the means by which the accuracy of visual identification is judged and therefore visual identification can never be more accurate than properly executed chemical characterization and ordinarily will be, in varying degrees, less accurate depending on the source in question. Since it invariably entails a sacrifice of accuracy, the only legitimate use of visual identification is in relation to analysis that would not otherwise be performed owing to the expense of chemical characterizations, either those pertaining to obsidian source analysis directly or those made possible by the availability of resources that would have otherwise been allocated to chemical characterization. Archaeology is, after all, subject to severe practical constraints among the most important of which are time and money. Archaeologists routinely accept these constraints and have developed a host of sampling strategies that enable them to extrapolate about unknowably large populations from limited information within certain limits of error. Visual identification should be undertaken for the same reasons and is, likewise, subject to error.

We suggest that rather than using either technique to the exclusion of the other, chemical characterization is most appropriately employed where visual identification is the most subject to error. Visual identification can be undertaken where chemical characterization is simply too costly, for example in cases that entail extremely large numbers of specimens.

The precise mixture of these techniques, of course, will vary with circumstances, but past experience in eastern California suggests that a rough guideline is provided by the observed tendency for certain artifact categories to exhibit greater variability in obsidian sources than others. In particular, within a given site highly curated tools specifically projectile points, generally exhibit a wider variety of sources and especially distant exotic sources than do non-curated categories, most notably debitage (Hughes and Bettinger 1984). Since the number of projectile points is generally low when compared to the balance of the chipped lithic assemblage present, and since visual identification is the least reliable where source diversity is great and likely to include exotics, the use of chemical characterization is clearly indicated. Taken as a first step, this establishes the likely range of sources represented in the balance of the lithic assemblage -- which will improve performance in any subsequent visual identifications -- and at the same time serves as a basis for the source specific obsidian hydration that is routinely performed on projectile points.

Debitage, by contrast, normally occurs in far greater quantity and is generally composed of a few local sources; visual identification is clearly the more appropriate technique for establishing the source composition of this category.

To conclude, we have stressed that visual identification is potentially capable of performing tasks that cannot be practically performed by chemical characterization. We believe that it is always worthwhile to examine the possible uses of this technique. If the utility of visual identification of obsidian is discounted out of hand without assessing the feasibility of its application a whole class of interesting archaeological problems are, at least for the present, going to go unexplored.

Table 1. Comparison between visual identification and chemical characterization of obsidian from central Owens Valley.

Visual	Chemical Characterization					
Identification	Fish Springs	Casa Diablo	Queen	Mt. Hicks	Other*	Total
Fish Springs	25	1		1		27
Casa Diablo		7				7
Queen			3	6		9
Mt. Hicks				1		1
Other		3		1	6	10
Total	25	11	3	9	6	54

*Note: five specimens are from unknown sources and one is from Mono Craters/Mono Glass Mountain.

Table 2. Comparison between visual identification and chemical characterization of obsidian from Long Valley.

Visual	Chemical Characterization					
Identification	Fish Springs	Casa Diablo	Queen/ Mt. Hicks	Bodie Hills	Other*	Total
Fish Springs	1					1
Casa Diablo	1	39			1	41
Queen/Mt. Hicks		1	10		1	12
Bodie Hills			1			1
Other				1	1	2
Total	2	40	11	1	3	57

*Note: all three specimens are from Mono Craters/Mono Glass Mountain.

Table 3. Comparison between visual identification and chemical characterization of obsidian from western and central Nevada.

Visual	Chemical Characterization					
Identification	Casa Diablo	Queen	Mt. Hicks	Bodie Hills	Majuba Mountain	Total
Casa Diablo	3			2	3	8
Queen		12			6	18
Mt. Hicks		3	19	1		23
Bodie Hills			3	7	1	11
Total	3	15	22	10	10	60

Table 4. Frequency of errors in visual sourcing.

	OWENS VALLEY		LONG VALLEY		NEVADA	
	commission	omission	commission	omission	commission	omission
Fish Springs	7.4%	0.0%	0.0%	50.0%	--	--
Casa Diablo	0.0%	36.5%	4.8%	2.5%	75.0%	0.0%
Queen	66.6%	0.0%	--	--	33.3%	20.0%
Mt. Hicks	0.0%	88.9%	--	--	17.4%	13.6%
Queen/Mt. Hicks	--	--	16.6%	9.1%	--	--
Bodie Hills	--	--	100.0%	100.0%	36.3%	30.0%
Majuba Mountain	--	--	--	--	0.0%	100.0%
Overall	77.8%		89.4%		68.3%	

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OBSIDIAN HYDRATION ANALYSIS

OBSIDIAN HYDRATION DATING AND FIELD SITE TEMPERATURE

Fred Trembour
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Introduction

The study of obsidian hydration has led to one of the newest dating methods available to investigators in archaeology and the earth sciences. Following its announcement in 1960 (Friedman and Smith 1960; Evans and Meggars 1960), the technique quickly attracted other participants in both application and further development (Clark 1961; Michels 1967; Meighan, Foote and Aiello 1968; Johnson 1969; Layton 1972; Friedman et al. 1973). This dual pursuit continues to this day and there is still much work to be done to bring out the full potential of hydration analysis as an absolute dating tool (Friedman and Trembour 1978). This paper is devoted to a discussion of the important factor of field temperature as it relates to interpreting the age of hydrating obsidian.

Any consideration of the hydration topic must keep the fundamentals of the method in mind. Hydration is a form of geologic weathering that begins when the pristinc glass first encounters the environment and continues as a progressive thickening of the hydrated layer. Under ambient conditions the hydration remains attached and integral with the artifact substrate for periods far longer than the span of archaeological time in the New World. The basic laboratory measurement made (usually in micrometers, μ m) is the depth of the hydrated rind on a surface in question.

It has been found that various obsidians possess specific hydration rates which are a function of their differing chemical compositions and some of these may vary by as much as a factor of 20 to 1 (Friedman and Long 1976). For any given obsidian and hydration temperature, however, the rind growth will proceed as the square root of time. The hydration rate for any particular obsidian rises exponentially with increasing temperature, following the Arrhenius diffusion equation (Figure 1). Thus, converting observed hydration depth of an obsidian sample into age terms requires 1) an estimate of the intrinsic hydration rate of the material (usually expressed as $\mu m^2/10^3$ yrs.) and 2) an estimate of the effective hydration temperature in the thermal history of the sample piece. In practice, all samples in close association at an archaeological site are assumed to have had the same thermal histories. As a simple case in relative dating, therefore, we can see that if two facets of the same artifact show different rind thicknesses, their relative ages are in direct ratio of the squares of these thickness measurements.

Temperature and Hydration Rate

According to the law that governs rate of hydration, increasing temperature causes a faster than linear rise in hydration rate, amounting to about a 10% increase in rate for each 1°C increase in ambient temperature. Hence at fluctuating (daily and seasonal) conditions the effective hydration temperature is not its simple arithmetic mean but some higher integrated value (Norton and Friedman 1981). The more closely this value is estimated at any particular archaeological site, the more reliable will be the hydration age determination.

Table 1 refers to the temperature dependent hydration properties of obsidian from a source outcrop near American Falls, Idaho which at 10.0°C has a hydration rate of 2.4 μm^2/1000 years (Friedman and Long 1976). As the temperature is raised or lowered by small increments, the hydration rate changes by about 0.03 μm^2/1000 years per 0.1°C. An error of 1°C in the hydration temperature of a 2000 year old specimen, for example, leads to age assignments between 1740 and 2200 years. The importance of obtaining accurate field temperature estimates may be better appreciated if temperature and time are considered as equal determinants in the formation of hydration rinds. In fact, we may calculate it the other way: if the "true" age of an obsidian artifact were assured by independent means (i.e. by a direct association between the artifact and a radiometrically dated sample), then the effective hydration temperature at this particular archaeological site could be derived from the hydration depth.

Table 2 is a selected listing of western North American obsidian sources for which hydration rates and temperature have been published. Some of these supplied the obsidian recovered from archaeological sites in the Great Basin (e.g. Hughes 1983).

To estimate the natural ambient temperature level at archaeological sites it has become customary to resort to published long-term mean annual air temperature values recorded at suitable nearby national weather stations. By comparing data from two or more stations a correctional factor for altitude differentials may be calculated and applied for the elevation of the archaeological site. An additional temperature refinement can be applied for subsurface locations. It should be noted, however, that this approach usually ignores the set of other variables that may contribute to the important concept of microclimate variation: vegetation and tree cover, direction and degree of terrain slope, snow cover and certain others.

Because the hydration process is so clearly temperature-sensitive, a word of caution is important here. We have found that even short exposures to abnormally high heat can severely distort the outcome of the dating analysis. Thus, surface-collected specimens should always be distinguished from excavated ones. When obsidian is being recovered in the field, the archaeologist should carefully note and record <u>any</u> associated signs of burning at the findspot, such as hearths, house fires, field and forest fires, etc.

On-Site Temperature Measurements

Obviously, post-discovery temperature determinations at selected archaeological sites could go far to exclude the imponderables that were referred to in the problem of microclimate assessment. What is needed is a means of obtaining an integrated record of ambient fluctuations at the locality over a sufficiently long time period, say a year or more. Preferably, these particular localities should then be compared with the records of a suitable weather station for the same period to permit adjustments if the test period has been abnormal with respect to the regional long-term mean.

Although recording instrumentation for this field purpose is available on the commercial market, its use poses problems: high initial expense, power supply, maintenance and protection against disturbance and natural damage.

An early attempt to achieve simplicity and economy for field applications of this kind was published by Pallmann et al. (1940; see O'Brien 1971), who used the method in forestry tree growth research in Switzerland. They devised a small glass ampoule containing a sucrose-water solution at a controlled pH value which inverts to glucose and fructose at a rate dependent on temperature. The extent of inversion after a period of time is measured as optical rotation of a beam of light with a polarimeter. Laboratory calibration enables conversion of the rotation reading to a mean integrated temperature figure. The Pallman device was the first integrating ambient temperature sensor to be free of all field support needs.

More recently, another principle, water diffusion through a permeable membrane or partition, was applied to the same purpose (Ambrose 1976) to date obsidian artifacts in the South Pacific Islands. Ambrose used a spherical shell (or cell) of epoxy resin, filled with a synthetic zeolite desiccant, surrounded by water. In this manner a 100% H_2O vapor pressure differential was maintained across the permeable cell wall, and the rate of diffusion and entrapment of water was a function only of temperature under specific conditions. With this assembly, weight change of the plastic desiccant container due to water uptake over a period of time becomes a measure of the integrated value of the fluctuating environmental temperature. Conversion of weight to a mean temperature figure is obtained by laboratory calibration of the cell at known temperatures.

It should be noted that the sensor operation is entirely maintained by ambient energy, and that neither a support system nor service attention are required between deployment and retrieval in the field. Emplacement of the units in the open air, water or soil are equally feasible. The effective field life or capacity of a cell varies with design; runs of a year or more are commonly carried out. The assemblies are inexpensive -- in the ten dollar range -- small and inconspicuous. Ordinary tools and supplies serve for fastening the devices to trees or burying in soil.

Our laboratory has worked with both the Pallmann and Ambrose type integrating temperature cells for some years. Figure 2 depicts the parts of a Pallmann assembly, including the sealed glass ampoule and the protective polyvinyl chloride 3/4" pipe length for ground emplacement in a prebored hole. The plastic probe may be up to 2 meters (6.6 ft.) long and contain several sensors for operation at various depths.

Figure 3 shows an original spherical Ambrose diffusion cell and our cylindrical modifications of acrylic resin and stainless steel designed to fit into tubular ground probes like those described above. The sensor cells may, of course, be either desiccant-filled or water-filled, with the other component on the outside. We have found that the water-filled model is preferable for very long field runs and/or warm situations, and that the desiccant-filled kind is better suited for places that are subject to frequent freezing and thawing cycles. The cells with water and desiccant components are enclosed in a capped polypropylene jacket tube (which is nearly impermeable to water) before loading into the protective ground probe. Figure 4 shows a short ground probe assembly for horizontal positioning close to the surface. To suppress abnormal vertical heat transfer in operation, the empty sections of a probe pipe are filled with insulation, and excess space in the bore hole is refilled with earth.

As implied earlier, two weighings of the sensor on a chemical balance (just before and after the field exposure) suffice to establish the mean diffusion rate for the temperatures prevailing at the site. This value is usually expressed as milligrams per day. The cells of a given design have been laboratory calibrated under controlled conditions beforehand, from which a conversion graph is prepared (Figure 5). From the appropriate weight change on the ordinate axis of this plot, the "Ambrose temperature" can be read at the abscissa. The temperature-diffusion rate continuity of the cell operation is virtually unaffected in crossing the water freezing point, and cell contact with either liquid H_2O or saturated vapor serves equally well as a water source at any temperature. The sensitivity of the temperature measurement of the Ambrose cell is between 0.1° - 0.2°C, depending on the temperature concerned.

It will be observed from Figure 5 that the cell's weight gain rate rises exponentially with temperature, much like the behavior of the rise in hydration rate of obsidian with temperature. Thus an adjustment from "Ambrose temperature" to the linear "effective temperature" scale is required. This adjustment must be made based on the annual temperature fluctuation range. For ambient air temperature at a site, this range can be estimated adequately using published maxima and minima from a relevant weather station. Some weather stations also record soil temperatures which vary in narrower regular annual cycles. In the absence of such data for an archaeological site, two instantaneous temperature readings made at the expected semiannual occurrences of soil maximum and minimum can provide useful range figures. Norton and Friedman (1981) have published a series of conversion graphs to derive "effective temperature" for both the Pallmann and Ambrose integrated means and for various temperature levels and ranges of fluctuation. The calculated relationships are based on measured activation energies of the reactions and assumed sinusoidal temperature variation within the ranges. An example is given in Figure 6; here it can be observed that for a mean of 14°C and a range of 17.5°C, the effective temperature is 15°C for an Ambrose reading and 16.6°C for a Pallmann reading.

Conclusions

This treatment of long-term integrated field temperature determination has focused on its application for obsidian hydration dating, particularly for archaeological purposes. Of the methods considered, the thermal diffusion cell of Ambrose is favored because of its comparative simplicity, compactness, ruggedness and economy. These advantages make it attractive for liberal use at particular archaeological sites, and in numbers for more thorough exploration of extensive areas. It should be as useful in aiding the temperature-sensitive amino acid racemization dating technique as for obsidian hydration. Many other environmental study applications can be predicted for the device, such as in biology, pedology and climatology.

The *Arrhenius equation* relating diffusion rate to temperature:

$$k = Ae^{-E/RT}\text{, where}$$

k is the obsidian hydration rate (micrometers squared per 10^3 yrs.)

A is a constant

E is the activation energy of the hydration process (calories/mole)

R is the gas constant (calories per degree per mole)

T is the absolute temperature in degrees Kelvin

Figure 1. The Arrhenius equation and the definition of its terms.

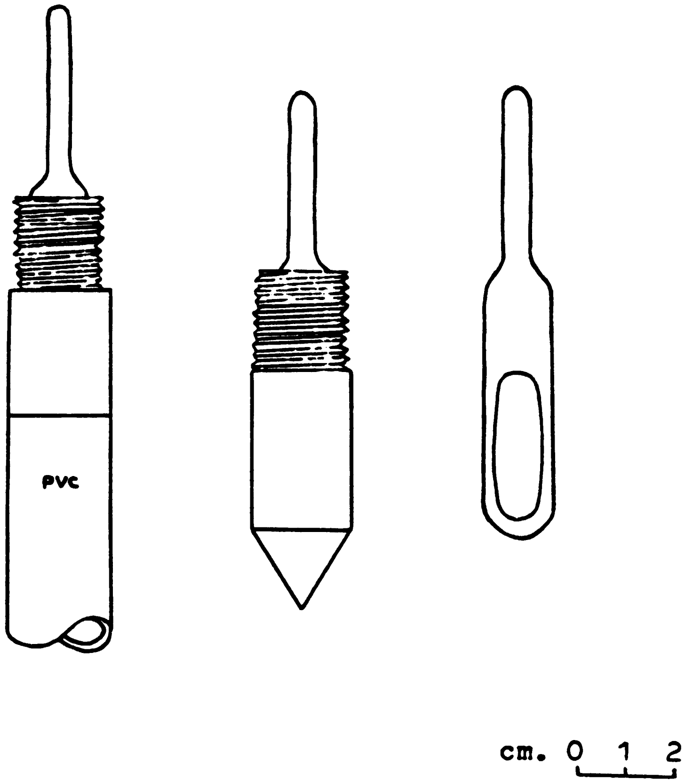


Figure 2. A Pallmann sugar inversion ampoule and ground probe elements for integrated temperature measurements.

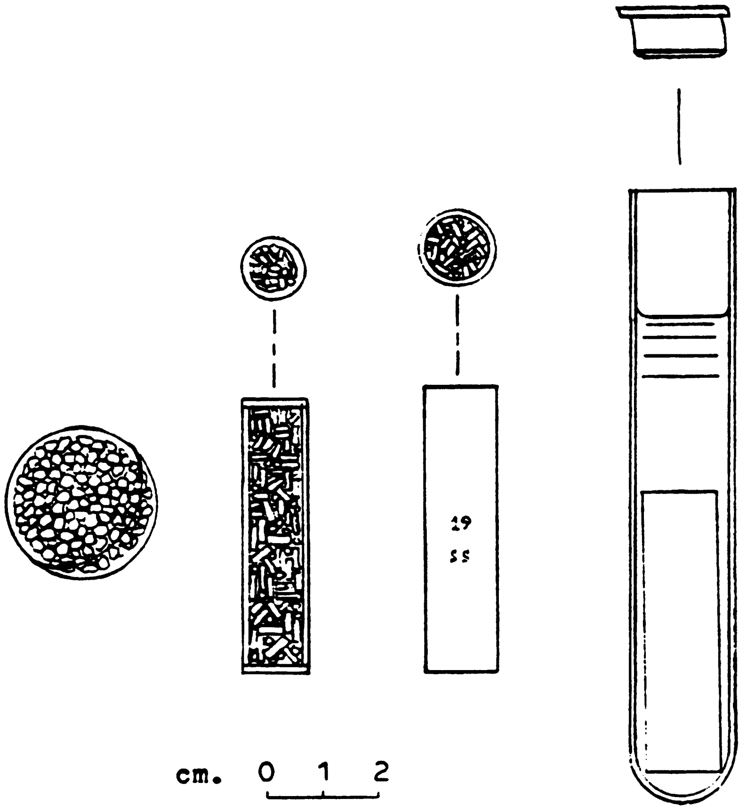


Figure 3. An original spherical Ambrose water diffusion cell and cylindrical modifications applied for integrated ground temperature determinations over long time periods.

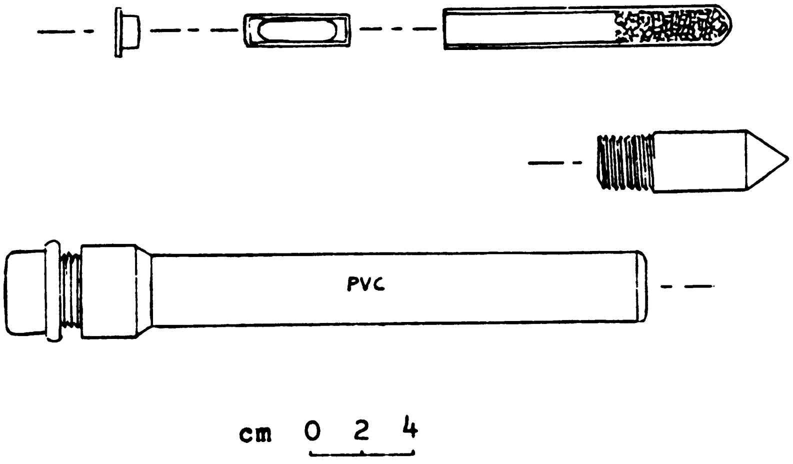


Figure 4. A short ground probe of PVC pipe with fittings that houses an activated water diffusion cell encased in protective polypropylene tubing that contains zeolite desiccant.

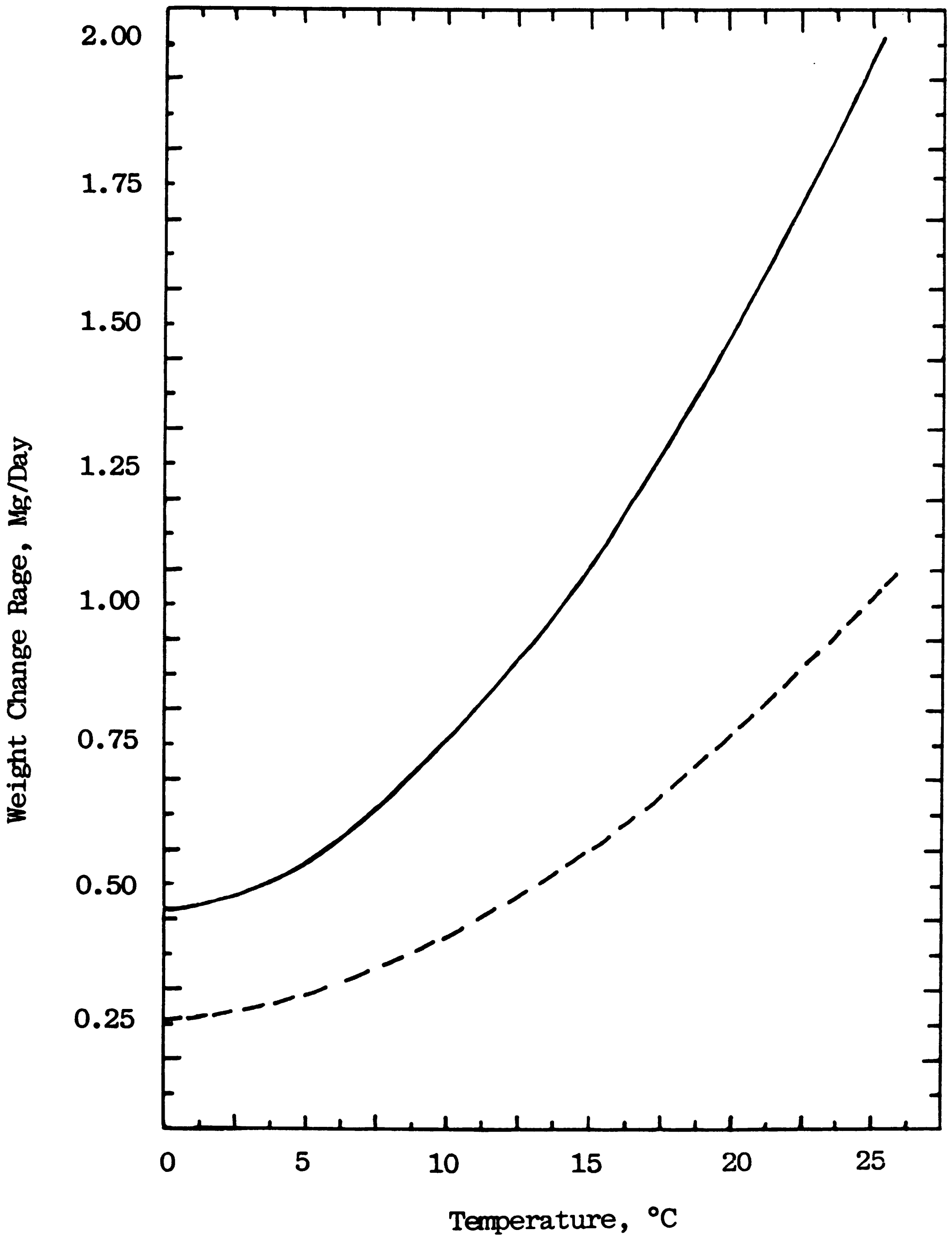
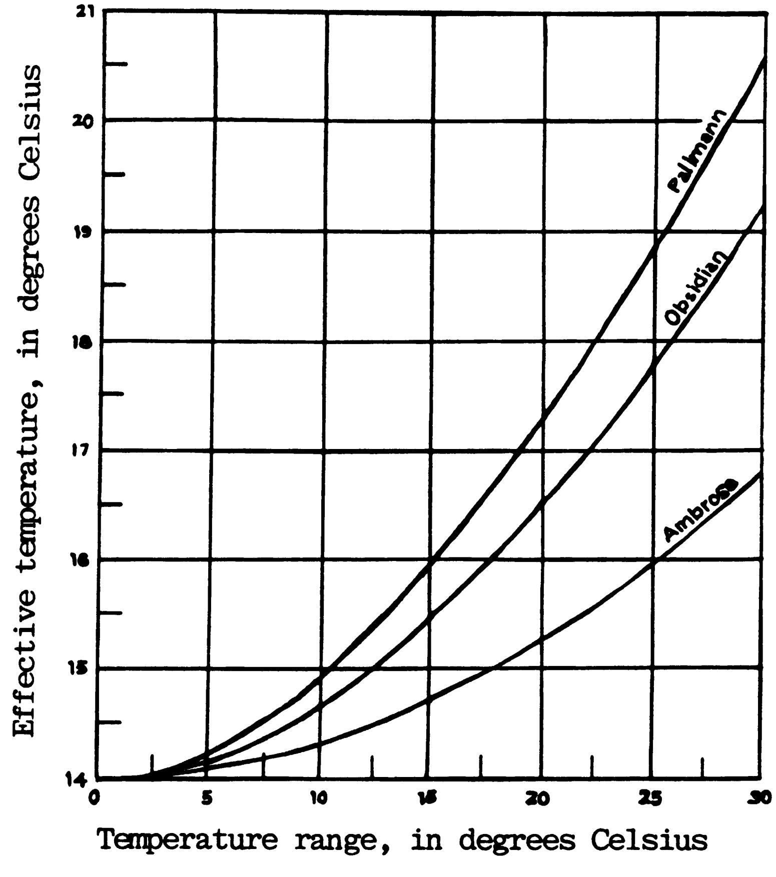


Figure 5. Typical time-weight change curves for water diffusion (Ambrose) cells of acrylic resin at normal temperatures and for two H_2O partial pressure differentials:

________ 100% ------- 50%



Arithmetic Mean = 14°C

Figure 6. Effective temperature versus fluctuation range for arithmetic mean of 14°C for three different temperature integrating systems.

Table 1. Interrelation of time and temperature effects on the hydration of a specific obsidian from American Falls, Idaho.

Effect of hydration temperature on age conversion for 4.8 $(\mu m)^2$ of hydration rind on a specific obsidian from American Falls, Idaho. (Adapted from data in Friedman and Long, 1976)

Effective Hydration Temperature °C	Hydr. Rate, $(\mu m)^2$/1000 yrs.	Age conversion for 4.8$(\mu m)^2$ of hydration Yrs. B.P.*
9.0	2.1	2225
9.2	2.2	2175
9.4	2.2	2125
9.6	2.3	2100
9.8	2.3	2050
10.0	2.4	2000
10.2	2.4	1950
10.4	2.5	1900
10.6	2.6	1850
10.8	2.6	1800
11.0	2.7	1725

* Calculated age values have been rounded to the nearest 25 yr. multiple.

Table 2. Selected source-specific hydration rates for obsidian sources that may have been used at some Great Basin archaeological sites.

Obsidian Source	Hydration Rate $(\mu m)^2/10^3$ yrs.	EHT* °C	Reference
Coso Hot Springs, CA	4.2	10.0	Friedman and Long 1976
Clear Lake, CA	0.65	10.0	Friedman and Long 1976
Medicine Lake, CA	0.75	10.0	Friedman and Long 1976
Panum Dome, CA	2.25	10.0	Friedman and Long 1976
Obsidian Cliff, WY	5.1	10.0	Friedman and Long 1976
Teton Pass, WY	0.82	8.2	Michels 1981a
Timber-Squaw Butte, ID	2.40	14.8	Michels 1981b
Hawkins-Malad, ID	2.07	12.8	Michels 1981c
Big Southern Butte, ID	1.10	12.1	Michels 1982b
Owyhee-Brown's Castle, ID	2.62	15.7	Michels 1982c
Annadel Farms, CA	1.63	15.6	Michels 1982d
Bodie Hills, CA	3.25	15.6	Michels 1982e
Napa Glass Mountain, CA	4.16	15.6	Michels 1982f
Casa Diablo, CA	3.51	11.8	Michels 1982a
Mount Hicks, NV	0.84	12.0	Michels 1983a
Pine Grove Hills, NV	0.59	12.0	Michels 1983b

* EHT = Effective Hydration Temperature

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TEPHRA HYDRATION RINDS AS INDICATORS OF AGE AND EFFECTIVE HYDRATION TEMPERATURE

Jonathan O. Davis

Introduction

The study of hydration rinds on obsidian has gained wide application as a dating technique since its introduction by Friedman and Smith (1960). Archaeologists have applied the technique to date the time elapsed since the fracture which produced obsidian artifacts, and geologists have used the method to date volcanic eruptions which produced obsidian (Friedman 1968). However, it is apparent that hydration of obsidian occurs at varying rates, depending both upon the chemistry of the obsidian and upon the environment of the glass, particularly the effective hydration temperature (EHT) during the period of hydration (Friedman and Long 1976). Chemistry of obsidian is comparatively easy to determine but EHT is not, because specimens subjected to variations in temperature diurnally or annually hydrate more rapidly than the average air temperature at their locations would suggest.

It is possible to use tephra layers which, like obsidian, are largely composed of volcanic glass, as geothermometers to indicate EHT. Because the glass of a tephra layer is everywhere of the same chemical composition and is of uniform age, observed variation in the degree of hydration among specimens of a particular tephra layer must be due to variations in environment of burial, mostly EHT. The approach employed here offers three advantages over others used to estimate EHT: 1) the phenomenon observed is itself hydration of glass, rather than some other physical or chemical process inferred to have a relation to the hydration of glass; 2) EHT can be inferred over time periods much longer than can be done using modern observations, including any climatic fluctuations during the time period; and 3) the method requires even less equipment than is required for obsidian hydration analysis.

Tephra Hydration Rinds

Hydration of tephra glass has been observed and studied by various researchers, particularly Virginia Steen-MacIntyre (1981). Hydration of tephra glass results in an increase of about .004 (up to .01 according to Steen-MacIntyre 1981) in refractive index, and in many silicic tephras hydration proceeds so rapidly that late Pleistocene tephra layers are completely saturated. However, measurement of hydration rind thickness seems not to have been systematically attempted except by Steen-MacIntyre (1981), probably due to the difficulty of obtaining thin sections perpendicular to the hydrated edges of the tephra particles, which usually are quite complex and involuted in shape. Nontheless, hydration rinds may easily be observed on tephra glass particles by immersion in a medium of $\underline{n}$ about.004 less than that of the hydrated rinds. Thus the hydration rim may be observed as a rind of higher refractive index, relative to the lower refractive index of the interior glass and the immersion medium. Figure 1 shows a hydration rind on a tephra glass particle immersed in this manner.

Measurement of hydration rind thickness is complicated by the complex shape of tephra glass particles. Figure 2 shows the effect of shape on the apparent thickness of the hydration rind, illustrating that accurate measurements may be taken only where the line of sight is tangent to spherical vesicle walls. I have observed many of these spherical vesicle walls and have found that the measurements determined with an ocular micrometer are quite consistent within a tephra sample. The measurements discussed here were made with a Nikon Labophot-Pol microscope equipped with an ocular micrometer and a 100X oil immersion objective lens at a total magnification of 1000X.

Effective Hydration Temperature

Friedman and Long (1976) have studied the relation of temperature, glass chemistry and hydration rate thoroughly, concluding that hydration of glass is a simple diffusion reaction. The thickness of the hydration rim is a function of time described by the equation:

$$\text{thickness in micrometers} = kt^{1/2} \qquad (1)$$

where t is time in years, and k is a constant determined by chemistry and temperature through the Arrhenius equation:

$$k = A\,e^{-E/RT} \qquad (2)$$

where A is a constant related to major element chemistry, E is the activation energy of the hydration reaction and R is the gas constant.

Friedman and Long (1976) described the relation of temperature, chemistry and hydration rate for several obsidians, and suggested that major element chemistry, particularly content of SiO_2, Al_2O_3, MgO, CaO and H_2O^+, may be used to determine this relation through the use of a "chemical index." However, only highly silicic glasses were studied, in part because these glasses were those commonly used during prehistoric times for obsidian artifact manufacture. Nonetheless, it is clear that hydration progresses more rapidly in silicic than in mafic glasses.

Although certain studies suggest that hydration does not proceed by the diffusion model described above (i.e. Ericson, Mackenzie and Berger 1976), in the present discussion the diffusion model will be employed. Variation of hydration rind thickness on a particular tephra layer must be due to variation in environment of hydration, regardless of the actual mechanism of hydration.

Observations

Figure 3 shows the locations of the specimens examined in Nevada and Oregon. Seven localities were chosen: Last Supper Cave (26-Hu-102) is an archaeological site at an elevation of about 1585 meters (5200 feet), where Mazama tephra overlies projectile points of the Great Basin Stemmed series (Davis 1978; Layton 1979); Sand Island (26-Pe-450) is an archaeological site at 1260 meters (4130 feet) elevation where artifacts of various sorts overlay the Mazama tephra (Rusco and Davis 1982); Hidden Cave (26-Ch-16) is an archaeological site at 1255 meters (4120 feet) elevation where Mono-Inyo tephra overlies Mazama tephra and artifacts occur between the tephra layers (Morrison 1964; Davis 1978; Thomas 1982a); Alta Toquima Village (26-Ny-920) is an archaeological site at 3350 meters (11,000 feet) elevation where Mazama tephra is overlain by Mono-Inyo tephra in a nearby meadow (Thomas 1982b; Davis, unpublished data);

Gatecliff Shelter (26-Ny-301) is an archaeological site at 2375 meters (7800 feet) elevation where Mazama tephra lay 11 meters below the modern surface, below artifacts of various sorts (Thomas 1983); Borealis is an area at about 2195 meters (7200 feet) elevation in which three Mono-Inyo tephra layers occur at archaeological site 26-Mn-197 (Pippin 1982); and Summer Lake, Oregon, is a geological locality at about 1280 meters (4200 feet) elevation where at least 48 tephra layers of Pleistocene and Holocene age occur (Allison 1945, 1966; Davis 1984). Each of the tephra specimens discussed has been identified by electron microprobe analysis for major elements. Table 1 shows the compositions of the tephras discussed here. Table 2 shows the hydration rind thicknesses measured. Rinds observed on the Mazama tephra ranged from 1.5 - 4.0 micrometers (μm), and those on Mono-Inyo tephra from 3.0 - 4.5 micrometers. Thicknesses were estimated within about ± .25 micrometers.

Temperature information is available from two of the localities. Hidden Cave air temperature is a fairly constant 16°C while at Borealis, the average air temperature (measured at the Borealis Mine) was 10°C during the year of 1981.

Discussion

Mazama Tephra. The glass chemistry of Mazama tephra (Table 1) is considerably more mafic than any of the glasses studied experimentally by Friedman and Long (1976), so that it is not possible to calculate the chemical index and proceed directly from the chemistry of the Mazama glass to the relation of EHT to temperature at each locality. Fortunately, Hidden Cave is a Mazama tephra locality where the temperature is constant, so that EHT may be assumed to be the same as the average air temperature. Here the rind of 3.8 microns on the 6800-year old Mazama glass reflects a hydration rate of 2.13 μm^2/1000 years. Reference to Figure 8 in Friedman and Long (1976) shows that a rate of 2.13 μm^2/1000 years at 16°C corresponds to a chemical index of about 25, and this provides a curve relating hydration rate to temperature for Mazama glass. Figure 4 reproduces this curve, which shows an EHT of 12°C for Last Supper Cave and Gatecliff Shelter, 17°C for Sand Island, and 2°C for Alta Toquima Village. Table 3 summarizes the inferred EHT for these and other localities.

Mono-Inyo Tephra. At least three tephra layers have been erupted from the Mono-Inyo Craters during the last 1500 years. These are extremely similar in chemical composition, so that it has not proved practical to distinguish them consistently at localities distant from the vents (Wood 1977; Davis 1978). From published literature, it is possible to infer that eruptions have taken place at about 600, 1100 and 1500 B.P. (Pippin 1982). The obsidian analyzed by Friedman and Long (1976) from Panum Dome is chemically very similar to the tephra glass and in fact was produced by one of these eruptions, so it seemed justifiable to use Friedman and Long's data relating hydration rate to EHT. Panum Dome has a chemical index of about 45, and Figure 4 reproduces the curve relating hydration rate to EHT for this obsidian. Using this curve and the 16°C EHT in Hidden Cave, this curve predicts a rate of 8.0 μm^2/1000 years, and the 3.0 μm hydration rind value indicates an age of 1124 B.P. (Table 3), which is remarkably close to the 1100 year age of Mono-Inyo tephra found in Walker Lake cores by Spencer (1977; Davis 1978).

The Borealis tephra layers, however, come from open sites where EHT cannot be estimated as readily as at Hidden Cave. If an age of 620 B.P. is arbitrarily assigned to the youngest layer at Borealis, ages of 1102 and 1394 B.P. are implied for the lower layers, which again are close to the estimated ages of the earlier Mono-Inyo eruptions. Unfortunately, the hydration rate required to derive these ages implies an EHT of 21°C, far higher than the 10°C average air temperature measured at Borealis during 1981 (Houston International Minerals, unpublished data) and unreasonably high for a locality at 2195 meters at this latitude. Yet to assign a slower hydration rate to these tephra layers means that the lowest is more than 1500 years old, and there is no other evidence that Mono-Inyo tephras of this composition were erupted before 1500 B.P. Furthermore, the lowest layer of tephra at Borealis is associated with radiocarbon dated materials which show that it is no more than 1500 years old (Pippin 1982). It is possible that the anomalously fast hydration rate of Mono-Inyo tephra at Borealis is due to their shallow burial, which would have subjected them to elevated temperatures during the summer due to solar heating, especially at the high elevation of Borealis. Furthermore, snow cover during the winter may have the effect of raising EHT (Friedman and Long 1976).

Summer Lake Tephra KK. Summer Lake tephra KK is tephra of intermediate chemical composition (Table 1), with an estimated age of about 180,000 years (Davis 1984). This glass exhibits a hydration rind 1.5 μ thick, which is in keeping with the finding of Friedman and Long (1976) that mafic glasses hydrate more slowly than silicic glasses. Although neither EHT nor the actual age of this layer is known, and experimental hydration rate data for glass of this chemistry is currently lacking, it seems likely that intermediate tephras can be employed to extend the use of tephra hydration rind measurement for age inference and EHT well back into the Pleistocene.

Conclusions

Although the precision of the tephra hydration geothermometer has not been explored, there exist significant differences in hydration thickness among specimens of the same tephra layer which seem attributable to variation in effective hydration temperature. At the least, the range of hydration rind thickness observed in the Mazama ash (1.5 - 4.0 μm) should serve as a demonstration of the importance of environment of burial in determining hydration rates. Considered in this context, obsidian hydration studies which assume a constant, linear rate for obsidian hydration from various sites probably are so inaccurate as to be practically worthless for determination of age for archaeological specimens. It should be possible to employ the Mazama tephra as a guide to determining effective hydration temperature in archaeological sites where it is found, and this ought to be done routinely in obsidian hydration studies in northwestern North America.

The data from Borealis suggest that shallowly buried glass has an effective hydration temperature much higher than that produced by the average air temperature. However, these data are only suggestive, because the ages of the tephra layers involved are not precisely known. Ongoing study of the chronology of these layers doubtless will resolve this question in the future.

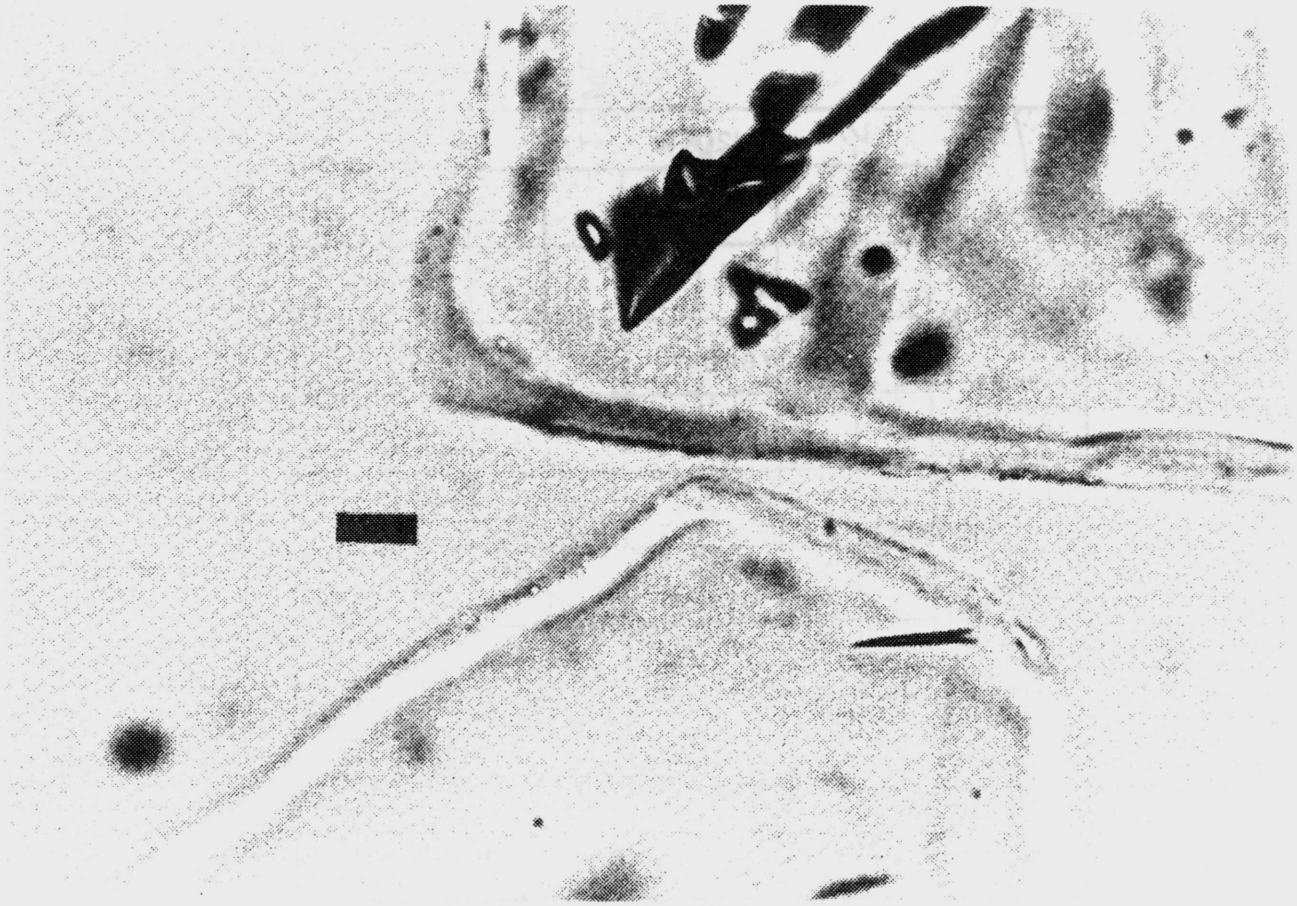

Figure 1. Photomicrograph of margins of two silic tephra grains immersed in refractive index medium which matches the interior of the grains. The hydration rinds are seen as rims around the grains, due to the higher refractive index of the hydrated glass. The black scale bar is 10 micrometers in length.

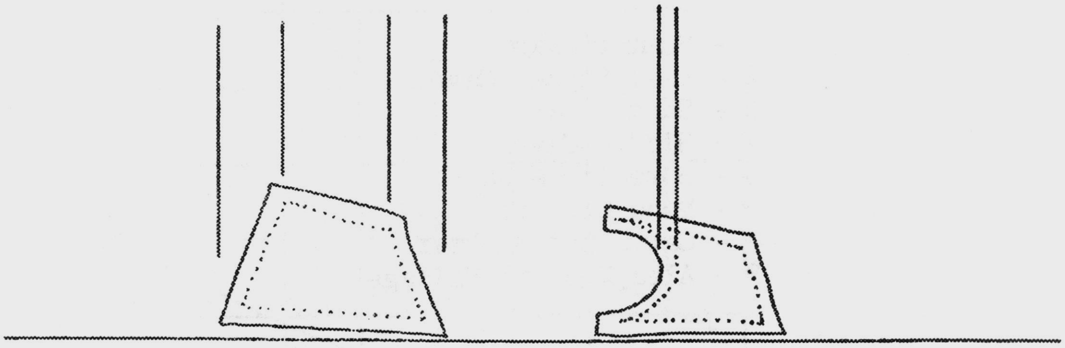

Figure 2. Illustration showing the effect of complex shape of tephra grains upon apparent hydration rind thickness. Accurate measurement by optical means is possible to spherical surfaces, as at right, whereas measurements at other points are erroneously large.

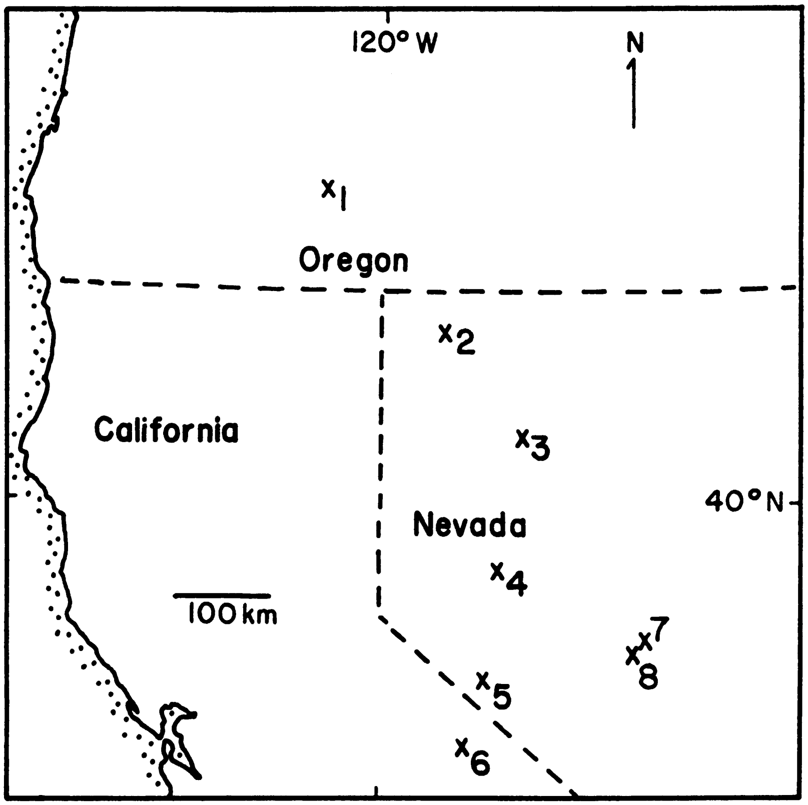

Figure 3. Map showing locations of specimens discussed in the text:

1 - Summer Lake
2 - Last Supper Cave
3 - Sand Island
4 - Hidden Cave
5 - Borealis Mine
6 - Mono Craters
7 - Gatecliff Shelter
8 - Alta Toquima Village

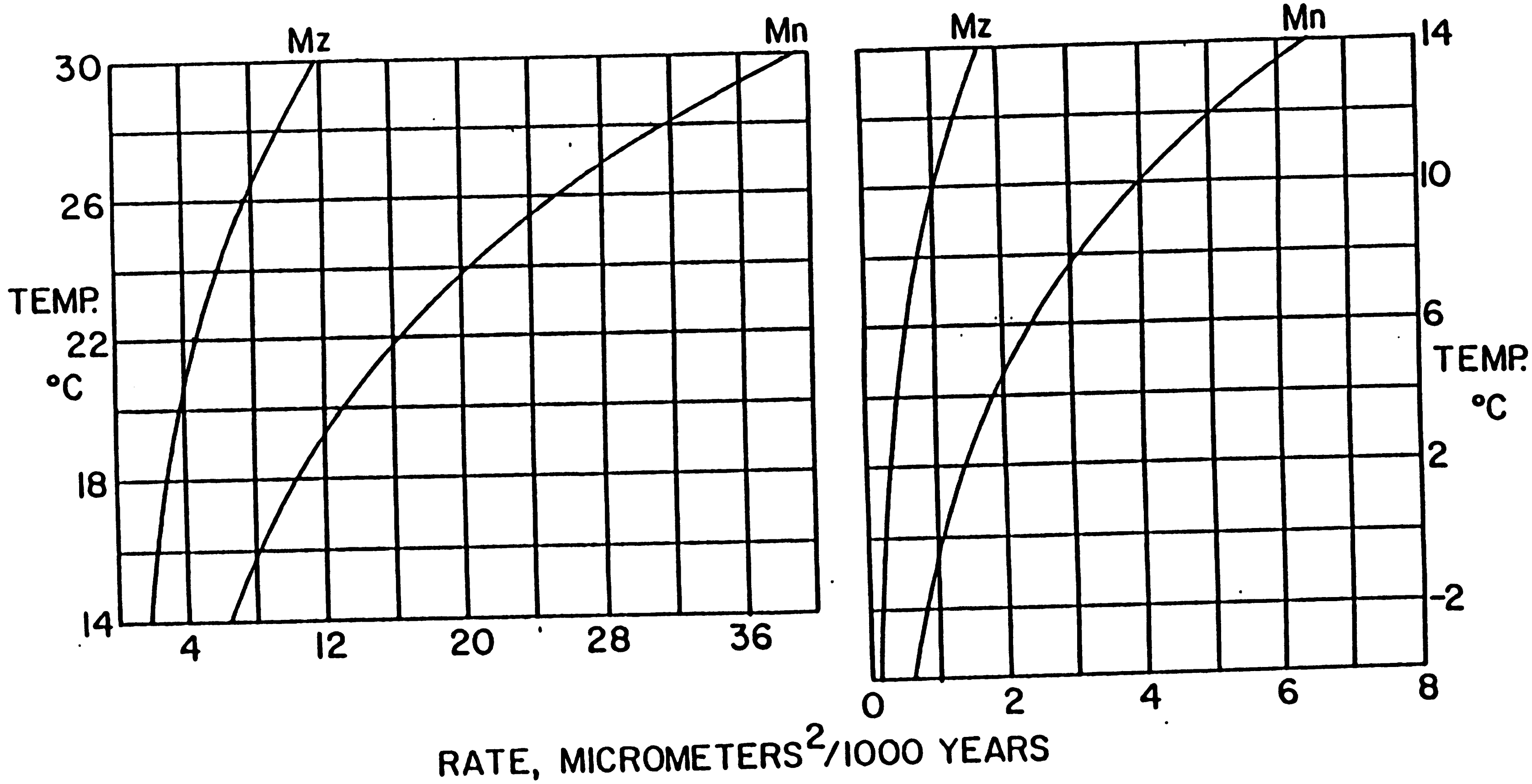

Figure 4. Curves showing the relation of hydration rate and EHT for Mazama glass (Mz) and Mono Craters glass (Mn). Note that the righthand diagram has an expanded horizontal scale relative to the lefthand diagram. Derived from Friedman and Long (1976).

	Mazama tephra	Mono tephra	Panum Dome	Summer Lake tephra KK
N	48	24	1	1
SiO_2	71.1±1.0	74.5±.8	75.8	63.3
Al_2O_3	14.4±.2	12.6±.1	12.9	16.4
Fe_2O_3	2.18±.04	1.14±.03	1.20	6.50
MgO	.44±.02	.03±.01	.07	2.00
MnO	.05±.01	.04±.01	.05	.12
CaO	1.58±.06	.51±.04	.60	4.77
BaO	.08±.01	.01±.01	ND	.09
TiO_2	.43±.02	.07±.01	.06	.99
Na_2O	5.1±.2	3.9±.1	3.9	4.8
K_2O	2.6±.1	4.5±.1	4.2	2.1
Cl	.16±.02	.07±.01	ND	.10

Table 1. Chemical compositions in weight percent of glasses discussed in the text. Tephra glass compositions determined by electron probe and corrected for matrix effects. Panum Dome determination from Friedman and Long (1976).
± values = one-sigma error; ND = Not Determined.

Sample	Rind Thickness, μm
Mazama	
Hidden Cave	3.8
Last Supper Cave	3.0
Sand Island	4.0
Gatecliff Shelter	3.0
Alta Toquima Village	1.5
Mono-Inyo	
Hidden Cave	3.0
Borealis	
upper	3.0
middle	4.0
bottom	4.5
Summer Lake KK	1.5

Table 2. Hydration rind thickness observed on tephra samples.

Locality	Rind (μm)	k	Rate	EHT (°C)
Last Supper	3.0	.0364	1.32 $\mu m/10^3$	12
Sand Island	4.0	.0485	2.35 $\mu m/10^3$	17
Gatecliff	3.0	.0364	1.32 $\mu m/10^3$	12
Alta Toquima	1.5	.0182	0.33 $\mu m/10^3$	2

Table 3. Hydration rind thicknesses, inferred hydration rate, and inferred EHT for Mazama ash specimens discussed in text.

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CURRENT PROBLEMS IN OBSIDIAN HYDRATION ANALYSIS

Robert J. Jackson

Abstract

Obsidian hydration is alleged by some to have developed into a dating technique fully capable of yielding absolute chronometric dates. While significant advances in our understanding of the hydration process and methods of determining source-specific hydration rates have been made, there are many unresolved problems that may limit the accuracy and trustworthiness of absolute rate formulations. Extant analytic problems are reviewed and results of inter-laboratory comparisons of obsidian hydration measurements are discussed.

Introduction

Obsidian hydration has become a commonly employed analytic technique, often to the extent that it is used without questioning the utility or accuracy of the method in specific archaeological applications.

There is little doubt that obsidian hydration can be very useful for the analysis of many collections, but its potential value must be assessed on a site specific basis, with a full awareness of current problems and limitations of the method. Problems and limitations imposed on hydration studies fall into three basic categories: 1) the physical process of hydration and environmental variables that affect it; 2) problems in the measurement process; and 3) application and interpretation of hydration data for archaeological purposes.

The Physical Process of Obsidian Hydration

The history and nature of obsidian hydration has been well-documented (Friedman and Smith 1960; Evans and Meggers 1960; Clark 1961, 1964; Michels 1965; Michels and Bebrich 1971; Friedman and Long 1976; Ericson 1977; Taylor 1976; Michels and Tsong 1980; and others).

Very simply, all glasses (natural and artificial) are thermodynamically unstable and undergo progressive alteration through the gradual absorption of moisture from the surrounding environment (soil and atmosphere). Absorbed water layers form gradients of concentration demarcated by diffusion fronts. The water content of the hydrated layers increases greatly. This increased water content changes both the density and the volume of the hydrated layers. It was found that rhyolitic obsidian, the most abundant form of natural glass, contains about 0.1 to 0.9 percent water by weight, as derived from the parent magma. After cooling, molecular water is incorporated into the obsidian from its surface, increasing the water content tenfold to approximately 3.5 percent by weight for most obsidians. An increase in density raises the index of refraction of light passing through the obsidian, while increased volume produces mechanical strain at the interface between the layer of absorbed water and the nonhydrated interior of the obsidian, resulting in an optical effect called birefringence (the power of double refraction). It is the strain-produced birefringence and the higher index of refraction that microscopically differentiate the hydrated from the unaltered obsidian. It was demonstrated that this hydration process is not only continuous, but the rate at which water enters the stone is relatively predictable and continued evenly despite the water content of surrounding environments, producing visible hydration rinds within a few hundred years of exposure (Friedman and Smith 1960: 482).

It has been clear for some time that obsidian from different geographic/ geologic sources hydrates at differing rates (Aiello 1969; Taylor 1976; Michels and Bebrich 1971; Ericson 1977; Kaufman 1980; and others). Source identification is but one hurdle to overcome in the delineation of source-specific obsidian hydration rates, and detailed chemical analyses have not yet been conducted for many obsidian source areas (cf. Hughes 1983; Kaufman 1980). In addition, while many major obsidian sources have been chemically differentiated, intra-source chemical variation and the potential effects on hydration have not been thoroughly explored (cf. Jack 1976; Taylor 1976; Ericson 1977; Hughes 1983).

The physical process of obsidian hydration is still poorly understood, though many diffusion models have been proposed for the reaction and diffusion of water from glass surfaces. Charles' (1958) model, for instance, relied on base exchange of water and alkali, while Moulsen (n.d.) proposed two models, both relying on direct reactions of water and silicon networks. Ericson et al. (1976) have reviewed these and other theories of water diffusion into glass and structurally complex, rhyolitic obsidians. Drawing comparisons between simple glasses and obsidian, researchers have distinguished three classes of obsidian, characterized by molecular quantities of Al_2O_3, CaO, and NaO + K_2O; or excess alimina, calcalkaline, and excess alkali rhyolitic obsidians. The reaction of water and OH ions is said to vary in intensity and speed with increases and decreases in the abundance of the three compounds (Ericson et al. 1976: 40).

Friedman and Long (1976), however, found little relationship between alumina ratios, but did find that as SiO_2 content increased, so did the hydration rate. They also found that increased CaO and MgO content reduces the hydration rate. From these findings Friedman and Long (1976: 347) derived a 'chemical index' which they suggest monitors hydration rate more accurately than silica content alone. Michels and Tsong (1980) and Michels (1982, 1983) also use alumina, alkali, and silica indices to determine the effects of chemistry on hydration rate. However, few obsidian sources have been chemically analyzed to determine the extent and nature of the intra-source variability for chemical components critical to the hydration process.

The effect of temperature on the rate of obsidian hydration has been more widely discussed, and is better understood than chemical composition (cf. Friedman and Smith 1960; Clark 1961; Michels and Berbrich 1971; Friedman and Long 1976; Ericson 1977; Taylor 1976; Michels and Tsong 1980; among others). It is recognized that hydration rate varies as a power function of temperature, so mean annual air temperature cannot be used to calculate hydration rates. In addition, it has been suggested that obsidian exposed on the ground surface will hydrate more rapidly than buried obsidian, a disparity that is greater at high elevations. Friedman (1983, personal communication) suggests that hydration rates for some obsidians may as much as double with a 10° Centigrade increase in temperature. Similarly, changes in the effective temperature on the order of 2-3° Centigrade may affect rates by 20 percent. This degree of temperature change may approximate that imposed by climatic fluctuations over the millenia. Various methods of calculating annual effective or ambient air temperatures and ground temperature gradients have been developed and proposed (Friedman and Long 1976; Michels 1982, 1983; Trembour and Friedman, this volume). While temperature is recognized as a significant affective variable in the rate of obsidian hydration, regional temperature data are often not incorporated into hydration rate formulations.

Obsidian is generally dark in color, readily absorbing heat like a small "solar collector." The temperature of surface exposed obsidian often far exceeds the surrounding air or ground temperature, and should be considered as a potentially important variable affecting the hydration rate. Layton (1973) was one of the few researchers to investigate differences in hydration between exposed and buried obsidian artifacts. He compared two artifact assemblages from archaeological sites in northwestern Nevada, both consisting of similar, temporarily diagnostic projectile points. Artifacts from one of the sites occurred on the exposed desert surface, whereas the second assemblage was excavated from a moist midden site. Comparison of hydration measurements for similar projectile point types from the two sites revealed that the surface assemblage exhibited much greater hydration thicknesses than buried materials. This led Layton (1973: 131) to conclude that high surface temperatures accounted for a greatly accelerated hydration rate. There are several problems with Layton's study which make his conclusions less than convincing. First, the geologic source(s) of the obsidian were not determined, but were assumed to be homogenous. Northwestern Nevada contains numerous obsidian sources (Hughes 1982, 1983), many of which have not been investigated. Furthermore, unlike flaking debitage, formal tools experience a higher incidence of curation and are more likely to be transported greater distances. It cannot be assumed, a priori, that projectile points from sites in close proximity to an obsidian source derived from that source. Variation in chemical composition, alone, might account for the disparity in hydration thicknesses between the two sites (cf. Hughes 1983). Secondly, Humboldt type bifaces were the most numerous point type in Layton's sample. Many Great Basin archaeologists consider Humboldt a temporally and functionally problematic type (Thomas 1981; Heizer and Hester 1978; Hughes 1983; and others). Excluding Humboldt points, Layton's sample of projectile points would be reduced to 12, which are further split into surface and subsurface projectile point lots between the two sites. Such a sample size may be too small to demonstrate consistent differences between surface and subsurface hydration.

Other investigators (Origer and Wickstrom 1981; Origer 1982) have addressed the problem of surface versus subsurface hydration in the North Coast Ranges of California, with very different results.

> The arid soils of the Great Basin are generally shallow, pavemented, and support widely dispersed bushes and some grasses with bare spots between patches of vegetation. Archaeological specimens laying on

> the ground surface were not insulated from solar radiation and when subjected to direct sunlight were described by Layton as too hot to hold in one's hand. In contrast, the soils of our study area are deep often churned by a variety of disturbing agents (i.e. gophers, worms, erosion, and discing), and generally support grasses, forbs, and occasional scattered trees that serve to insulate archaeological specimens from intense solar radiation. It is suggested that exposure to extreme temperatures of the Great Basin influenced the hydration rate in Layton's study (1973) while the temperatures of the Santa Rosa Plain had much less effect since insulated from less intensive solar radiation (Origer 1982: 81).

Stability and integrity of archaeological deposits is perhaps the most overlooked issue regarding the surface-subsurface hydration problem. Many hydration analyses suggest that small archaeological materials experience considerable post-depositional, horizontal and vertical movement (Layton 1973; Jackson 1982, 1983; Hall 1983; Origer 1982; among others).

Many archaeological materials were undoubtedly deposited on living surfaces that were subsequently buried, yet the temporal range of site occupation is often reflected by the artifact types on the surfaces of deep archaeological deposits. In many instances, there is no reason to assume that buried obsidian artifacts were not exposed on the surface as long as material observed at the time of archaeological recording and collection. Archaeologists may never be able to determine the depositional history of individual artifacts to the degree necessary for precise hydration temperature calculation. Without taking these issues into account, temperature calculation may also misrepresent the accuracy of the method for many archaeological applications. This is not to suggest that temperature should be ignored. Ambient air temperature data should be calculated and used for those archaeological materials that appear to evidence long-term surface exposure and intact depositional provenience for features such as burials. For many sites, however, the most reasonable approach might be the calculation of regional temperature calibrations based on both air and ground temperature data. Other variables potentially affecting the rate of hydration are soil chemistry, weathering, and burning.

Kaufman (1980: 379) has suggested that both geothermal activity and soil pH may be important affective variables in the hydration process, but very little research in this area has been conducted. Friedman (1983, personal communication) has found that alkali soils often remove or obliterate hydration rinds. He further notes that a whitish coating on artifacts can indicate prolonged contact with alkaline soils.

Further research is also necessary to understand the process of patination as it relates to obsidian hydration. Empirically, heavily patinated artifacts often produce diffuse, ill-defined hydration rinds. It is also possible that exposure to alkaline soils or patination accounts for the obliteration of hydration on artifact surfaces.

Weathering of obsidian can physically remove hydration rinds through mechanical processes. Water tumbling and erosion from wind-borne particles are the two most common sources of weathering (Friedman and Smith 1960: 485), thus measurements obtained from weathered specimens may be erroneously small or non-existent. Logically, it would seem that since older artifacts have been exposed for longer periods, they would therefore have had more opportunity to weather and erode. However, the specific microenvironments in which artifacts were deposited probably played the greatest role in determining the severity of such impacts.

It should be apparent that the possibility of anomalous or poor resolution in hydration data may result from current problems relating to the physical circumstances of the hydration process and the environment in which it occurs. More detailed technical discussion of these various topics appears in Friedman and Smith (1960), Clark (1964), Michels and Bebrich (1971), Taylor (1976), Ericson (1977), and Michels and Tsong (1980).

Measurement of Obsidian Hydration

More than one archaeologist has been discouraged from conducting obsidian hydration studies because of poor results obtained by inexperienced technicians whose fundamental errors were not detected for several years. There are currently no agreed upon means of assessing such knowledge and ability.

The basic procedures for the preparation and measurement of obsidian hydration specimens appear, from textbook descriptions, to be quite easy (Clark 1961; Michels 1965; and Michels and Bebrich 1971). Anyone with access to a polarizing microscope, lapidary saw, and a few miscellaneous, inexpensive supplies can obtain an appropriate text, learn the fundamental procedures, and prepare thin sections. There are a multitude of subtle problems and pitfalls in the technique which can deceive the self-taught or inexperienced analyst and produce inaccurate data. For instance, large hydration bands are relatively easy to observe, but small hydration bands can be quite difficult to measure. Thick hydration bands usually produce obvious birefringence, but hydration layers in the one micron range tend to be faint and difficult to discern, often requiring a more trained, experienced eye.

Technical categories potentially producing variability or affecting the visual nature of the hydration band include: the location and nature of the hydration cut on the artifact; the method of grinding and mounting; the quality and magnification of the microscope; and the locations and method of measurement. Many technical descriptions of the preparation process are relatively detailed, but slight modifications in procedures have been and should be made according to the particular attributes, idiosyncracies and needs imposed on individual laboratories by different equipment and personnel. Ultimately, the accuracy of certain sets of techniques should be determined by the degree of replicability in measurements between laboratories and technicians.

The concern for replicability of hydration rim measurement is by no means new. In the early 1960's Donovan Clark re-examined slides he had studied earlier and found a mean deviation of 0.13 microns (Michels 1965: 17). In the mid-1960's Joseph Michels conducted a series of experiments to determine the variance in hydration readings on the same specimen by two analysts using the same equipment. He found an average variance of approximately 0.01 microns between the two readers involved in the experiment (Michels 1965: 18, 19). An error factor of 0.2 microns, imposed by optical limitations inherent in the magnification process, is generally accepted. Michels' test and others like it are valuable for gauging the accuracy of readings between technicians working with the same procedures and equipment.

Inter-laboratory Data Comparisons

To my knowledge, no published reports have appeared which discuss the comparability of hydration readings between separate laboratories, each using their own equipment and procedures. To address this problem, inter-laboratory comparisons of obsidian thin sections were conducted. Two sets of obsidian hydration slides were selected. The first set consisted of 30 slides from a site in Napa Valley, California, prepared at the U.C. Davis Obsidian Hydration Laboratory several years ago. These specimens were selected for two reasons: 1) the technician responsible for their preparation measured the specimens at 500X magnification, different than the magnification used for examination of the second data set at U.C. Davis; and 2) an independent preparator insured that both technicians involved in the experiment were unfamiliar with the specimens. Thus, bias resulting from preparation or knowledge of the archaeological assemblage was avoided. The second set of specimens (n=31) were prepared from obsidian samples obtained from Owens Valley archaeological sites.

The U.C. Davis Obsidian Hydration Laboratory examined both sets of thin sections under 1250X magnification using an oil immersion objective on a Lietz polarizing microscope. Eight readings were recorded for each specimen, four on each of two sides of every thin section. A two-tailed, difference of means t-test was applied to the resulting data to determine the statistical similarity between different edges of each specimen. If mean values for both edges were found to represent the same hydration thickness, a grand mean was derived for all eight readings. If the two sides were found to be dissimilar, the mean hydration value for the readings from each side were calculated. The 61 specimens were then submitted to the Obsidian Hydration Laboratory at Sonoma State University. The Sonoma technician commonly examines specimens at 563X magnification using an American Optical microscope (Origer 1982). Six readings were taken on each specimen and a mean value derived.

A very good correlation between laboratories was obtained for the Napa Valley specimens (Table 1A). The average difference between the Sonoma State and U.C. Davis readings was 0.15 microns, less than the inherent error factor of 0.2. Measurements were identical for 10 of the 20 specimens when rounded to the nearest tenth micron. While the range of differences was 0-0.6 microns, only three specimens differed more than 0.2 microns.

However, the U.C. Davis and Sonoma State readings for Owens Valley specimens were quite dissimilar (Table 1B). In this case the Sonoma technician had great difficulty identifying and measuring hydration bands on the Owens Valley slides; he was unable to measure 12 of the 31 specimens, and commented on additional measurements that the slides appeared "poorly prepared," or that they exhibited "ragged edges." The Davis technician had little difficulty measuring these same Owens Valley specimens. Of the specimens that he found readable, the average difference between Davis and Sonoma measurements was 0.7 microns, and the greatest difference was 1.4 microns. Such discrepancies can translate to several hundred years of elapsed time, depending on the obsidian source under examination.

From results of the Napa specimens it appeared that both technicians obtained similar hydration measurements under certain circumstances, but that inter-laboratory difficulties arose when specimens were prepared for examination under 1250X magnification. One possible explanation for the discrepancy between laboratories on the Owens Valley sample relates to the difference in specimen preparation according to the intended magnification. A higher power objective, such as the 100X oil immersion lens, captures a smaller percentage of the transmitted light field so that illumination of the image is not as great as that achieved with lower magnification. Higher magnification produces larger images which may, in some instance, allow the analyst to discern and more precisely measure small hydration bands. To compensate for decreased light under high magnification, there has been a tendency to prepare hydration sections quite thin, thus exceeding the range of thickness optimal for measurement under lower magnification. Consequently under high magnification there is a greater tendency for partial obliteration of thin section edges resulting from thinner sample preparation. This particular example illustrates that such affective variables do intervene in the measurement process and that, in some cases, these can be attributed to differences in sample preparation. Procedures for thin section preparation have been modified since this comparative study was completed in order to increase the potential for interlaboratory calibration.

Another inter-laboratory comparison of obsidian hydration results was recently conducted, involving measurement of hydration by two laboratories, each cutting, preparing and examining separate thin sections on the same obsidian specimens. Artifacts from archaeological sites in Kern County, California (CA-Ker-317 and 878) were submitted to the Obsidian Hydration Laboratories at U.C.L.A. and Sonoma State University. Laboratory procedures follwed at U.C.L.A. were unavailable at the time of this writing, but Sonoma State lab methods were the same as those discussed in conjunction with the previous study. Measurements obtained by each laboratory are listed in Table 2. Data from several specimens which were in no way comparable, such as a "no visible hydration" determination from one laboratory compared with two hydration bands observed by the other laboratory (Table 2) were not included in statistics derived from the comparative study. Of 31 compared specimens, the average difference between laboratory measurements was 0.56 microns, quite similar to the difference obtained in the Sonoma-Davis study, while the greatest difference was 1.8 microns. Sixteen (50%) of the compared specimens varied 0.3 microns or less. Considering the potential differences in preparation and measurement procedures, equipment, technicians, and location of hydration cuts, the differences in measurements between laboratories is not altogether surprising.

One may question whether or not it is desirable or necessary that slides prepared for one laboratory be interchangeable or measureable by another. Under normal circumstances hydration specimens are prepared at a specific laboratory with the expectation that thin sections will be measured at the same lab. Apart from the issue of inter-laboratory comparability, practical problems sometimes arise which argue for standard preparation procedures. For example, obsidian hydration examination of several hundred artifacts was recently conducted for a large archaeological project in the North Coast Range of California. The analysis was performed by both Sonoma State University and U.C. Davis laboratories, each examining part of the assemblage. Scheduling conflicts required that specimens prepared for analysis at one of the labs be sent to the other for measurement. Standardization of preparation procedures since the time of the previous comparative study enabled a technician from one laboratory to prepare thin sections suitable for measurement at the other laboratory. The lack of correspondence in many hydration measurements between laboratories should not be dismissed as minor, but let us consider the implications of inter-laboratory differences in hydration data with respect to interpreting the hydration data from the Two Eagles site in Owens Valley (Table 1A). While significant variation in individual hydration measurements existed between the two laboratories, the majority of measurement obtained by both labs fell between 3.0 and 4.0 microns. These data are relatively well clustered, suggesting major site occupation during a relatively restricted time period. A number of different obsidian artifacts from the same site were examined for obsidian hydration by the laboratory at U.C. Riverside with very similar results in terms of mean and range of hydration.

Inter-laboratory comparative data suggest that obsidian hydration measurements obtained for individual artifacts may occasionally be in error for any number of reasons, so hydration measurements for single specimens should not be heavily relied on for chronologic information. Inter-laboratory comparisons suggest that large samples may be most appropriate to insure that the ages (relative or absolute) of archaeological sites are accurately reflected.

Further intra- and inter-laboratory comparisons should be made, including examination of selected specimens by different technicians using the same equipment, the same technicians using different equipment, and different technicians using different equipment. In addition, multiple hydration cuts on the same artifacts by the same and different technicians should be made and measured.

It is important that some system of monitoring the consistency and comparability of results between laboratories be developed so that technicians are adequately trained and there are means of checking work quality and precision. While each laboratory will develop procedures suited to the equipment and individuals involved, broad guidelines should be established to encourage inter-laboratory comparisons of methods and data. Once major variables in the preparation and measurement process are identified and controlled, it will be possible to isolate those which produce significant inter-laboratory variability, and improve the precision of the hydration measurement process.

Table 1A: Summary of data from inter-lab comparison of obsidian hydration measurements.

Owens Valley Archaeological Sites

UCD Lab #	U.C. Davis Reading	Sonoma State Reading
	Two Eagles Site	
891	3.27	4.0
890	3.36	3.9
889	2.91	3.4
888	2.77	3.4
887	2.96	2.9
886	2.86	3.0
885	3.24	3.8
884	3.06	3.4
883	3.48	-
882	3.17	-
881	3.49	4.3
880	1.22	2.6/3.1
879	NVH	-
878	3.56	-
877	3.23	3.8
	Readings from aberrant, later feature at Two Eagles site	
896	2.03	-
895	1.4	-
894	1.72	1.6
893	1.97	2.5
892	3.65	4.0
	Crater Midden Site	
900	1.8	-
899	1.88	-
898	2.01	2.5
897	2.26	2.9
	Pinyon House Site	
876	1.21	-
875	1.23	-
874	NVH	1.1
873	6.3	5.3
872	1.6	2.2
871	NVH	NVH
870	3.5	-

Mean Difference on mutually read specimens = 0.7 microns (the "-" symbol represents specimens that could not be read; NVH denotes no visible hydration). Measurements in microns (µm).

Table 1B: Summary of data from inter-lab comparison of obsidian hydration measurements.

Napa Valley Archaeological Site CA-Nap-58

UCD Lab #	U.C. Davis Reading	Sonoma State Reading
1191	2.74	2.7
1179	4.29	4.5
1186	2.23	2.2
1177	1.93	2.2
1155	3.12	3.1
1149	2.38	3.0
1148	1.16	1.3
1146	3.0	2.9
1145	3.4	3.2
1142	2.86	2.9
1139	2.01	2.2
1133	3.13	3.1
1129	2.71	2.7
1127	1.54	1.2
1124	1.95	2.6
1122	1.74	1.6
1118	3.91	3.5
1114	1.95	2.2
1240	2.4	-
1235	2.66	2.7
1230	2.86	3.1
1229	-	-
1226	2.36	2.3
1223	-	1.0
1225	-	-
1218	1.72	1.7
1214	3.23	3.2
1208	-	-
1207	1.64	1.6
1201	1.5	1.3

Mean Difference on mutually read specimens = 0.15 microns

Measurements in microns (μm).

Table 2: Summary of data from inter-lab comparison of obsidian hydration measurements.

Specimen Cat. No.	Sonoma State Measurement	U.C.L.A. Measurement
	CA-Ker-317	
317-091	1.3	1.0
317-108	4.9	1.8/3.8
317-109	5.0	5.3
317-111	5.8	5.9
317-122	8.0	7.6
317-182	5.8	5.9
317-187	7.2	7.2
317-191	8.3	8.8
317-049	4.6	4.4
317-062	8.9	8.0/9.0
317-073	9.5	9.4/10.7
317-018	2.7/4.6	3.7
	CA-Ker-878	
78-001	0.9	NVH
78-025	2.3	1.6
78-027	1.9	3.7
78-030 *	2.2	NVH
78-037	4.4	4.0
78-069	3.3	2.1
78-074	2.3/5.2	5.4
78-088	1.4	2.5
78-092	-	NVH
78-093a	3.5	3.1
78-093b	2.2	1.4
78-110	NVH	NVH
78-120	2.2	1.4
78-123	4.3	4.6
78-140	3.3	2.5
78-160	7.3	6.6
78-181	8.0	8.0
78-193 *	3.9	NVH
78-210 *	2.6/6.2	NVH
78-217	7.1	6.9/7.3
78-220	7.1	6.8
78-226	6.0	5.4
78-243	8.0	7.9
78-251	7.0	6.0
78-257 *	7.3	7.0
78-263 *	2.6	19.4

* Hydration specimens not included in calculation of inter-laboratory differences in measurements.
NVH indicates no visible hydration band.
Measurements in microns (μm).

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INTERPRETIVE STUDIES

A REASSESSMENT OF OBSIDIAN PRODUCTION ANALYSES FOR THE BODIE HILLS AND CASA DIABLO QUARRY AREAS

Thomas L. Jackson

Introduction

With the advent of geochemical fingerprinting of obsidians from western North America, archaeologists have entered into a new dimension in the analysis of prehistoric trade and exchange. The ability to recognize, with a high level of confidence, obsidians in the archaeological record far removed from their primary geological source provides the archaeological interpreter with direct physical evidence of the cultural distribution of a specific commodity in prehistory, presumably as part of formal or informal trade and exchange networks. By controlling the temporal dimension of their studies, investigators may isolate economic relationships between peoples of specific geographical settings within particular time frames, and gauge the productivity and economic influence of individual obsidian source areas. Observed distortions or extinctions of aspects of obsidian distribution patterns may be seen as indicative of cultural change, although the scale or causes of such change may not always be clearly discernable.

Because California and the western Great Basin are endowed with numerous natural obsidian sources, and because these regions provide evidence of a long, culturally complex prehistory, archaeologists there have found ample opportunity to explore the topic of prehistoric obsidian trade and exchange, as well as related studies such as obsidian hydration dating. After a decade of investigation and interpretation, it is safe to say that we have made considerable progress in the archaeological study of obsidian trade and exchange. The level of problem-solving in these investigations has moved from the initial, tentative definition of broad-scale temporal and geographical distribution patterns (e.g., Jack and Carmichael 1969; Jackson 1974; Jack 1976; Ericson 1977) to questions related to very specific socio-economic issues (e.g., Singer and Ericson 1977; Hughes 1978; Bettinger 1982).

This paper evaluates interpretations by Ericson and Singer (Singer and Ericson 1977; Ericson 1977, 1981, 1982) concerning the history of obsidian production at the Bodie Hills and Casa Diablo obsidian sources (Map 1). Effective interpretation of the prehistoric exploitation of these resources hinges on accurate dating of the analyzed artifactual materials, but the exclusive use of obsidian hydration dating in this endeavor promises that the production studies for these obsidian sources will be subject to repeated re-evaluation as understanding of the obsidian hydrating dating technique changes and evolves.

The general configuration of the "production curves" represented by Singer and Ericson (1977) and Ericson (1977, 1982) for the two quarries is viewed with serious reservations. The adequacy of the sampling of the quarries and other methods employed in the construction of the production curves are suspect. Production analyses advanced by Ericson and Singer address only the exploitation of obsidian at the primary geological source. However, Bodie Hills and Casa Diablo obsidians, geographically widespread, having been redeposited in geological strata of more recent age than the original flow, affording prehistoric peoples numerous potential quarry sites away from the principal flow. Not only are obsidians available from primary and secondary geological sources, but from archaeological deposits as well. Moratto (1972), for example, reports that archaeological deposits were evidently mined for obsidian tools by more recent prehistoric inhabitants of sites in the Buchanan Reservoir area. Comprehensive production analyses should attempt to acknowledge all sources of obsidian raw material, otherwise the production histories may be confidently represented only for the *specific* quarry site(s) under investigation, and the explanatory value of the production analyses would be diminished. In none of the various relevant papers by Ericson and Singer are corroborative data for their quarry production curves sought from archaeological sites located away from the quarries, despite the fact that they extrapolate their findings to presumed variations in production and consumption throughout the prehistoric regional economic system.

Raw data concerning the types of artifacts which were analyzed are not available in any of the relevant papers by Singer or Ericson. Although the basic obsidian hydration measurements (n=98) for the Bodie Hills analysis (Singer and Ericson 1977) are compiled in Meighan and Vanderhoeven (1978), the types of artifacts dated are not identified. Lacking the essential raw data, any evaluation of the means by which the quarry production curves were drawn is forestalled. Consequently, the discussion to follow concentrates on the issue of the supposed decline and termination of obsidian production at the two quarry areas.

Several new hydration rates for Casa Diablo and Bodie Hills obsidians have appeared in the literature (e.g., Hall 1983; R. Jackson; Bouey and Basgall, this volume) to add to the clutter of rates already proposed (e.g., Michels 1965, 1982; Ericson 1975, 1977, 1978, 1981; Meighan 1978). Although the matter of source-specific obsidian hydration rates is important in the following discussion, it is not my intent to evaluate any particular hydration rate *per se*, but, instead, to illustrate how divergent interpretations of archaeological data are possible when we cannot firmly situate ourselves in the temporal dimension. Further, I do not advocate that any of the previously proposed source-specific hydration rates provides for an accurate translation of microns of hydration into units of absolute time across the full temporal span of prehistory in the region. The emphasis in this paper is to suggest the absolute temporal position of the recent end of the production curves of the Bodie Hills and Casa Diablo quarries proposed by Ericson and Singer, and, having done so, to make an interpretation linked to that temporal anchor.

Production Analysis of the Bodie Hills and Casa Diablo Quarries

One of the most important papers published regarding production and distribution of obsidians from western Great Basin sources is that of Singer and Ericson (1977). This essay has also been incorporated, virtually *in toto*, in Ericson's doctoral dissertation (1977, cf. 1981). While the focus of the production analysis by Singer and Ericson was the Bodie Hills quarry, Ericson (1981, 1982) has sought to demonstrate that a similar history of production may be interpreted for the Casa Diablo quarry source, located approximately 72 km south southeast of Bodie Hills (not 130 km, as reported in Ericson (1982: 136); Map 1). Ericson's most recent interpretation (1982) of these quarry production data is at considerable variance from his earlier, preliminary conclusions.

Ericson's (1982: 138-140) interpretive history of obsidian production at the Bodie Hills quarry may be summarized, as follows. Production at the site began "before 5000 B.P.," and maintained a relatively constant output "until about 4000 B.P. when it began to increase for 1000 years [sic]." Based on obsidian hydration dating of 98 specimens from the quarry (12 of which exhibit no visible hydration band (Meighan and Vanderhoeven 1978)), it would appear that production at Bodie Hills terminated ca. 1500 B.P. However, Ericson apparently now believes that while the earlier large biface industry at the quarry may have ended at about that time, a concurrent technological shift to a "blade/flake production technology," with actual artifact production carried out at sites away from the quarry itself, may have created the illusion of an extinction of all production. A highly coincidental production history is elucidated by Ericson for the Casa Diablo source, based on analyses of materials from the Mammoth Junction site (cf. Michels 1965), varying only as regards the initiation of production, which apparently began ca. 7000 B.P. (Ericson 1982: 142-143).

The critical element in the analysis of diachronic production at the Bodie Hills and Casa Diablo sources is the dating of the archaeological remains. For the Bodie Hills analysis, Singer and Ericson (1977: 181-182), and Ericson (1977, 1981, 1982) rely upon a source-specific obsidian hydration rate of 650 years/micron established for Bodie Hills glass by Ericson (1975; cf. Ericson 1977: 279, wherein a source-specific hydration rate of 670 years for Bodie Hills is advocated). According to the information provided by Ericson (1977: 67, 352-353), the source-specific obsidian hydration rate for Bodie Hills obsidian was derived from results of a total of seven C14 age determinations made on both charcoal and bone collagen samples, and compared with a total of 12 obsidian hydration rim measurements ascertained for artifacts found associated with the radiometrically dated samples. Not only is the control sample for the derivation of a source-specific rate quite small, but none of the materials employed are from archaeological locations climatically similar to the high desert region in which the Bodie Hills quarry is located (cf. Michels and Tsong 1980; and Michels 1982).

As additional support for their dating, Singer and Ericson (1977: 182-183) cite a coincidence of fit between the measured hydration rim thickness of temporally sensitive projecting points collected at the quarry and the proposed 650 years/micron hydration rate. According to Singer and Ericson (1977: 175), the projectile point forms employed "have been shown to be excellent time markers." Further: "The bracketing dates [for production at the quarry, 6000 B.P. to 1500 B.P.] are well supported by typological analysis and hydration dating of two nearly complete Elko-eared points (1625 years B.P. and 2600 years B.P.) and one complete Silver Lake point (5980 years B.P.) These points are considered 'Archaic' forms typical of the Middle Horizon of California prehistory" (Singer and Ericson 1977: 182).

Here again, we are confronted with a sample (three projectile points) which is of questionable value. Also arguable is the utility of these point types as precise temporal markers. Use of Elko Eared points in the region, for example may span a period of more than 2100 years (cf. O'Connell 1967: 132; Moratto 1972: 254; Thomas 1981), hardly affording the restrictive time frame within which such artifacts would be of real value for the purposes to which Singer and Ericson would put them.

To date the production history of the Casa Diablo quarry, Ericson (1977: 289, 295; 1982: 143, 144) relies on a source-specific hydration rate of 1000 years/micron; a rate derived from Michels (1965, 1969) and ascribed to a <u>non-source-specific</u> central California hydration rate proposed by Clark (1964). The use of the hydration rate attributed to Clark is open to question on several grounds. First, the rate is not determined from populations of artifacts with known source attribution; second, as Origer (1982: 87) has pointed out, some samples originally employed by Clark are not in satisfactory association with reported radiometrically dated samples; third, samples dated by Clark are from archaeological sites in central California, a region climatically dissimiliar from the environments of the Bodie Hills and Casa Diablo quarries; and, fourth, the hydration rate calculation formula proposed and employed by Clark (1964: 77, D = 0.0105t3/4; cited by Michels and Tsong (1980) as, $x = kt^{3/4}$) is different from the "linear" diffusion equation of Meighan, et al. (1968), and the Friedman and Smith (1960) diffusion equation, $x = kt^{1/2}$. As reported by Clark (1964: 177), for example, 3.5 microns of hydration would correspond to the passage of approximately 2,512 years, not 3,500 years as suggested by Ericson's source-specific Casa Diablo rate. Even Clark's computation is in error, however, since the conversion of 3.5 microns of hydration should equate to 2,311 years. In fairness, however, it should be noted that Clark's calculations would have relied upon logarithms and are more approximate than those obtained by the use of modern micro-computers.

A number of researchers have proposed source-specific hydration rates for Casa Diablo glass which differ considerably from that employed by Ericson. Meighan (1978) has suggested a hydration rate of approximately 220 years/micron. Garfinkel (1980), Basgall (1983) and Hall (1983) have advocated the use of the linear rate model of Meighan et al. (1968), although their formulations for the translation of microns of hydration to absolute time are slightly different: Garfinkel $Y_{BP} = 665.41x - 745.00$; Basgall, $Y_{BP} = 700.0x - 933.6$; Hall, $Y_{BP} = 668.54x - 637.30$ (see Bouey and Basgall, Table 1, this volume). Basgall, Garfinkel and Hall each derived their hydration rate based on the analysis of time-sensitive projectile point forms from the western Great Basin, some or all of which are geochemically sourced, but not samples in direct association with radiometrically dated materials. Michels (1982) has calculated a hydration rate for Casa Diablo glass derived from induced hydration experimentation such that the hydration rate constant employed for the Friedman and Smith model is 3.51 microns^2/1000 years. Michels' experimental rate is especially appropriate to the question of the rate of hydration at the Casa Diablo source since his calculations of effective hydration temperature employ climatic data from the Mono Lake weather station located near the Casa Diablo source (1982: 5). Ironically, the hydration rate constant suggested by Michels closely approximates the diffusion model constant initially calculated, but subsequently rejected, by Ericson (1977: 67, cf. 289; 1978: 51) of 3.9532 microns^2/1000 years. For example, using the diffusion model, an absolute age conversion of one micron of hydration using the two constants would differ by only 32 years (ca. 253-285 years B.P.)

In an indirect evaluation of the 1000 years/micron source-specific hydration rate for Casa Diablo obsidian, Jackson (1983: 89ff) reviewed the results of of hydration rim measurements made on 685 obsidian artifacts collected from 21 archaeological sites on the Sierra National Forest. Of these 515 had been determined by x-ray fluorescence (XRF) to be of Casa Diablo glass, and the balance (170) are probably of Casa Diablo obsidian, although geochemical analyses were not performed (Kipps 1982; Jackson 1983). Hydration measurements on an additional 132 Casa Diablo artifacts (all sourced by XRF) from various sites on the Sierra National Forest have been provided by K. Moffitt, Forest Archaeologist. The sample for study thus constitutes a total of 817 artifacts with measurable hydration rims.[1] The mean hydration rim values from the sampled sites are presented in Figures 1-3, and sample site localities appear on Map 2. The majority of hydration samples are debitage flakes. The single most striking aspect of the data base is that of these 817 samples, only a single artifact exhibits a hydration rim measuring less than 1.0 micron. Although the total sample of artifacts probably represents a span of prehistory in excess of 5,000 years, many of the artifacts are from sites with late prehistoric or historic period artifact forms (e.g., Desert Side-notched projectile points; Jackson 1983: 92-94). There is apparently no technical reason to suspect that the initial 1.0 micron of hydration is not being detected and measured, and some reports of archaeological investigations in the southern Sierra Nevada do list hydration measurements of less than 1.0 micron on obsidian artifacts from late prehistoric assemblages (e.g., Garfinkel et al. 1980: 66; McGuire and Garfinkel 1980: 50-51).[2]

It now appears that obsidian from the Casa Diablo source hydrates at a rate must faster than 1000 years/micron, the rate employed for Ericson's production

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[1] Samples for which no hydration rim could be measured (n=42) are not included in this analysis. Such samples are excluded because there is no way at present to determine why there is no detectable hydration rim: technician error; loss of the hydration rim by heating of the specimen; etc. In the period between the drafting and publication of this paper, approximately 800 additional hydration rim measurements have been obtained for artifacts collected from various sites on the Sierra National Forest, primarily in the Shaver Lake area. While hydration rim thicknesses as small as 0.8 micron have now been detected, the general trend of the measuremetns indicated in this paper has been maintained; that is, there are a disproportionately small number of samples with hydration rims measuring less than 1.0 micron.

[2] It is implied, if not expressed, in the published literature regarding the obsidian hydration dating technique that hydration rims, if they are present at all, regardless of their thickness, and given adequate preparation and measuring devices, can be measured. The fact that there are so very few hydration rim measurements less than 1.0 micron from California archaeological specimens is telling, however, and suggests that either there is a real uniformity in the rate at which the initial micron of hydration is created on obsidian specimens, regardless of the source of the glass, or that the technical aspect of detection and measurement is in some respect lacking. Perhaps the archaeologists working in the Sierra Nevada might endeavor to resolve this matter by addressing a large-size sample of obsidian artifacts recovered from very late perior prehistoric or early historic period sites.

analyses. Taking the data from the Sierra National Forest sites at face value, if we were to assume that 1.0 micron of hydration was equal to 1000 years of elapsed time, we would be forced to conclude that we have misplaced approximately 1,000 years of prehistory in this portion of the Sierra Nevada! On the other hand, the experimental induced hydration rate offered by Ericson (1977: 67) and Michels (1982), and Meighan's rate of 220 years/micron seem much more compatible -- *at least at the recent end of the temporal scale* -- with the known culture history of the region. Similar indirect evidence in support of a hydration rate faster than 650 years/micron is presently accruing for Bodie Hills obsidian. Of approximately 200 Sierran archaeological artifactual samples of Bodie Hills obsidian processed by the Obsidian Hydration Laboratory at Sonoma State University, none with measurable hydration has a rim with a thickness less than 1.0 micron, although sites with late prehistoric components are represented in the sample (T.M. Origer, personal communication).

A re-evaluation of the temporal dimension of production analysis at the Bodie Hills and Casa Diablo obsidian quarries, one which moves Ericson's temporal data points forward in time, affords a quite different interpretation of the production curves than those advanced previously by Ericson and Singer. I would suggest that, for Casa Diablo obsidian artifacts in the southern Sierra Nevada, the temporal period represented by the first micron of hydration may correspond with the initiation of a dramatic population reduction and the eventual ultimate termination of native cultures. If 1.0 micron of hydration were equivalent to ca. 220 elapsed years (cf. Meighan 1978), the dating of this hypothetical population decline would be ca. A.D. 1760, or about the time of the advent of the Spanish missions in southern California. While it is generally concluded that Sierran native cultures in the region were reduced following the influx of argonauts into the gold fields ca. A.D. 1850, massive epidemics had previously wasted California Indian populations, beginning shortly after the establishment of the Spanish missions in California, the first of which was founded in San Diego in A.D. 1769 (Cook 1978). However, the rates proposed by Ericson and Michels, based on induced hydration experimentation (ca. 250-280 years/micron) might also be compatible with such an explanation. It is not impossible that a disease-induced radical decline in native populations may have commenced even earlier than the construction of the initial mission in Alta California, as the result of direct or indirect contacts with populations associated with Spanish military explorations or missions from areas beyond California (such as the Spanish provinces of Sonora, Nuevo Mexico, or Baja California). In Baja California, for example, efforts at Spanish settlement had begun as early as 1535, but it was the successful establishment of the mission at Loreto in 1697 which spelled the demise of the native populations on the peninsula by A.D. 1700 (Cook 1937; Massey 1949; cf. R. Jackson 1981 and Ramenofsky 1981). Thus, not only might the interpreted rapid production increase at the Bodie Hills and Casa Diablo quarries correspond with a hypothesized dramatic aboriginal population growth in the late prehistoric period in the California region (Ericson 1982: 145; cf. Moratto 1972), but the supposed production decrease could relate to the decimation of the native populations due to introduced diseases and Euro-American genocidal campaigns.

Another implication of the identification of late prehistoric production at the Bodie Hills and Casa Diablo quarries is that Ericson's (1982: 138-140, 144-145) most recent explaining away of the apparent decline in "luxury" (an unfortunate and inappropriate term) biface production may not be necessary. Indeed, there is no conclusive evidence in the archaeological record of the central and southern Sierra Nevada or the foothills, which would lead one to believe that the production of the sorts of bifaces actually discussed by Ericson and Singer (roughouts, blanks, preforms, not finished bifaces) at either the Bodie Hills or Casa Diablo source actually terminated in late prehistoric times. Such artifact forms or related debitage are commonly found in late prehistoric period assemblages in the region, especially in sites in upper elevations (cf. e.g., Peak 1981; Goldberg 1983; Jackson 1983). However, I agree with Ericson that a late prehistoric period shift to smaller projectile point forms could have resulted in a net decrease in the number of relatively large, rough biface forms produced, with a corresponding increase in the lithic debris and intermediate artifact forms associated with the so-called "blade/flake technology." The shift to a focus on relatively small obsidian flakes as the raw material for tool manufacture could have permitted the removal of materials from the quarry sites without the introduction of manufacturing residues such as would have been associated with the on-site roughing-out of bifaces. As Ericson notes, this would convey the impression of an overall decline in production at the quarry.

Conclusion

Several lines of evidence have been submitted which argue against Singer and Ericson's (1977) and Ericson's (1977, 1982) conclusion that obsidian production at the Bodie Hills and Casa Diablo quarries declined or terminated ca. 1500 years B.P. Source-specific obsidian hydration rates employed by Ericson and Singer may be challenged on a number of grounds, including their use of inadequate numbers of samples, or inappropriate samples, for establishing correspondence between radiometrically dated materials and specimens with measured obsidian hydration rims. Ericson's (1977, 1982) apparently arbitrary selection of the source-specific hydration rate of 1000 years/micron for Casa Diablo obsidian, supposedly derived from Clark's (1964) non-source-specific central California hydration rate, cannot be supported on any grounds. Additionally, the persistent recovery of Bodie Hills and Casa Diablo obsidian from late prehistoric or early historic archaeological assemblages in the central and southern Sierra Nevada clearly indicates that production at the two quarries continued, with no evidence of any late prehistoric decrease, until the disruption of native cultures by invading Euro-American populations.

Although a number of different hydration rates have been proposed for Casa Diablo obsidian, with various researchers advocating either the "linear" equation of Meighan, et al. (1968), or the "diffusion" equation of Friedman and Smith (1960), one point of agreement among these researchers is that the hydration of Casa Diablo obsidian occurs at a rate faster than 1000 years/micron. By any reckoning, production of obsidian at the Casa Diablo quarry continued until more recently than 1500 years B.P. Depending upon one's choice of hydration rate, however, various interpretations of the "production curves" for the quarries are possible.

A sample of 817 artifacts of Casa Diablo glass with measured hydration rims is now available from 44 sites on the Sierra National Forest. Only one artifact in this sample exhibits a hydration rim thickness less than 1.0 micron although many of the sites represented in the sample contain late prehistoric assemblages. The question then arises as to the temporal significance of this apparent 1.0 micron measurement threshold. At least three papers (Meighan, et al. 1968; Ericson 1978; Michels 1982) have been published which advocate a source-specific hydration rate for the Casa Diablo glass on the order of between 220 and 280 years/micron. If we were to accept any of these hydration rates, or, conveniently, the mean of them (250 years/micron), the period represented by 1.0 micron of hydration would fall within the early historic era in California. It would be precisely at that time in which we might anticipate being able to detect the effects of the Euro-American invasion on the native populations. One such effect might take the form of a rapid decline of native population due to the introduction of foreign diseases. If one were then to employ a rate of hydration of ca. 250 years/micron as a means of establishing the temporal position of the recent end of Ericson's production curve for the Casa Diablo quarry there could be a rough coincidence between production curves and projected prehistoric and historic population curves in the California region. In short, production at the obsidian quarries may have declined simply because there were fewer people alive to exploit the resource. Indeed, production at the quarries was "terminated," but some 1,300 years more recently than proposed by Ericson and Singer.

While the clear evidence of the continued importation of Bodie Hills and Casa Diablo obsidians to the western slopes of the Sierra Nevada into late prehistoric and early historic times, and the unanimity among researchers that the rate of hydration for Casa Diablo obsidian is less than that advocated by Eriscon (as is the rate for Bodie Hills apparently less than 650 or 670 years/micron), there remains another element to the obsidian hydration data which is perhaps not adequately explained. That is, the near absence of hydration measurements less than 1.0 micron. Although there may be no technical reason such small hydration rims (say those between 0.5 and 1.0 microns) are not being detected and measured, we must nonetheless become convinced that this initial 1.0 micron of hydration represents some valid culturally-related phenomenon and not some product of the chemical or physical aspects of the hydration process. Obviously, the key variable in any interpretation of the Bodie Hills or Casa Diablo production curves is the dating of the archaeological materials. So long as we are without an adequate source-specific obsidian hydration rate for either of the sources, we cannot represent interpretations of production levels at the quarries as anything other than speculation. As demonstrated by this discussion and other papers in this volume, the resolution of the problem of source-specific hydration rates for the various western Great Basin obsidian sources is key to the understanding of the prehistory of the Sierra Nevada, an area in which the recovery of radiometrically datable materials in archaeological contexts is an infrequent occurrence, but an area in which archaeological obsidian is abundant.

Acknowledgements

I would like to thank Matthew C. Hall, Richard E. Hughes, Michael J. Moratto, Thomas M. Origer and Polly McW. Quick for comments on an earlier draft of this paper. Matthew Hall recalculated the absolute age equivalent of 3.5 microns of hydration using Clark's rate, and reminded me of Clark's dependence

on log tables for the calculation of exponential functions in those days before the now ubiquitous handheld calculator. Kathy Moffitt, Forest Archaeologist, Sierra National Forest, provided hydration measurement data from several sites on the Sierra National Forest. Obsidian hydration results originally reported in ACRS (1983) and Jackson (1983) were obtained through research sponsored by Southern California Edison Company.

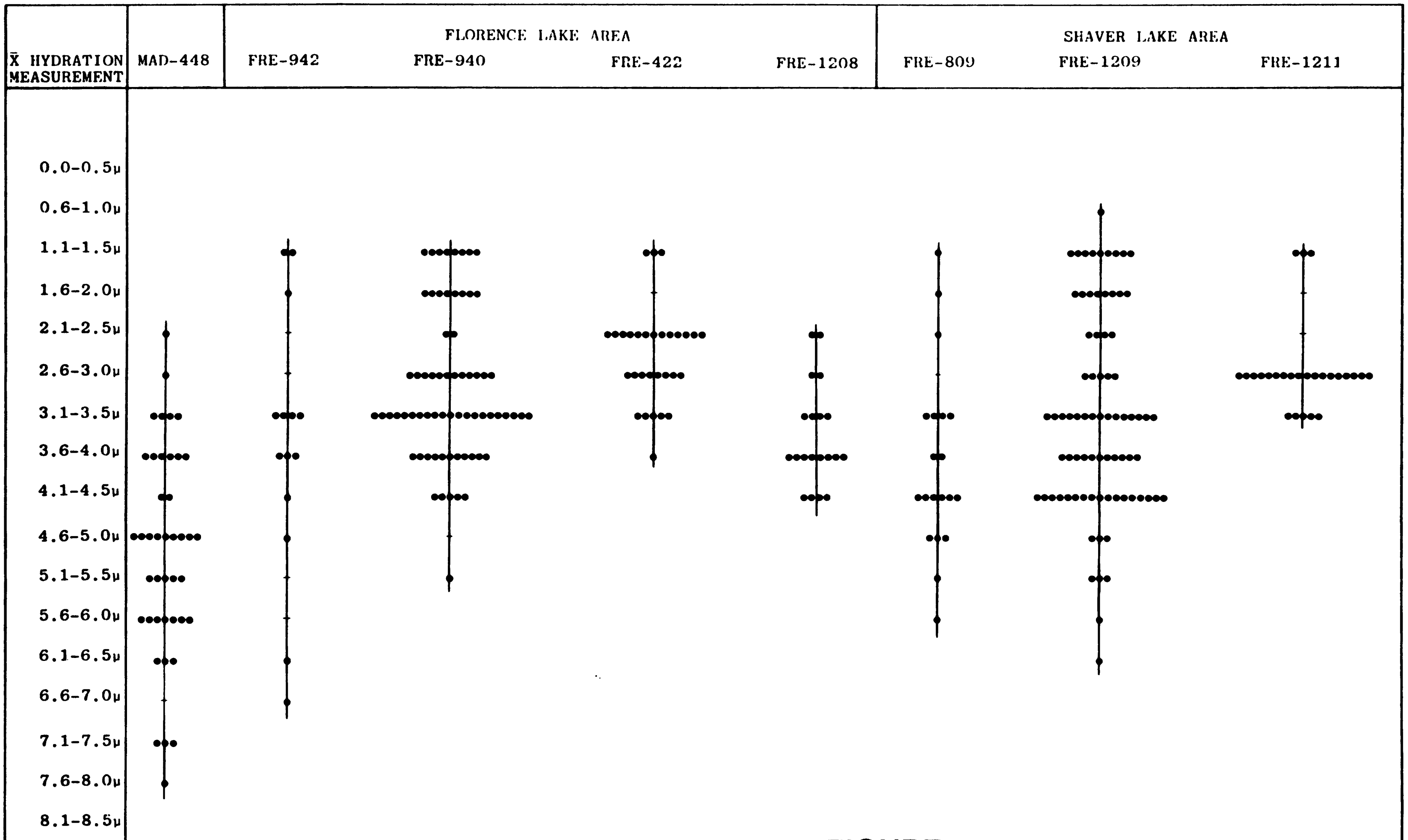
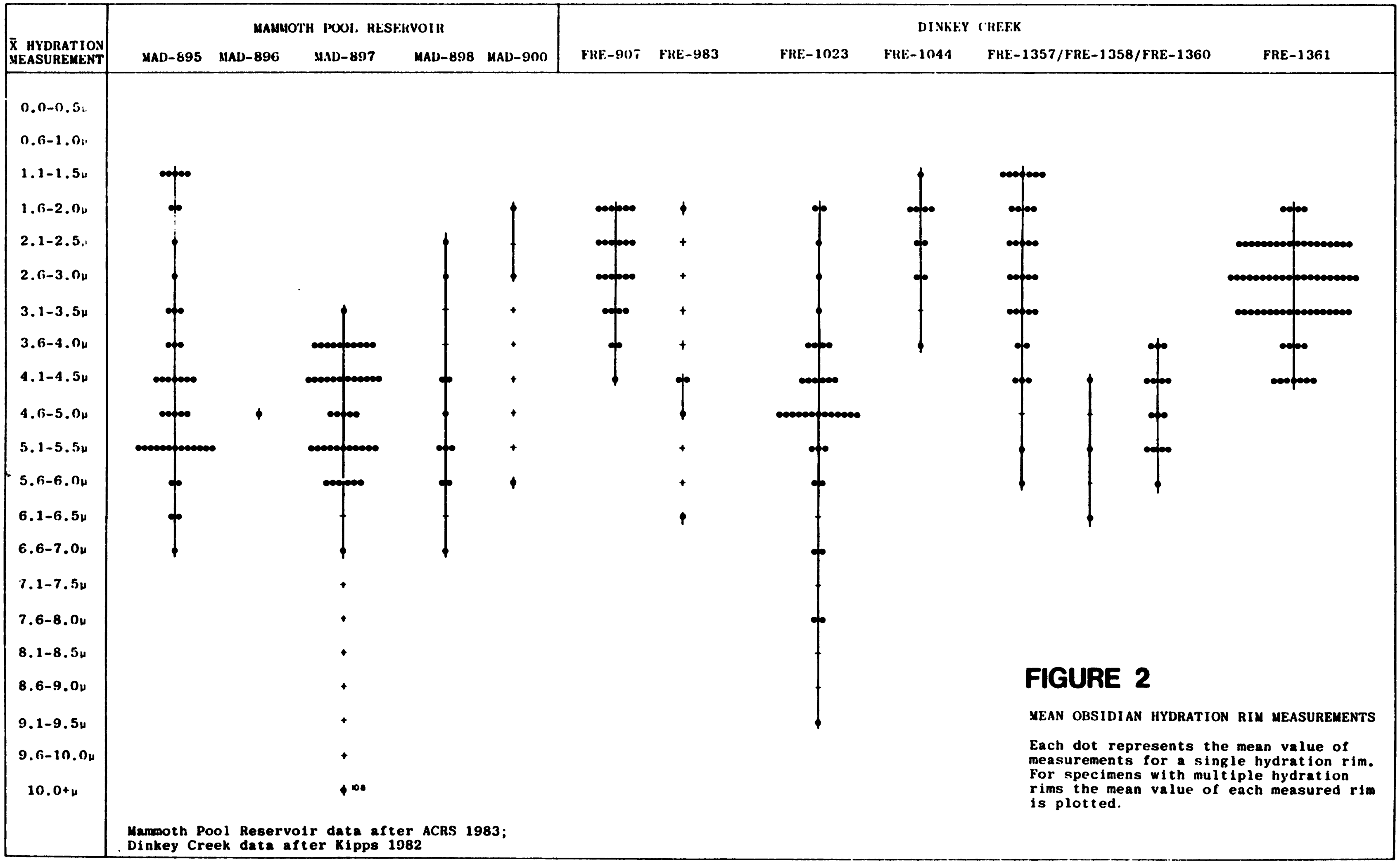


FIGURE 1

MEAN OBSIDIAN HYDRATION RIM MEASUREMENTS

Each dot represents the mean value of measurements for a single hydration rim. For specimens with multiple hydration rims the mean value of each measured rim is plotted.

MAD-448 data after Peak 1981
Data for Florence and Shaver lakes areas after Jackson 1983

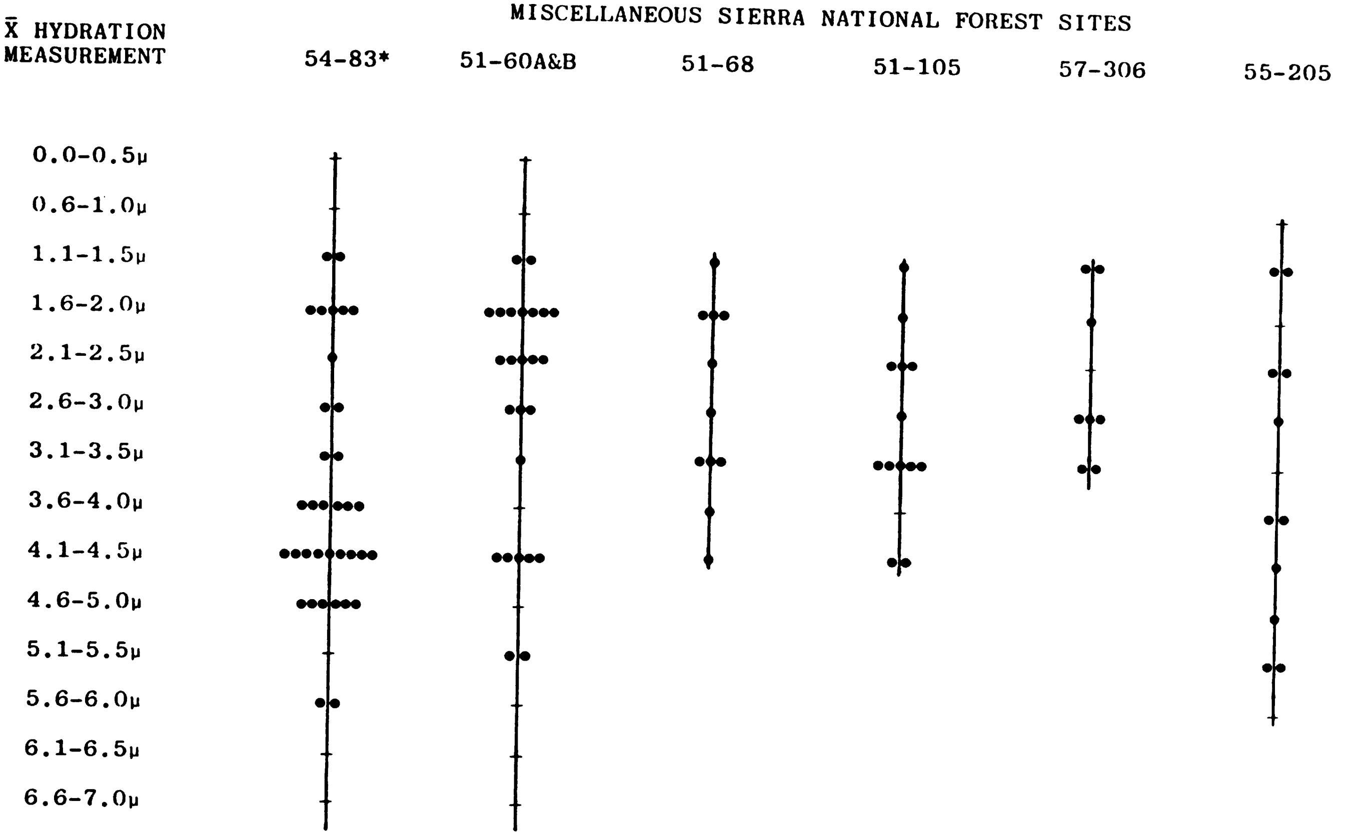


Mammoth Pool Reservoir data after ACRS 1983;
Dinkey Creek data after Kipps 1982

FIGURE 2

MEAN OBSIDIAN HYDRATION RIM MEASUREMENTS

Each dot represents the mean value of measurements for a single hydration rim. For specimens with multiple hydration rims the mean value of each measured rim is plotted.

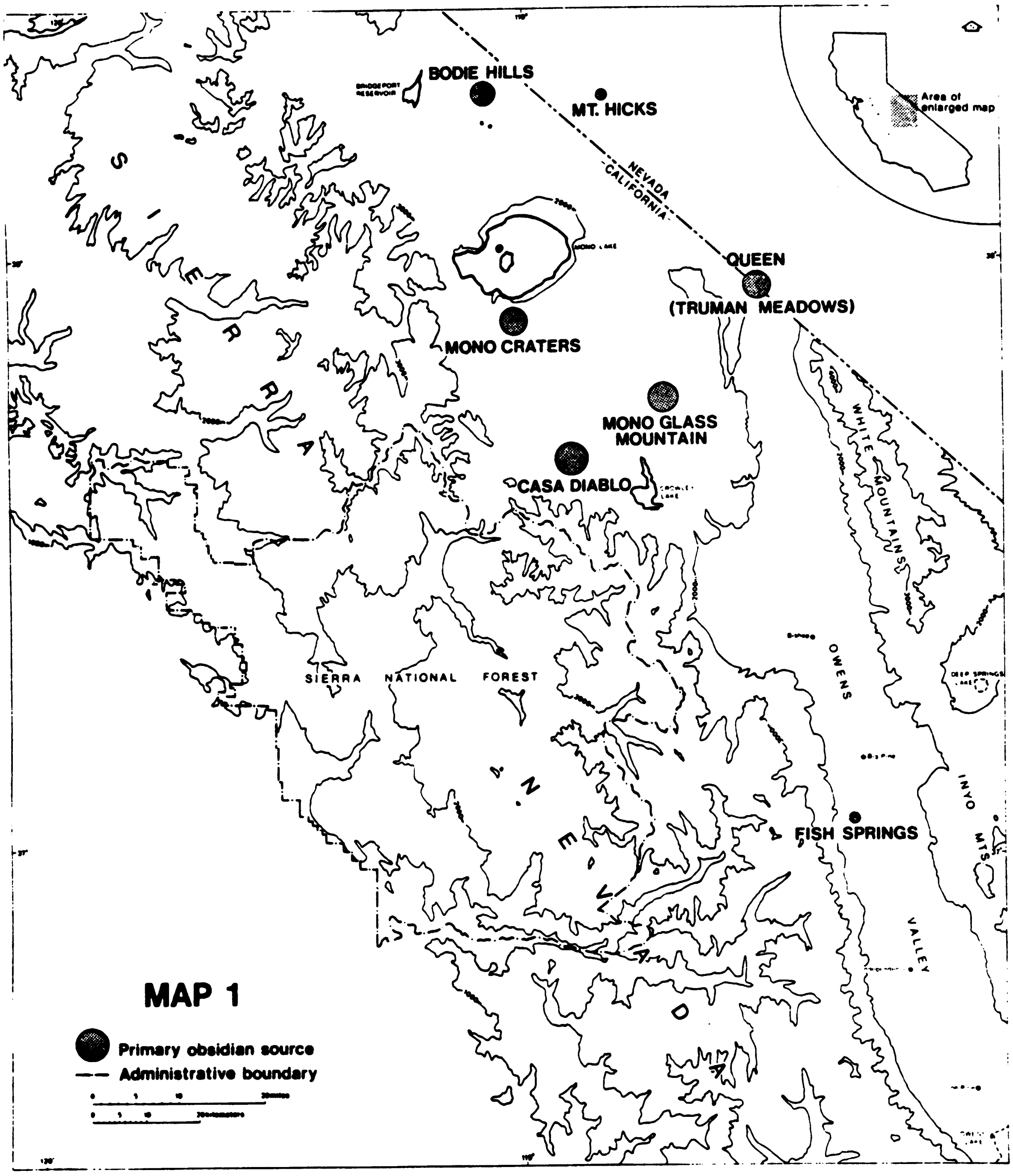


Miscellaneous hydration rim measurements: 53-361, 2.7μ; 54-14, 4.3μ, 4.6μ; 54-15, 3.7μ; 54-24, 1.0μ; 54-72, 1.3μ; 54-110, 4.5μ; 54-112, 2.7μ; 54-265, 1.4μ, 2.2μ; 54-376, 1.4μ; 54-426, 1.5μ; 54-461, 1.9μ; 54-497, 3.0μ; 54-499, 4.4μ; 54-539, 1.9μ, 3.2μ; 54-565, 4.0μ; 54-591, 1.8μ; Bald Timber Sale #2, 2.1μ, #28, 1.1μ (isolated finds); 57-09, 1.2μ, 1.6μ, 1.7μ; 2.0μ.

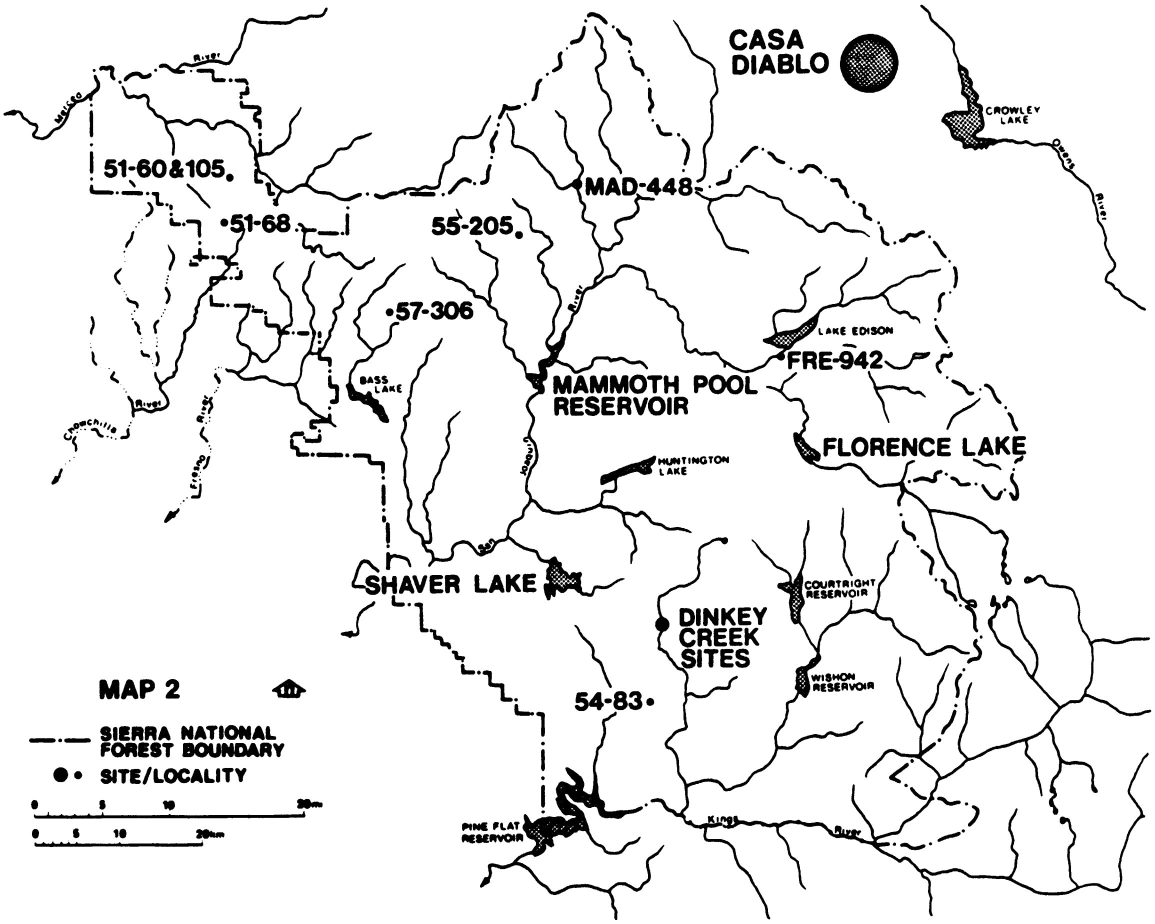
* All site numbers are Sierra National Forest designations; data provided by K. Moffitt, Forest Archaeologist, Sierra National Forest.

FIGURE 3 MEAN OBSIDIAN HYDRATION RIM MEASUREMENTS

Each dot represents the mean value of measurements for a single hydration rim.



Map 1. Map of the study area showing the locations of obsidian sources.



Map 2. Locations of archaeological sites discussed in the text.

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TRANS-SIERRAN EXCHANGE IN PREHISTORIC CALIFORNIA:

THE CONCEPT OF ECONOMIC ARTICULATION

Paul D. Bouey
Mark E. Basgall

Introduction

The study of obsidian distributions in western North America has shifted from a broad perspective, attempting to delineate general socio-economic trends (e.g. Jack 1976; Ericson 1977a, 1977b, 1982), to more detailed and areal-specific research on territorial boundaries and temporal/spatial variation in particular exchange networks (e.g. Bettinger 1982a; Hughes and Bettinger 1984). In the California culture area, several studies have examined the relationship between the "producers" of obsidian artifacts in the Great Basin and the "consumers" of those items in California (Ericson 1977a, 1977b, 1982; Jack 1976; Jackson 1974). Of these, however, only Jackson's considered the contextual information provided by the archaeological material (although he recognized numerous shortcomings) and recognized California and the Great Basin as articulating systems, not isolated spheres. According to such an approach, the constituent systems are seen as interdependent, with "perturbations" in the production and/or exchange processes of one having repercussions in the other. Such changes should be reflected in the archaeological record of both regions and should, therefore, be amenable to explanation.

Using the concept of "economic articulation" as a foundation, a review will be made of archaeological data in the Mammoth Lakes/Long Valley area of central-eastern California, followed by an examination of the obsidian distributions on the western slope of the Sierra Nevada, in central California, and in the Napa Valley. Based on an evaluation of the observed patterning, it will be argued that each of those regional components fits into a single, more encompassing system. The data re-evaluated here have been collected by numerous individuals, each with their own research interest(s); therefore, there are certain comparability problems involved. Further, each project possessed its own sample limitations, these with respect to size, configuration, and mode of selection. While certainly recognized, such problems will not be explored further. Our feeling is that the inconsistencies cited above, though compromising our arguments to some extent, lost their individual significance in light of the larger patterning reflected in the available data. It is this overall pattern which provides significant insight into the evolutionary trajectory and historical development of those regions of California.

Explanations for the patterning will be proferred which account for the known archaeological data and which can serve as working hypotheses for later research. It should be stressed that this study represents but an interim statement; much more work needs to be done on the problem (Basgall and Bouey n.d.).

The Obsidian Data

In order to evaluate the proposed obsidian exchange network in its complete context, consideration must be given to the archaeology of the eastern slope of the Sierra Nevada, the western slope, central California, and the Napa Glass Mountain region. These areas reflect major components of the network, and contain the information necessary for delineation of processes affecting, even accounting for, the patterns described herein. Each of the regions will be examined in turn.

Eastern Sierra. That portion of the eastern Sierra of principal interest to the present study encompasses the Casa Diablo obsidian source in Long Valley caldera (Figure 1). The archaeology of this region is comparatively well-known, having a firm chronology (Bettinger and Taylor 1974), as well as partial documentation of prehistoric land-use patterns (e.g. Bettinger 1977; Cowan and Wallof 1974; Davis 1964; Hall 1983; R. Jackson n.d.; Meighan 1955). Most recently attention has shifted to the study of exchange patterns in the area (Basgall 1982, 1983; Bettinger 1980; Ericson 1977a, 1982; Hall 1983), with a full suite of lithic reduction/production localities in Mammoth Lakes undergoing extensive investigation.

Casa Diablo represents the eastern node of the exchange network under discussion.[1] Located immediately east and northeast of Mammoth Lakes, California (Figure 1), the Casa Diablo source covers at least 15 km^2 and had extensive distribution in prehistoric California (Ericson 1977a, 1977b, 1982; Jack 1976; Jackson 1974). Several hydration rates have been proposed for Casa Diablo; these are reviewed below and tested against independent projectile point data from several sites in central-eastern California. The most reliable rate will then be used to characterize the chronometric framework for Casa Diablo obsidian production, a requisite to comparison with similar patterns for Napa Glass Mountain (see below).

Source-specific hydration rates for Casa Diablo have had good results in dating obsidian from that source (e.g. Basgall 1983; Ericson 1977a, 1978; Garfinkel 1980; Hall 1983; Meighan 1981; Michels 1982a), although the caliber of certain rates varies substantially. In evaluating the various rates that are available (Table 1), hydration readings on a sample of Casa Diablo projectile points from three sites in central-eastern California (Iny-2146 (Garfinkel 1980);

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[1] One major "eastern" obsidian source with a wide distribution in California, Bodie Hills, is excluded from discussion. Although Singer and Ericson (1977) have characterized the purported production curve for that quarry, a tested hydration rate is still unavailable. In addition, adequate source/hydration data from non-quarry areas remain as yet unpublished, and we feel a detailed discussion of the source would be premature. It should be noted, however, that Bodie Hills probably represented still another node of the exchange system under consideration and its integration with Casa Diablo and Napa Glass Mountain would be desirable. While there is no formal discussion of Bodie Hills in the present paper, we are in agreement with Hall (1983) in noting that its production history should parallel that of Casa Diablo. If so, much of our argument for Casa Diablo probably holds for Bodie Hills as well.

Mno-529 (Basgall 1983); and Mno-561 (Hall 1983)) were tested against typologically derived age estimates from each (e.g. Hester 1973; Bettinger and Taylor 1974; Thomas 1981). This limited test (Table 2), based strictly on specimens that were morphologically unambiguous, clearly indicates that Hall's (1983) rate provides the most consistent results. Two other rate characterizations, those of Basgall (1983) and Garfinkel (1980), provide reasonable temporal placements, but falter in treating materials from the later prehistoric period. Based on these observations, Hall's (1983) hydration rate will be applied to all Casa Diablo obsidian in the present study.

Those sites comprising the eastern Sierra sample are all located in the immediate Mammoth Lakes area, and while they are immediately adjacent to Casa Diablo, they are not associated with specific quarry locales. As such they can be characterized as "secondary" reduction loci, closely tied to actual obsidian outcrops. Due to their proximity, we assume that the sites served as primary quarrying areas and that they provide accurate indications of production at the Casa Diablo source. In fact, such localities, having been used for long duration, may provide a better reflection of production than restricted, individual quarries which may have been used more episodically and/or at more random points in time.

The eastern Sierra sample includes three sites, Forest Service Forty (Mno-529 (Basgall 1983); Mammoth Junction (Mno-389, Michels 1965; Sterud 1965); and Mno-561 (Hall 1983), all of which have considerable samples of hydration data, extensive site investigation, and, most importantly, similar functional configurations. With respect to the latter attribute, all sites used in the study contain great quantities of obsidian debitage, high frequencies of preforms/blanks, and little evidence for subsistence/maintenance activities. A detailed technological analysis of flaked-stone material from Mno-529 (Jackson et al. 1983) provided thorough documentation of extensive preform reduction/production at that locality; less detailed information from the other two sites suggests a similar orientation.

Based on Hall's (1983) hydration rate, the three sites parallel one another in exhibiting production peaks during the Newberry period (cf. Bettinger and Taylor 1974). While the exact character of the production pattern at each site differs slightly (Table 3; Figure 2), all three show an increase in lithic activity at ca. 3000 B.P., followed by high production levels until ca. 1350 B.P., with a continuing decline after that time. A composite curve, using data from all three sites (Figure 3), provides perhaps the best reflection of overall Casa Diablo production.

Previous discussions of production at Casa Diablo have been based on a rate of 1000 years/micron (Ericson 1977a, 1977b, 1982; though see Basgall 1983 and Hall 1983) which often produces dates outside of the range of the expected projectile point time periods (Tables 1 and 2). It is pertinent, therefore, to contrast the two viewpoints (Figure 4). By the old rate, based only on data from the Mammoth Junction site (Michels 1965), it was suggested that Casa Diablo production commenced at the end of the Lake Mohave period, ca. 5000 B.P. (Bettinger and Taylor 1974), gained momentum during the Little Lake period, and evidenced a decline midway through the Newberry period (ca. 2500 B.P.).

Divergence between the alternative curves is quite pronounced and has considerable effect on temporal placement of the production decline.

Western Sierra. For the purposes of this study, discussion of the western Sierra Nevada will be restricted to that region from Yosemite south through Fresno County. While archaeological investigation in this region has been extensive (e.g. Heizer and Elsasser 1953; Hindes 1962; T. King 1976, 1978; Moratto 1972; Moratto et al. 1978), published studies specifically focusing on obsidian source or hydration analyses have been limited. As a result, our characterization of western Sierran obsidian fluctuation is less documented and systematic than would be desired.

Although this lack of resolution is a general problem, Moratto et al. (1978) do suggest that obsidian use remained constant during the entire sequence at Buchanan Reservoir (ca. 2800 to 100 B.P.). While this may be true, the Buchanan data have yet to be systematically sourced and shifts between production localities may still be recognized.

The western Sierran sample is drawn from three sites and/or projects -- two in Madera County and one in Yosemite (Figure 1). The Mammoth Pool Reservoir project provided hydration data from three sites (05-15-55-631, -785, -786) which can be described as task-specific temporary camps (Archaeological Consulting and Research Services 1983). Lithic material was fairly limited at these locales, but predominately of Casa Diablo obsidian. Further data come from CA-Mad-448 (Peak 1981), an extensive site with a deep deposit and vast quantities of obsidian flaking debris. On the basis of debitage density, Peak concluded that Mad-448 was a "manufacturing site and trading node related to trans-Sierran economic [obsidian] exchange systems" (1981: ii). Finally, hydration data from the 1981 El Portal Archaeological Project (Baumler and Carpenter 1982) have been used to characterize the pattern in the Yosemite region (Origer and Jackson 1982). Debitage from Casa Diablo dominated four different assemblages (at Mrp-250B, Mrp-250C, Mrp-182A, and Mrp-382A), although Bodie Hills glass was also highly represented. All sites from El Portal represented temporary camps, and each contained relatively high frequencies of flaking debris.

On the basis of Hall's (1983) hydration rate for Casa Diablo, the temporal distributions of western Sierran obsidian can be depicted (Table 3; Figure 5). Once again, the curves for all localities show peaks during a time-frame commensurate with the Newberry period in central-eastern California (Figure 6; cf. Bettinger and Taylor 1974). Variation for Mad-448 is the most extreme, showing a secondary "surge" at ca. 1500 B.P. The extreme fluctuations, however, may be due to the limited sample from that site (24 specimens).

In contrasting the composite pattern for the western Sierra with that from the Mammoth Lakes/Long Valley region (Figure 3), it becomes apparent that the production/consumption curve for the former sample exhibits a slightly earlier peak (at ca. 3100 B.P.), commensurate with the onset of the Newberry period east of the Sierra. Likewise, on the basis of western slope data, production/consumption initiates (ca. 3400 B.P.) and drops-off earlier (ca. 2300 B.P.). While there is some divergence between the eastern and western data, the overall fit is remarkable. Minor fluctuations aside, both patterns indicate a marked decrease in the use of Casa Diablo obsidian after ca. 1300-1700 B.P.

Central California. This region includes the Sacramento/San Joaquin Delta, as well as part of the San Francisco Bay area. Archaeological research in central California has been devoted until recently (e.g. Gould 1964; Schulz 1981) to the examination of burial lots and to the development and refinement of a tripartite cultural chronology (Early, Middle, and Late Horizons; e.g. Lillard, Heizer and Fenenga 1939; Heizer and Fenenga 1939; Beardsley 1948, 1954). This chronology has remained essentially unchanged except for a few conceptual modifications (Fredrickson 1973, 1974a).

The majority of these reports have presented rather generalized descriptions of period-specific obsidian patterns. A relatively small number of well-made bifaces were characteristic of the Early Horizon graves, followed by a higher frequency of occurrence during the Middle. The Late Horizon witnessed a further increase in the total number and typological breadth of grave goods, but obsidian artifacts were found in smaller, more utilitarian forms (e.g. projectile points) and were generally of a relatively poorer workmanship.

Jackson's (1974) sourcing of certain central California materials revealed that the high quality, ripple-flaked artifacts of the earlier two horizons were made principally from eastern obsidians, primarily Bodie Hills and Casa Diablo. Toward the latter part of the Middle Horizon, Napa obsidian, which was present from very early times onward in very small quantities, became more common and also was used increasingly to manufacture strictly utilitarian artifacts. That process continued to the point where during the Late Horizon, Napa obsidian virtually replaced eastern obsidian entirely (Table 4).

Within the Bay area specifically, Napa obsidian has been found to dominate over the whole temporal span. During the Middle to Late Horizon transition, however, the general increase in obsidian use (cf. Fredrickson 1968, 1969) was paralleled by a decline in the use of eastern obsidians (Table 5; Figure 7; Banks and Orlins 1979; 1980; and Jackson 1974).

This source-area transition occurred during the Middle Horizon and dates between approximately 1000 B.C. and A.D. 500 (Fredrickson 1974; Schulz 1981). This pattern of increasing obsidian use in general, and of Napa material in particular, depicts a consumer-pattern in central California which complements the production pattern previously described for the Mammoth Lakes/Long Valley region.

The Napa Valley Region. The final area of interest is the Napa Valley in the southern North Coast Ranges. Napa Glass Mountain, located within the eastern flank of the valley, was the major source of the production node at the western end of the proposed exchange network and hence is of particular interest to this discussion. Unlike the work associated with the Casa Diablo source area, only a few sites have been examined in the Napa Valley, and most of these have not received thorough and systematic study. A byproduct of this is the absence of a firm chronology for the region.

Attempts to derive an accurate hydration rate for Napa Glass Mountain obsidian have produced mixed results and no definitive characterization. As with the Casa Diablo rates, those proposed for Napa Glass Mountain (Table 1; e.g.

Ericson 1977a, 1978; Michels 1982b; Origer 1982) were tested against an independent projectile point sample (drawn from Origer 1982: Appendix 2) representing types of known age. It should be emphasized that North Coast Range point forms are not as well dated as Great Basin series, particularly in the earlier time frames (cf. Baumhoff 1982; White et al. 1982). Given the difficulty of assigning a priori temporal ranges to some North Coast Range points, evaluation of Napa Glass Mountain hydration must remain more tentative.

Notwithstanding these problems, the limited test of previously proposed rates (Table 2) indicates that use of an equation developed by Ericson (1977a: Equation 4, Table 1) is the least inaccurate of those available. Because the rate is to be used primarily in delimiting gross temporal trends, not for fine-grained chronological placement, inaccuracies should prove to be of relatively minor consequence. Date estimates derived from this hydration rate will be assigned to debitage from selected sites in the Napa Valley.

The archaeological sites to be examined from the Napa Valley are not directly associated with a primary quarry. They are, however, in the vicinity and can be considered "secondary" production areas, comparable to the sites discussed for the Mammoth Lakes region. The sample includes six sites, CA-Nap-58, Nap-326, Nap-328, Nap-526, Nap-528, and Nap-531, all located on the California State Parks and Recreation Bale Grist Mill property. Excavation of those sites was exploratory and did not result in very large or systematically collected samples.

A large sample of debitage from these sites subjected to both source and hydration analysis (R. Jackson n.d.) showed a dramatic increase in production toward the more recent end of the temporal spectrum. These frequencies were duplicated at every site except Nap-528 and a restricted loci of Nap-328 (Table 7; Figure 8), where the early material had greater representation. Other sites contained limited material from earlier periods, but only those two appeared to be associated with notable early production. This pattern is not necessarily anomalous in any respect, for the assemblages from the latter loci could be related strictly to local use of the material. All of the data contained in Jackson's report have been consolidated to produce a single frequency diagram (Figure 3), which clearly shows a considerable increase in lithic production during the later prehistoric period. Using Ericson's (1977a) rate to actually date this shift, the curve takes a dramatic change at ca. 2500 B.P.

Political Economies

Overview. Although a description of evolving obsidian exchange patterns is by its nature narrow in focus, such materials surely existed within the context of cultural systems and should thus provide substantial insight into the systemic processes operative during periods of flux.

In some cases, explanations for observed shifts in the archaeological record have fallen into the non-discriminating mire of simple environment/culture correlation (e.g. Moratto et al. 1978). That is, they are often achieved through reference to some climatic/environmental perturbation which coincides with a change in the archaeological record. Most often the relative severity of the environmental change is not well understood, nor how such a shift would effect the cultural system under analysis. Those types of explanation, equating correlation and causation and ignoring questions of scale, are perhaps best characterized as "vulgar" environmental determinism.

It would seem to be more realistic and perferable to envision a cultural system as something more than an adaptive response to the structure of a given environment, thus somewhat independent of change in the latter sector. These systems, in fact, existed within a matrix of cultural systems, all of which shared some interaction with one another. As a component of such a matrix, each system must have had economies which compensated for such interaction -- through organization, production, and exchange -- or else run the risk of adaptive "lag" or even "extinction." The product of such a response, in association with other responses to various internal developments, would be an economy appropriately labelled a political economy: that which diverts some of its production from primary and immediate consumption to the financing and support of various political institutions (Earle 1978). Such institutions might include social hierarchies, specialized production, or specialized trade, among others.

From that basis, as part of its systemic processes, a cultural system by definition interacts or "articulates" with others. The form which that articulation assumes is, of course, dependent on the character of the economies involved (Bradby 1975; Taylor 1979). In particular, the orientation and scale of a specific economy will structure the demand of consumers, as well as influence the productive potential of producers. Within that context, the potential exists for a consumer group to have "demands" which are beyond the productive capacity of the supplier group, which may not have the population and/or organizational structure sufficient to meet the needs of the former. On the other hand, the consumers may have altered their desire for a specific type of material (e.g. obsidian), one of the groups may have shifted its activities (e.g. settlement-subsistence strategies) away from exchange production, or the groups for some reason may have been "cut-off" from one another. Any one of these scenarios, and almost certainly a multitude of others, would alter the type of articulation between any two groups.

With regard to obsidian exchange networks in California, consideration will now be given to each of the four regions in terms of the archaeological evidence for the existence of such political economies. Patterns of obsidian distribution will then be evaluated in their appropriate economic context, and explanations will be proposed for the processes evolving throughout the prehistoric period.

Archaeological Manifestations. In order to distinguish the traits of a political economy in the archaeological record, one must typically look beyond subsistence-settlement data. Among highly complex groups, that type of evidence is relatively obvious in special structures and/or in large, spatially discrete accumulations of exotic/valued goods. Detecting that form of social organization is more difficult among less complex groups, particularly hunter-gatherer populations. In such situations, the archaeologist can probably only define generalized trends in socio-political complexity; almost certainly many relevant data are either unusable due to ambiguity or are actually lacking from the record.

In California, grave lots have most often been used to infer prehistoric social organizational complexity. Some of these assemblages have been examined with the intent of discerning social differentiation (Fredrickson 1974b; L. King 1970; T. King 1976, 1978; Hughes 1978; Stickel 1968), while numerous others have only been described and never systematically studied and/or published (e.g. the materials from central California).

Recognizing the limitations of mortuary data (Binford 1971; Tainter 1978), they still provide the best measure of organizational complexity in the regions under consideration. The archaeological evidence concerning political economic development in each of the four areas will now be reviewed. It will become apparent that a considerable disparity exists in the quantity and quality of the data from region to region. As with the obsidian data reviewed previously, we propose that such inadequacies are somewhat compensated through the overall scope of the observed patterning.

Eastern Sierra. Although the ethnographic literature for central-eastern California suggests a greater level of sociopolitical complexity in Owens Valley (Bettinger 1978, 1982b; Steward 1933, 1938) than in most other portions of the western Great Basin, archaeological evidence for such organization is for the most part lacking. Bettinger and King (1971) have proposed a model whereby the presence of an elaborate redistributive exchange system was requisite to the development and persistence of such cultural atributes as sedentary villages and hereditary headmen. While we have no grave reservations regarding such a scenario, it should be stressed that the hypothesis remains as yet untested. Moreover, it is crucial to date the onset of such elaboration. Data from recent excavations in Owens Valley (Bettinger, personal communication) suggest that large, semi-permanent villages did not appear until the Haiwee period (ca. 1350 B.P.). Before that time it appears that the overall adaptation was one of great mobility and minimal sociopolitical complexity, probably reflecting Steward's (1955, 1970) family band/nuclear family model or Bettinger's (1978, 1982b) Desert Culture strategy. It also seems apparent that this strategy (Steward 1938, 1970) was marked by extensive home ranges tied to broad social networks, in contrast to the late prehistoric/ethnographic Owens Valley pattern which reflected greater territoriality (Bettinger 1982a; Steward 1933) and more spatially restricted social interaction.

In the Mammoth Lakes/Long Valley region to the north of Owens Valley the organization was apparently even less complex. Such ethnographic data as do exist for the area (Davis 1961, 1965; Steward 1933, 1934) indicate that the Long Valley/Mono Basin region never assumed the level of complexity recorded further to the south, and that the more mobile, egalitarian-type structure seems to have persisted until contact. So little is known about the ethnography of Long Valley, however, that its cultural affinities remain questionable: it may have held a permanent, autochthonous population (though certainly small) or it may have been a satellite zone to neighboring population centers (e.g. Owens Valley; see Basgall 1983; Bettinger 1982b; Hall 1983).

The archaeology of Long Valley provides support for the above characterization (Bettinger 1977; Davis 1964; Enfield and Enfield 1964; Cowan and Wallof 1974). Pre-Haiwee period occupation (Bettinger 1977; Jackson 1984).

seems to reflect short-term, probably resource-specific orientation rather than any permanent, functionally diverse subsistence-settlement strategy. It was only at the onset of the Haiwee period (ca. 1350 B.P.) that more substantial occupation sites (e.g. midden accumulations, extensive milling equipment, etc.) began to appear (Basgall et al. n.d.). Even then, the population of Long Valley must have been limited to several small bands or families.

The sole evidence of exotic sociotechnic artifacts in Long Valley comes in the form of shell beads from several sites (Basgall et al. n.d.; Davis 1964; Enfield and Enfield 1964). These items occur throughout the sequence, but perhaps show their greatest representation during the early part of the Newberry period (ca. 3150 to 1350 B.P.), a pattern that seems to hold for parts of the Basin (c.f. Bennyhoff and Hughes n.d.). We would submit that while the distribution of shell beads, reaching its maximum during this period, certainly marks exchange of some sort, it need not reflect development or operation of an elaborate trade network whereby Great Basin populations were producing and trading vast quantities of commodities. Rather, the adaptive strategy operative in much of the Basin during Elko-times would have been incongruous with such a system and such beads as are recovered probably gained their distribution purely as a result of the relatively great mobility of Elko populations and their concomitant need to maintain extensive social networks, perhaps as a "risk minimization" strategy (see Gould's (1978, 1980) discussion of the same phenomenon with respect to Australia).

In sum, sociocultural complexity seems to have developed, at its earliest, after ca. 1350 B.P. Further, there is no reason to believe that non-egalitarian organization east of the Sierra at any time reached levels reflected in regions to the west.

Western Sierra. On the western side of the Sierra, evidence for social complexity is more convincing. Analyses by Moratto (1972; Moratto et al. 1978) and King (1976, 1978) at Buchanan Reservoir demonstrated that the cemetery assemblages indicated an evolving social structure which fluctuated between egalitarian and non-egalitarian organization. They argued that social organization during the Chowchilla Phase (2800 - 1200 B.P.) was relatively complex, while the Raymond Phase (1400 - 500 B.P.) it became more egalitarian. Finally, during the Madera Phase (500 - 100 B.P.), organization again assumed greater complexity. This is an intriguing pattern, particularly in light of the radical reversals noted, and such shifts would presumably have been effected by the exchange of commodities through the area.

Central California. In central California a large amount of evidence exists regarding social complexity, but no systematic excavation nor research has even been carried out on those materials. Lacking that type of information, it is still apparent based on both ethnographic (cf. King 1972) and archaeological data (Beardsley 1948, 1954; Lillard, Heizer and Fenenga 1939; Heizer and Fenenga 1939) that within central California there was a significant degree of non-egalitarian social organization which appears in the prehistoric record at least by Middle Horizon times. Although data necessary for definitive characterization are lacking, it seems reasonable to suggest that the level of complexity in central California was at least comparable to, if not greater than that inferred for other regions under discussion.

Within the periphery of the Delta region, there is other evidence of non-egalitarianism developing contemporaneously with that in the "core area" (King 1970), as well as during the latter part of the historic period (Fredrickson 1974b). Such data add credence to inferences drawn from the Delta proper, and further indicate that central California exhibited considerable sociopolitical complexity from a very early time.

The Napa Valley Region. The archaeology of the Napa Valley region is not very well known (Heizer 1953), hence it is difficult to comment on the area's developmental prehistory. Limited ethnographic data suggest that some degree of social complexity existed among the Wappo (Driver 1936; Sawyer 1978), and although these could be extrapolated further, they do not indicate the extent of its antiquity. Thus, while ethnographic evidence exists for some organizational complexity late in time, it is not possible to address the earlier phases.

Summary. In terms of prehistoric political economies, there is ample evidence that portions of California were organized in a non-egalitarian mode from at least the Middle Horizon (or commensurate time-depths) on. Throughout this period one could argue that processes linked to intensification (e.g. Brookfield 1972) involved population growth and the corresponding use of a broader, perhaps less cost-effective resource base (e.g. balanophagy; see Basgall 1982b, 1984). These shifts may have allowed or even necessitated the development of sociopolitical complexity (cf. Basgall 1984; Cohen 1981; Dickel et al. 1983; Dumond 1972), in that they generated conditions permitting the first achievable resource surpluses. Concomitant with those processes would have been an escalation in interaction, with such activities as exchange, inter-marriage, and warfare becoming increasingly frequent. Furthermore, those networks of interaction would have increased in scope as well as intensity through time. It is apparent that those groups in California, as "independent" cultural systems, became ever more interdependent and more like a single, larger system.

Such organizational transitions would have had a direct impact on the type of articulation a group could support. For example, one would expect that in a non-egalitarian system there would be a special demand for sociotechnic commodities relative to the office and type of status they supported. It has been shown in northwestern California (Hughes 1978), and could be argued for central California as well, that obsidian objects functioned in such a status role. On the other hand, in an egalitarian hunter-gatherer system, one would not expect there to be the kind of status positions demanding various types of imports, nor the organizational arrangement to produce quantities of materials solely for export. These examples provide a cursory illustration of how a group's political economy could effect the production and exchange of obsidian artifacts, and therefore the broad patterning ultimately observed in the archaeological record.

Discussion

The major consumer area, and apparently the hub of a major portion of economic activity, was central California. It has been argued that the region was organized in a non-egalitarian manner and therefore possessed a concentrated demand for status goods. Based on burial associations, obsidian bifaces from eastern California were some of the objects which fulfilled that role during the Middle Horizon. They subsequently lost that status as Napa obsidian in more utilitarian forms became more prevalent and dominated the market.

In the east during that time span, what appears to be a production pattern reached a maximum between ca. 3000 B.P. and 1600 B.P. (Figure 3), during the Middle Horizon in central California. Production fell off during the ensuing periods in a manner paralleled by the decrease in relative frequencies of eastern obsidian in central California. As has been discussed, the eastern Sierra adaption during the Newberry period appears to have been linked to a very mobile hunter-gatherer strategy which was probably associated with an egalitarian social organization (contrast with Bettinger 1983), These circumstances would have worked to preclude the development or persistence of large-scale obsidian production.

On the western slope, the demands of non-egalitarian sociopolitical organization during the Chowchilla phase (Newberry period/Middle Horizon; Figure 6) seem to coincide with the production pattern seen in the east. Likewise, the simultaneous decrease in obsidian movement and shift toward egalitarianism suggests some type of relationship between the two changes.

The pattern in the Napa Valley region indicates an increase in obsidian production at approximately 2500 B.P. Initially this material entered the market and served in both status and utilitarian roles. Ultimately, however, after the Napa source reached the point of supplying most of central California with raw material and obsidian artifacts, obsidian began to lose its position as a status marker. That is, at the same time eastern obsidian decreased in relative frequency and became less popular as a status object, Napa glass took over in quantity and served principally in utilitarian functions.

The sequence of events outlined above represents the range of data supplied by the archaeological record. The overall pattern now requires explanation or, at least, interpretive elaboration. Several scenarios will be explored for each region, both with respect to independent, region-specific patterns and in terms of the more general obsidian fluctuations exhibited throughout the entire area under examination.

Western Region. Two scenarios could account for the pattern seen in the western region -- one in which the assumption is made that eastern obsidian was cut-off from central California, and the other in which no such assumption is necessary.

In the first case, it could be argued that the resulting obsidian "vacuum" in central California would have forced the occupants of that region to direct attention toward the Napa Valley in an effort to maintain the social institutions/obsidian functions already in existence. While central California was never devoid of Napa glass, during the Middle Horizon it was certainly of secondary importance with respect to eastern material. That Napa did replace eastern obsidian during the Late Horizon suggests that such redirection did, in fact, occur. If the needs/demands of the central California population were principal, it implies that such factors acted in some fashion to coerce Napa Valley occupants to escalate their production and participate in an exchange process of much larger scale than that operating earlier. Further, the contextual shift in the role of obsidian during the later prehistoric period suggests that the scale and the intensity of this production was greater than that necessary to fulfill mere status support, so large that it swamped the market and changed the whole tenor of the original demands or functions. This exaggerated production would have presumably resulted, at least in part, from a feed-back relationship between the two regions; Napa residents may have exported greater amounts of obsidian, not to meet central California wants, but to support their own extant (or developing) sociopolitical structure.

Alternatively, residents of the Napa Valley may have begun to develop, completely on their own and without central California intercession, a greater productive capacity and thus of their own accord exported relatively more obsidian into the latter region. This is not to say that central California consumer demands/needs were non-existent or irrelevant, or that once started a feed-back relationship did not evolve, only that *in situ* North Coast Range developments or transformations were of primary importance. Such escalation in Napa production, occurring concomitantly with continuing eastern production, could in turn have inflated the value of both materials, thus lessening their worth as status markers. This decline in relative obsidian value could then have been responsible for the drop in eastern imports as well as the lower frequency of higher quality obsidian artifacts in grave lots.

Eastern Region. In elaborating the pattern at the eastern node of this proposed network, the principal concern is with explaining the fall-off in Casa Diablo production. Two general kinds of scenarios can be suggested: those attempting to simply correlate the production decrease (and concomitant sociopolitical shifts) with environmental/climatic change, and those exploring cultural interactions and their consequences.

We have argued that the peak of production in the eastern Sierra, linked to an adaptation stressing high mobility, extensive (as opposed to intensive) social networks, and minimal or non-existent territoriality, would have been incongruous with the development or persistence of a large-scale production system in which Paiute (or predecessor) groups were the "producers." In fact, it appears likely given these parameters that groups residing on the western slope travelled to the east to obtain Casa Diablo obsidian and carried it back to the west side themselves (Basgall 1983). This would be an example of direct access, an exchange mode (Clark 1979; Ericson 1977a; Hodder 1974; Renfrew 1977) which up to this time has remained difficult to trace archaeologically. It appears, then, that groups residing on the western slope (e.g. Buchanan Reservoir area and such) were the real suppliers of eastern obsidian to central California and the San Francisco Bay area.

Moratto et al. (1978) have suggested that disruption of the Chowchilla phase adaptation could be tied to climatic change, in particular the onset of an interval of warm, dry conditions after ca. 1400 B.P. During this "drought" period (Raymond phase) occupation was reflected by greater demographic fragmentation, and, perhaps, lower population density (though see

Schulz 1981). Sociopolitical complexity and population amalgamation only returned after ca. 500 B.P. (during the Madera phase) when cooler/moister conditions reappeared.

This scenario has already been critiqued (e.g. Byrne 1979; Hall 1983; Schulz 1981), there being good reason to believe that prehistoric environmental fluctuations were much more complex than the authors suggest. A further, and perhaps more telling, criticism focuses on the rather cavalier manner in which Moratto et al. (1978) tied culture change to environmental shifts. By simply equating the two phenomena, without actively exploring the logical consequences of the culture-environment interaction, they have failed to evaluate the broader range of cultural factors that may have been relevant. With respect to the present problem it is important to consider the potential effects/function of obsidian exchange in the development and persistence of sociopolitical complexity among western slope populations.

If western slope groups were the principal producers and suppliers of eastern obsidian, disruption in either the availability of that obsidian or the organizational/demographic structure operative in the western Sierra region, would have had ramifications for central California and Bay area populations. In exploring the first possibility -- that access to Casa Diablo obsidian was restricted or cut-off -- we can again refer to both environmental and cultural factors.

Hall (1983) has presented a provocative argument suggesting that volcanism in the Mammoth Lakes/Long Valley region during the later prehistoric period acted to truncate access to the Casa Diablo source. While he does not argue that western slope populations were directly impacted, Hall does propose that eruptions in the period between ca. 1900 and 500 B.P. did preclude Long Valley populations from producing obsidian at previous levels (or, alternatively, kept western groups from attaining direct access to the resource?). In sum, Hall's (1983) model largely relies on late Holocene eruptions in eastern California to account for the decline in Casa Diablo production and distribution.

Alternatively, the pattern in obsidian production/distribution in the general eastern/western Sierra region could have been the result of *in situ* cultural transformations or adaptive shifts. With respect to the eastern Sierra we can propose that greater territoriality developed concomitantly with the sociopolitical elaboration seen (at least in Owens Valley) in later prehistoric and ethnographic times -- or as a result of the more extensive resource consolidation and intensive land-use patterns suggested by Bettinger and Baumhoff's (1982) "Numic model" -- thus establishing conditions of restricted access for western slope peoples. Without the option of direct access, and if Long Valley/Owens Valley groups were uninterested or incapable of large-scale production, such circumstances would have contributed to a decrease in the flow of Casa Diablo obsidian. That a more spatially restricted production (with lesser magnitude?) and exchange system did develop later in time is indicated by the ethnographic record (Barrett and Gifford 1933; Davis 1961; Gayton 1948a, 1948b; Steward 1933, 1934), but the overall character of this differs markedly from that suggested for earlier periods. Further, obsidian was apparently a minor commodity ethnographically, salt being the principal exchange item (Bettinger 1982b; Steward 1933, 1934).

Finally, the possibility of population intrusions or replacements in the western Sierra may have contributed to the pattern seen, certain linguistic data (Levy 1979; Whistler 1977) suggesting such an intrusion/replacement may have occurred during the critical time frame. The problem has not been thoroughly examined, however, though it remains provocative. While such a situation might not result in complete termination -- even temporarily -- of obsidian movement, it could certainly generate disruption in the set pattern and lead to considerable reduction in production and exchange levels. The economic ties maintained during previous periods would have been severed, and while perhaps quick to re-develop, would only do so with time and then perhaps toward the structure seen in the Madera phase archaeology and ethnographic record.

Summary. As the above review portrays, many factors could account for patterns shown in any one region or distributions exhibited by any given source locale. In terms of the Napa Glass Mountain and Casa Diablo sources focused on in this study, we have ended up with two rather different synthetic models that could explain the observed macro-patterns. Both of these revolve around the inferred relationship between the character of Napa Glass Mountain production and central California populations, one being ostensibly divorced from developments in the Sierran region and the other being inextricably linked to the same.

According to the first possibility, the acceleration and expansion of Napa production/distribution was seen to be principally the result of *in situ* cultural transformations that spurred residents of the Napa Valley region into intensifying their participation in the central California market. While central California consumer needs and demands were important, it is significant that the occupants already had access to eastern obsidian. As such, the primary rationale for the shift should probably be seen in a developing level of social complexity in the North Coast Ranges. Once initiated there would, of course, have been a feed-back relationship between the two regions which might account for the high production ultimately achieved. As obsidian became "cheaper" with quantity it also began to assume functions commensurate with its inflated value. It should be stressed that according to this model western developments were independent of conditions in the east, or, more properly, they were the major determinants of the obsidian patterns exhibited in the Sierra. Quite simply, if the market for eastern obsidian disappeared, becoming too expensive relative to Napa material, Casa Diablo production would have naturally fallen off.

The alternative model suggests that developments in the Sierra were crucial to central California systems and, by extension, to what generated the increased production and distribution of Napa glass. The escalation of Napa production is seen to have occurred after eastern obsidian had become scarcer or even cut-off from central California populations. This void in a material of presumed importance to maintenance of the region's complex social institutions was subsequently filled through expanded use of Napa obsidian, suggesting that the increased

North Coast Range production was perhaps closely related to needs or demands of central California groups. One significant question is left unaddressed by this scenario: what caused the original decline in Casa Diablo production?

In discussing the Sierran region, we concluded that adaptive patterns expressed in central-eastern California during the period of peak production were inconsonant with the kinds and levels of production indicated by the archaeological record. As a result, we suggested that it was western Sierran populations, obtaining obsidian through direct access, that were both the producers and suppliers of Casa Diablo obsidian which reached central California during the Middle Horizon. Based on this foundation, several attendant scenarios were examined to account for the production decline: that of environmental collapse in the western Sierra, disrupting the Chowchilla phase adaptation; that of volcanism in the Long Valley/Mono Basin region which precluded efficient access to the Casa Diablo source; that of increasing societal complexity, together with more pronounced territoriality, east of the Sierra that curtailed the free access of earlier periods; and, finally, that of population intrusion/replacement in the western Sierran region, disrupting and at least temporarily truncating the elaborate exchange system working in Chowchilla times.

While the data necessary to formally and fully test and evaluate either the major models or their attendant scenarios are currently unavailable, certain of the proposals seem to possess greater theoretical and logical strengths than others.

Conclusions.

Discussions have been presented thus far regarding our own leanings toward economic articulation, the archaeology of California, and the possible scenarios which might function as explanatory models. Of these, some of the more simple models just reviewed could account for the patterns observed in the archaeological record. It seems more appropriate in terms of the available archaeological and ethnographic data, however, to envision a sequence of processes involving all parts of this economic network. While it is presently difficult or impossible to define the precise nature of a population replacement in the western Sierra, if it occurred it probably did so after access to the Casa Diablo resource area was becoming more restricted. This would have happened concurrently while the economic system in Napa Valley grew in capacity and made a more concerted effort at participating in the central California market. Ultimately, the feed-back between the faltering eastern suppliers and the more aggressive westerners would have accelerated and completed the processes for both.

By most evaluations, the archaeological record in portions of California is somewhat incomplete. Consequently, in certain portions of this analysis, assumptions were made regarding the types of behavior expected from a cultural system and to the manifestation of human behavior in the archaeological record. Although for some, those assumptions may number too many, we argue that they are basically sound and that such steps are necessary to grasp an understanding of cultural systems which lack an "adequate" archaeological record.

It is well recognized that in cultural systems, production and exchange are two of the primary structural components. As one studies the role of exchange within any system, we must not only distinguish its nature, i.e., what, from whom, to whom, etc., but also its structure, i.e., the context of its production, distribution, and consumption (Kohl 1975). These are important concepts for any reasearch, and specifically for obsidian in California. To date, archaeologists have documented the nature of obsidian exchange, but its structure is only beginning to be understood. If we are to grasp a more complete understanding of evolutionary prehistory, we must ultimately account for both internal developments and external contexts; evaluations must be made of economies in articulation and not in isolation. Within that framework, research into the prehistory of California can assume a stance whereby processes and explanations can become an obtainable goal.

Acknowledgements

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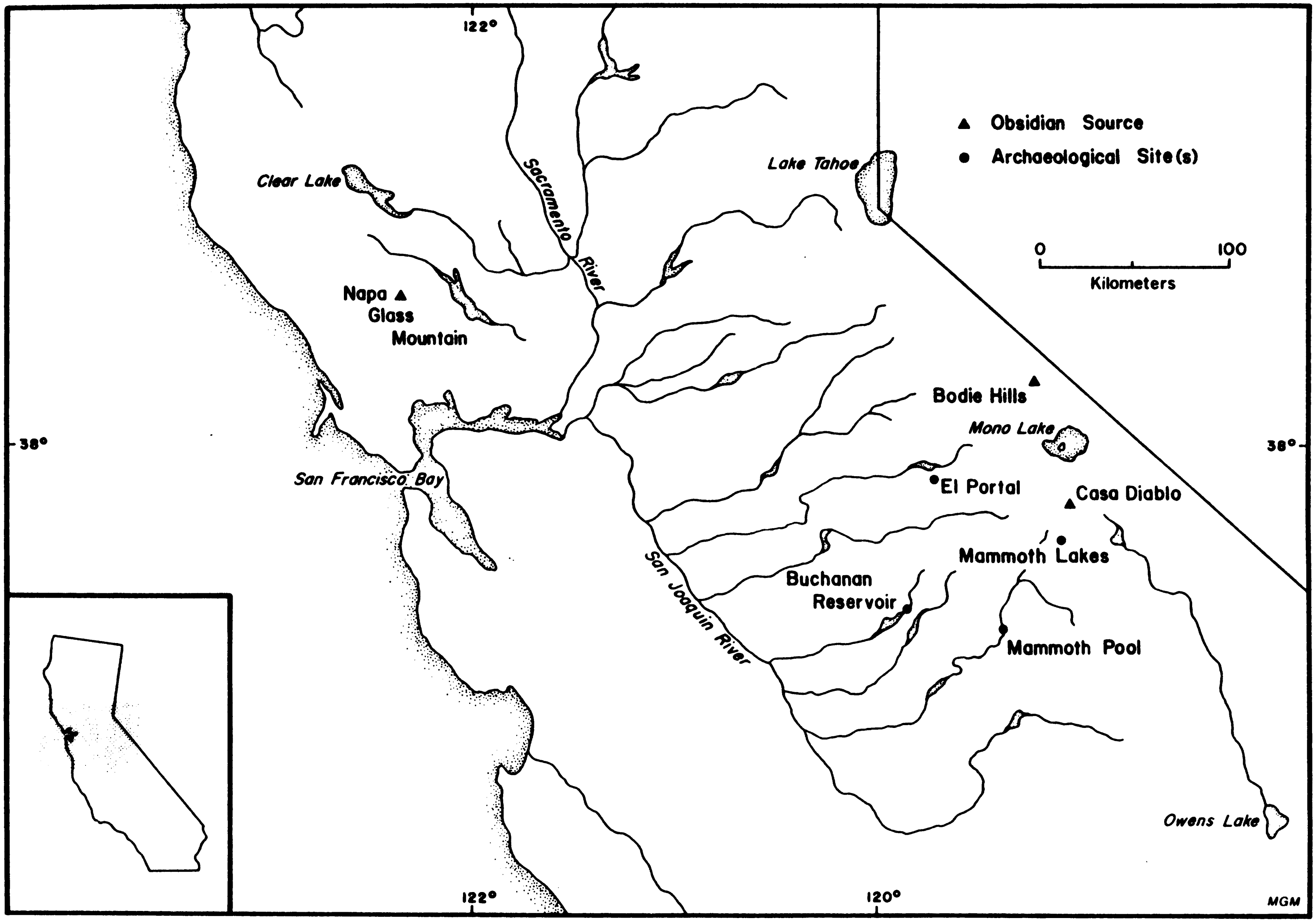

Figure 1. Map of California showing the principal locations discussed in the text.

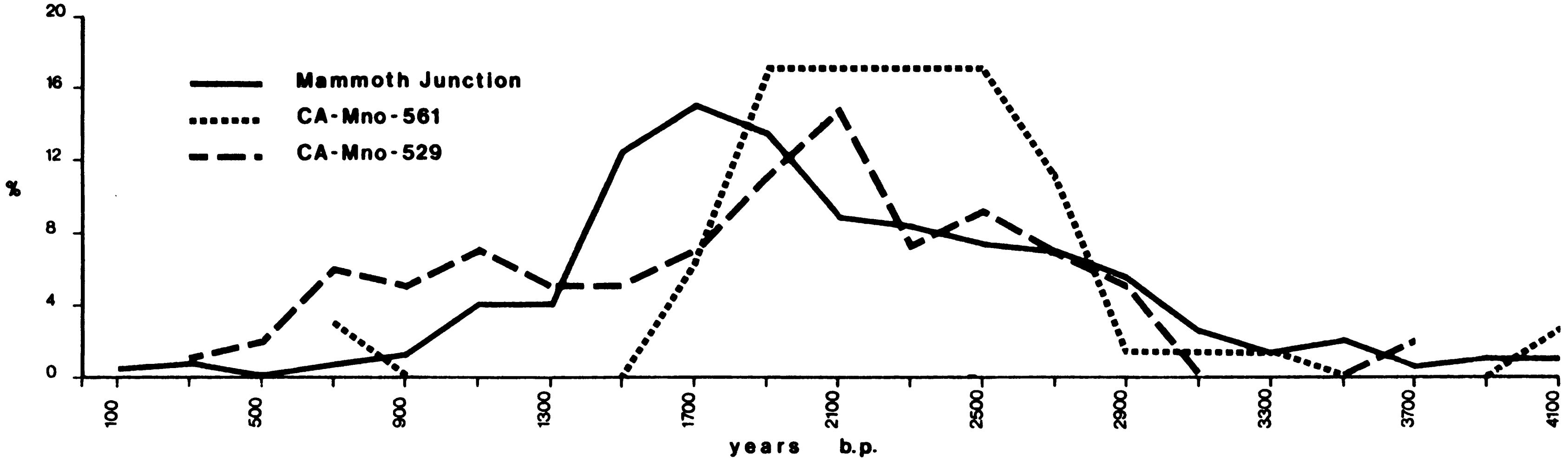

Figure 2. Temporal distributions of Casa Diablo obsidian production for three sites in the Mammoth Lakes region of central-eastern California (based on the hydration proposed by Hall (1983).

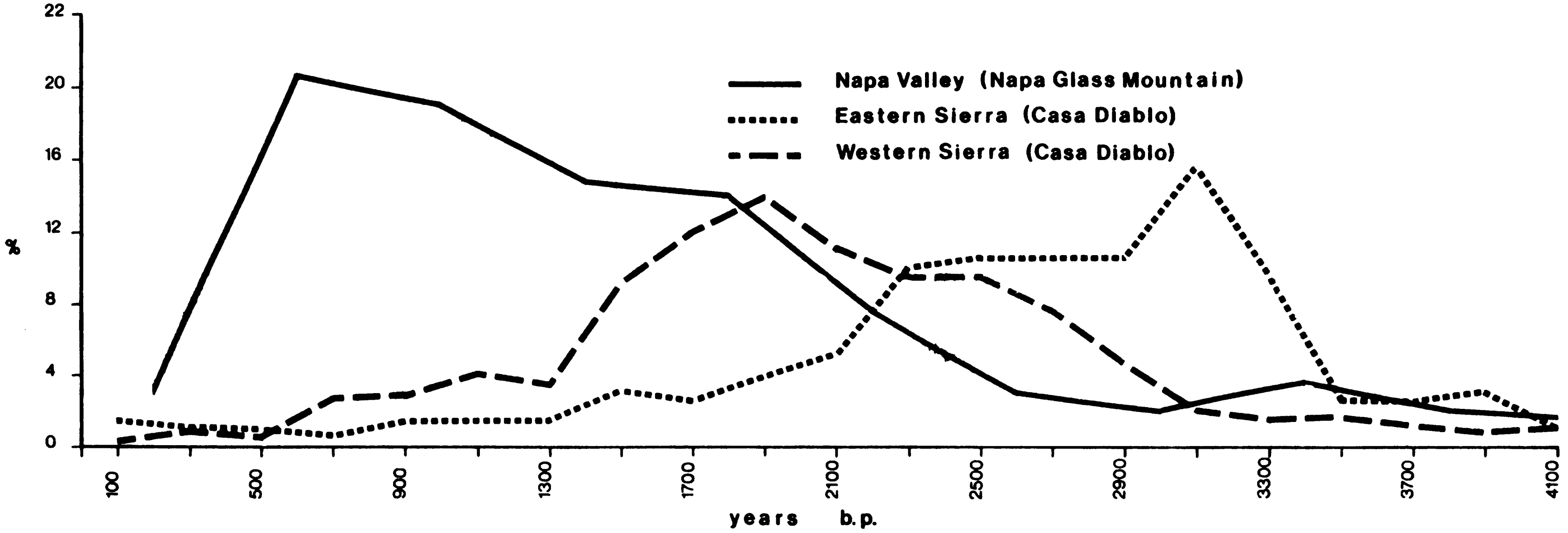

Figure 3. Temporal distributions of obsidian frequencies for Casa Diablo and Napa Glass Mountain within the three regions of California discussed in the text.

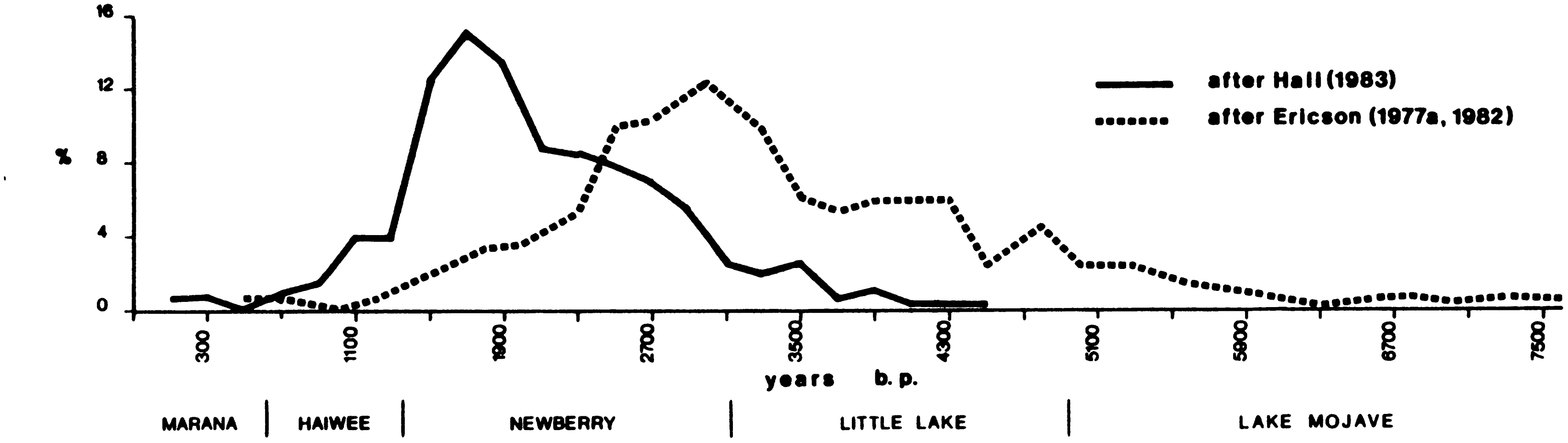

Figure 4. Variation by chronological period of Casa Diablo production as depicted by Hall's (1983) hydration rate versus Ericson's (1977a) of 1000 years/micron.

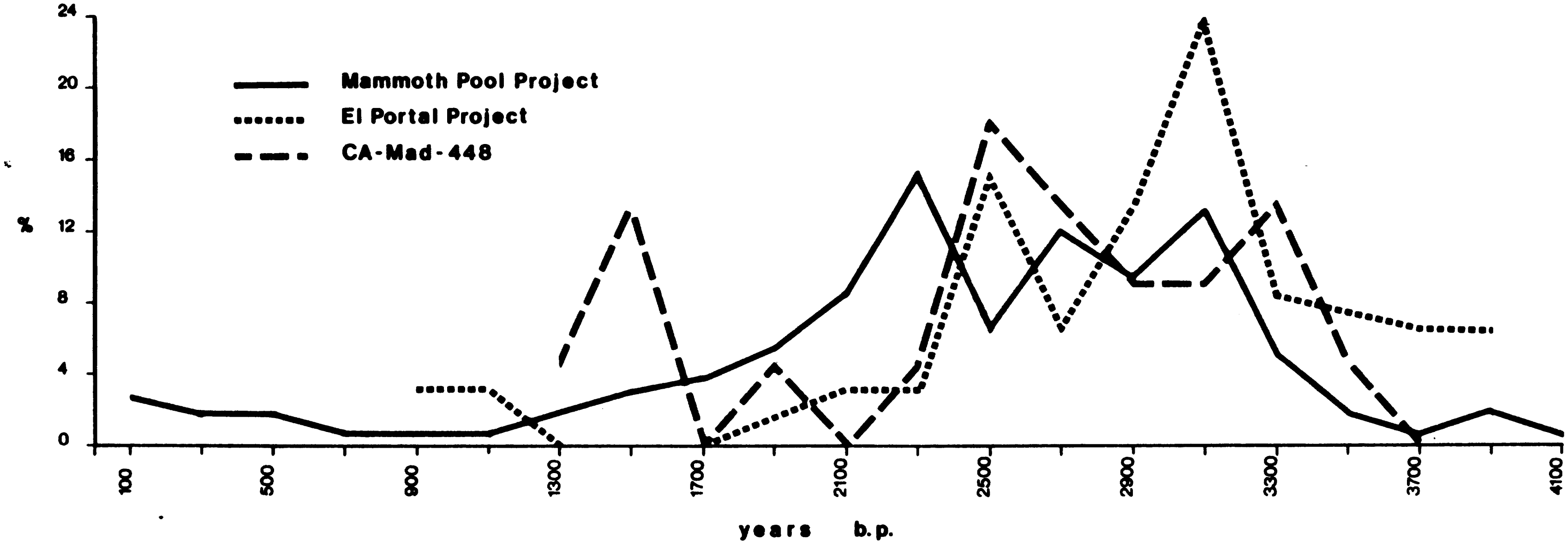

Figure 5. Temporal distributions for Casa Diablo obsidian production/consumption in three areas on the western slope of the Sierra Nevada.

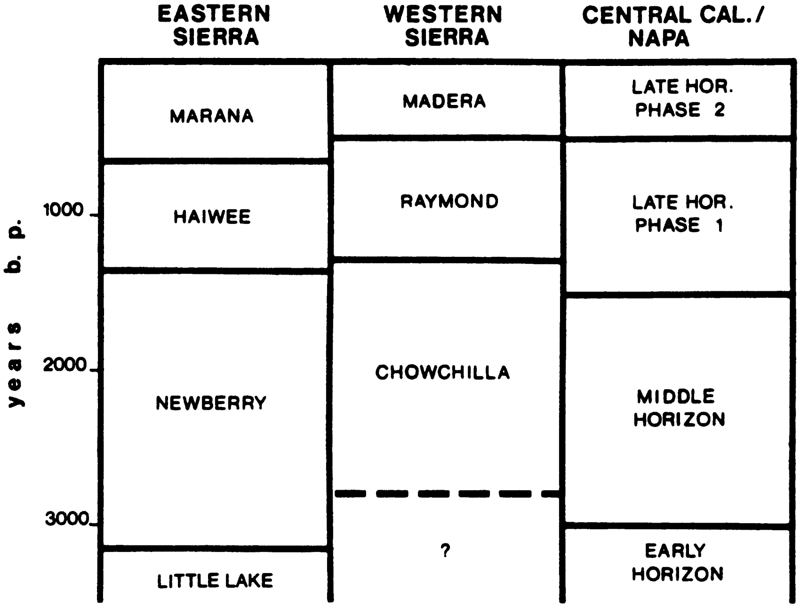

Figure 6. Comparison of chronological sequences for the three regions discussed in the text.

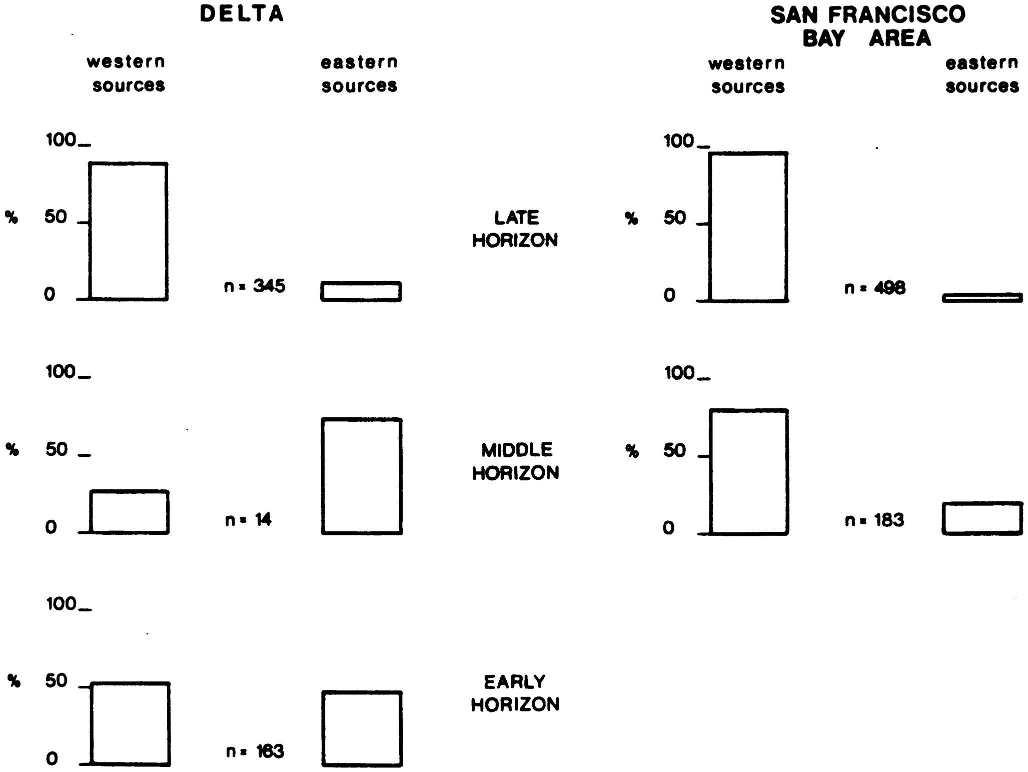

Figure 7. Percentages of obsidian from eastern and western sources by temporal period for central California (see Table 5 for specific percentages).

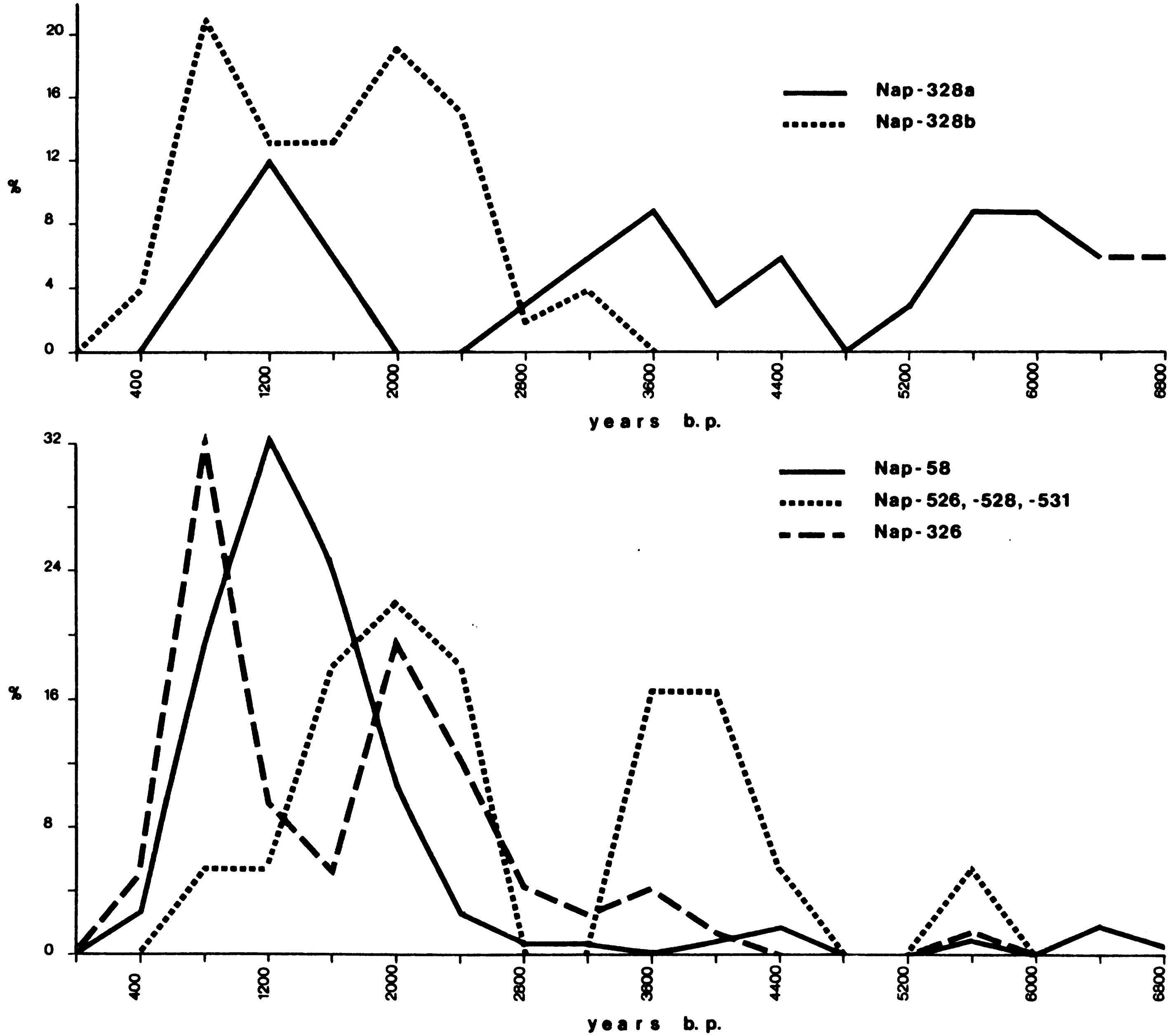

Figure 8. Temporal distributions for Napa Glass Mountain obsidian production at six sites in the Napa Valley.

Equation	Formula	Constants		Source
		Casa Diablo	Napa	
1	$T = aX^{1/2}$	$a = 487.280$	$a = 1112.325$	Ericson (1977a)
2	$T = bX$	$b = 111.0$	$b = 670.0$	Ericson (1977a)
3	$T = cX^{1.33}$	$c = 127.806$	$c = 466.960$	Ericson (1977a)
4	$T = dX^2$	$d = 39.532$	$d = 211.602$	Ericson (1977a)
5	$t = eX^3$	$e = 6.432$	$e = 57.183$	Ericson (1977a)
6	$T = f(X^2 - X)$	$f = 47.126$	$f = 298.541$	Ericson (1977a)
7	$T = gX^h$	$g = 386.189$	$g = 42.825$	Ericson (1977a)
		$h = 0.671$	$h = 3.287$	
8	$T = iX^2$	N/A	$i = 153.4$	Origer (1982)
9	$T = X^2(1000)/j$	$j = 3.51$	$j = 4.16$	Michels (1982a, b)
10	$T = kX + 1$	$k = 665.41$	N/A	Garfinkel (1980)
		$l = - 745.00$		
11	$T = mX + n$	$m = 700.00$	N/A	Basgall (1983)
		$n = -933.6$		
12	$T = oX + p$	$o = 668.54$	N/A	Hall (1983)
		$p = - 637.30$		
13	$T = X(1000)$		N/A	Meighan (1981)

Table 1. Proposed obsidian hydration rate formulas for the Casa Diablo and Napa Glass Mountain sources. T = years B.P.; X = micron measurement.

Specimen	Site	S/S-S	Type	Rind[a]	Eq 1	Eq 2	Eq 3	Eq 4	Eq 5	Eq 6	Eq 7	Eq 9	Eq 10	Eq 11	El 12	Eq 13
L-197	Mno-446	S-S	E	4.38	1020*	486*	911*	758*	540*	698*	1040*	5466*	2169	2132	2291	1226*
L-454	"	S-S	E	5.31	1123*	589*	1177*	1115*	963*	1078*	1183*	8033*	2788	2783	2913	1487
109-14	Iny-2146	S	E	5.50	1143*	610*	1234*	1196*	1070*	1166*	1212*	8618*	2915	2884	3040	1540
294-4	Mno-529	S	EG	2.30	739	255*	387*	209*	78*	141*	675	1507*	785	676	900	644
294-5	"	S	CT	1.50	597	166	219	89*	22*	35*	506	641*	253	116	365	420
294-6	"	S	E	4.40	1022*	488*	917*	765*	547*	705*	1044*	5516*	2183	2146	2304	1232
294-7	"	S	LL	6.80	1271*	755*	1636*	1828*	2022*	1859*	1398*	13,174*	3780	3826	3909	1904*
294-336	"	S	DSN	1.20	534	133	163	57*	11*	11*	436	410	53*	-94*	165	336

Note: S/S-S = Surface/Sub-Surface;
Type: E = Elko Series, 1350 - 3150 B.P.; EG = Eastgate Series, 650 - 1350 B.P.;
CT = Cottonwood Series, 100 - 650 B.P.; DSN = Desert Side-Notch, 100 - 650 B.P.;
LL = Little Lake Series, 3150 - 4950 B.P. All dates in years B.P.

* Denotes dates in disagreement with typological temporal ranges.

[a] Measurements in microns (µm).

Table 2. Selected specimens from Great Basin projectile point series tested against available hydration rates for the Casa Diablo quarry source. All sites are located in central-eastern California.

Region/Project	Hydration reading frequencies																				
	0.00-1.25	1.26-1.55	1.56-1.85	1.86-2.15	2.16-2.45	2.46-2.75	2.76-3.05	3.06-3.35	3.36-3.65	3.66-3.94	3.95-4.24	4.25-4.54	4.55-4.84	4.85-5.14	5.15-5.44	5.45-5.74	5.75-6.04	6.05-6.34	6.35-6.64	6.65-6.94	>6.94
EASTERN SIERRA																					
El Portal					2	2			1	1	2	2	9	4	8	10	5	2	4	4	
CA-Mad-448							1	3		1		1	4	3	2	2	3	1			1
Mammoth Pool	3	2	2	1	1	1	2	3	4	6	9	16	7	13	10	14	6	2	1	2	1
WESTERN SIERRA																					
CA-Mno-561				2					4	11	11	11	11	7	1	1	1				2
Mammoth Junc.[1]	1	2		2	4	12	12	37	44	39	26	25	23	21	16	7	5	7	2	3	3
CA-Mno-529																					
Flakes		1	2	6	3	7	5	5	7	11	14	7	9	7	5				2		
Bifaces		1	1	1	1				2	5	2	2	2	1	1	2	1	1	1		

Note: [1] Data from the Mammoth Junction site, the assemblage of which is unsourced, are from all formal tools except projectile points (e.g. "knives", "choppers", "scrapers", etc.). Whereas the former artifact classes typically reflect local material/manufacture consistently, points often do not (Basgall 1983; Hughes and Bettinger 1984) hence their exclusion. All other data come from flakes/debitage unless otherwise noted.

Table 3. Hydration data from Casa Diablo obsidian used in characterizing the production/consumption patterns for that source. Original sources of data presentation for these sites/projects are cited in the text. Measurements in microns (μm).

Temporal Period	Site	n	Obsidian Sources (%)								Source region (%)		Source region (% of total)	
			West			East								
			N	A	BL	BOD	CD	MH	MO	Q	W	E	W	E
Early Horizon	SJo-56	5	20.0			60.0	20.0				20.0	80.0		
	SJo-68	87	73.6	1.2		19.5	3.5	1.2	1.2		74.8	25.4		
	SJo-145	46	58.7	6.5		19.6	8.7	2.2	4.4		65.2	34.9	53.3	46.7
E-M Transition	SJo-91	25	12.0	4.0		28.0	40.0	8.0	8.0		16.0	84.0		
Middle Horizon	Sac-66	14	35.7			21.4	21.4	14.3	7.1		35.7	64.2	25.9	74.1
Late Horizon	Sac-6	45	88.9		2.2	6.7		2.2			91.1	8.9		
	Sac-29	75	86.7	1.3		1.3	4.0	2.7		1.3	88.0	9.3		
	Sac-99	62	91.3			3.0		1.8	3.9		91.3	8.7		
	Sac-145	43	83.8	2.3		9.3	2.3	2.3			86.1	13.9		
	Sac-225	42	57.2	2.4		28.6	7.1	4.8			59.6	40.5		
	Sac-267	24	87.5		4.2	4.2	4.2				91.7	8.4		
	SJo-43	13	100.0								100.0			
	SJo-80	10	90.0						10.0		90.0	10.0		
	SJo-82	8	87.5						12.5		87.5	12.5		
	SJo-91	23	91.3			4.3	4.3				91.3	8.6	87.9	12.1
													(2 unknowns)	

Note: N = Napa; A = Annadel; BL = Borax Lake; BOD = Bodie Hills; CD = Casa Diablo; MH = Mount Hicks; MO = Mono Glass Mountain/Craters; Q = Queen; W = Western; E = Eastern.

Table 4. Obsidian source data for Central California Delta sites (after T. Jackson 1974: Table 15).

County	Site	Horizon	Sample	% Western	% Eastern
Mrn	170 201 209 216 232 234 298 402	Late	194	100.0	0
SMa	100 125 140		68	89.1	10.9
CCo	138 259 308 312 297		199	98.5	1.5
Ala	329		37	94.6	4.2
TOTALS			498	95.8	4.2
Mrn	26 27 168	Middle	49	98.8	1.2
SMa	77		6	33.3	66.7
CCo	268 269 270 271 298		36	91.7	8.3
Ala	12 13 307 309 328		92	73.1	26.9
TOTALS			183	80.0	20.0

Table 5. San Francisco Bay Area obsidian for western and eastern source regions (data for Marin, San Mateo, Contra Costa, and Alameda Counties; after Banks and Orlins 1979, 1980; and Jackson 1974).

Specimen	Site	Type	Rind [a]	Eq 1	Eq 2	Eq 3	Eq 4	Eq 5	Eq 6	Eq 7	Eq 8	Eq 9
2319	Son-456	CN	1.1	1167*	737*	530*	256	76*	33*	59	186	291
2621			1.4	1316*	938*	731*	415	157	167	129	301	471
2851			1.0	1112*	670*	467*	212	57*	0*	43*	153	240
3026			1.7	1450*	1139*	946*	612*	281	355	245*	443	695*
3154			1.3	1268*	871*	662*	358	126	116	101	259	406
2272	Son-456	SER	1.8	1492	1206	1020	686	333*	430	296*	497	779
2865			1.6	1407	1072	872	542	234*	287	201*	393*	615
3002			2.5	1759*	1675*	1580*	1323	893	1120	870	959	1502
3170			2.2	1650*	1474	1333	1024	609	788	572	742	1163
3235			1.5	1362	1005	801	476	193*	224	162*	345*	541
2061	Son-456	EX	3.0	1972	2010	2013	1904	1544	1791	1585	1381	2163
2118			3.3	2021	2211	2285	2304	2055	2266	2168	1671	2618*
2217			2.3	1687	1541	1414*	1119*	696*	893*	662*	811*	1272*
2510			2.9	1894	1943	1924	1780	1395*	1645	1418*	1290	2022
2504	Son-466		3.4	2051	2278	2378	2446	2248	2436	2391	1773	2779*
33	Son-655	CON	2.8	1861*	1876*	1837*	1659*	1255*	1505*	1263*	1203*	1885*
210			2.6	1794*	1742*	1664*	1430*	1005*	1242*	990*	1037*	1625*
160	Son-1048		3.1	1958*	2077*	2103*	2033*	1704*	1944*	1765*	1474*	2310*
169			4.3	2307*	2881	3249	3913	4546	4236	5175*	2836	4445
13-10	Son-358		4.2	2280*	2814	3149	3733	4237	4012	4790	2706	4240

Note: CN = Rattlesnake Corner-Notch series, 100 - 500 B.P.; SER = serrated corner-notch forms, 500 - 1500 B.P.; EX = Excelsior series, 1500 - 2500 B.P.; CON = Mendocino Concave Base series, 2500 - 5000 B.P. All dates in years B.P.; * Denotes dates in disagreement with typological temporal ranges; [a] Measurements in microns (μm).

Table 6. Selected specimens from North Coast Range projectile point series tested against available hydration rates for the Napa quarry source. All sites are located in Sonoma County (after Origer 1982).

Site	Hydration reading frequencies															
	0.00-1.37	1.38-1.94	1.95-2.38	2.39-2.75	2.76-3.07	3.08-3.37	3.38-3.64	3.65-3.89	3.90-4.12	4.13-4.35	4.36-4.56	4.57-4.76	4.77-4.96	4.97-5.14	5.15-5.33	5.34-5.50	> 5.51
Nap-328a		2	4	2			1	2	3	1	2		1	3	3	2	8
Nap-328b	2	11	7	7	10	8	4	1	2								1
Nap-326	4	23	7	4	14	9	3	2	3	1				1			1
Nap-58	3	22	37	28	12	3	1	1		1	2			1		2	1
Nap-526 Nap-528 Nap-531		1	1	2	4	2			3	3	1			1			

Table 7. Hydration data from Napa Glass Mountain obsidian used in characterizing the production/consumption patterns for that source (after R. Jackson 1982). All sites are in Napa County (frequencies for sites Nap-526, Nap-528, and Nap-531 are combined). Measurements are in microns (μm).

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OBSIDIAN HYDRATION: APPLICATIONS IN THE WESTERN GREAT BASIN

Robert J. Jackson

Abstract

Despite the many unresolved problems with obsidian hydration analysis, archaeologists can usefully apply the technique to produce chronological data. While perhaps not as accurate as radiocarbon dating, the cautious use of obsidian hydration may be a practical and relatively accurate means of placing prehistoric site occupation and obsidian artifacts within a cultural context, which should be the major goal of archaeological dating. Two methods for developing dating schemes are discussed for the Casa Diablo obsidian source in central-eastern California.

Introduction

For many years archaeologists have worked at developing obsidian hydration rates in an attempt to 'elevate' obsidian hydration from a relative dating technique to an absolute chronometric dating tool (cf. Michels and Tsong 1980). Despite these attempts, there are currently no sources in California or the western Great Basin for which obsidian hydration rates apply without contention and debate. The reasons for this are many, including problems inherent in the physical process of hydration, paucity of well controlled, directly associated, radiometrically dated samples, and an inability (and/or unwillingness) to control several critical variables in the measurement and rate calculation process. Many of these problems have been discussed elsewhere in this volume.

Current literature is characterized by polemics over the accuracy of proposed hydration rates and new rate proposals. Numerous rates have been developed for certain obsidian sources but, to date, there have been few attempts to assess their relative accuracy (cf. Ericson 1977; Michels and Tsong 1980; Meighan 1983).

What has been lacking in many published obsidian hydration studies of the last decade are practical applications that address archaeological problems, such as the identification of cultural periods of prehistoric site occupation, detailed analyses of cultural stratigraphy, or stone tool manufacturing technologies and histories. These applications are commonly espoused, but seldom undertaken (cf. Michels and Bebrich 1971). I believe archaeologists have pursued long range goals of absolute rate determination without realizing many short-term relative dating benefits. Relative dating with obsidian hydration is an effective means of accumulating hydration data necessary for evaluating absolute hydration rates, and at the same time it provides archaeologists with a temporal ordering tool.

Background in Application of Hydration Data

Initial investigations into the process of obsidian hydration by Friedman and Smith (1960) demonstrated that hydration accumulated from a freshly exposed surface, but the data base with which they were working required temporal expansion in order to determine if increased hydration rind thickness correlated with greater time of obsidian surface exposure. It was during the course of these investigations that Friedman and Smith called upon archaeologists to supply obsidian specimens of known age (from radiocarbon-dated burials) so that the rate of hydration could be accurately determined.

Hydration measurements were obtained from obsidian artifacts excavated from a deep, stratified archaeological site in southwest Equador (Evans and Meggers 1960). Friedman and Smith (1960: 477) found that the deepest stratigraphic levels correlated with thicker hydration rinds than did specimens from shallower depths. These data suggested that hydration rates might be discernible, creating initial archaeological interest in obsidian hydration as a dating method. Donovan Clark, then a graduate student in archaeology at Stanford University, studied central California archaeological obsidian specimens with the goal of developing a regional hydration rate and a chronometric dating tool. Clark's (1961) contributions included the use of hydration to compare ages of regional sites. He also examined obsidian artifacts from burial lots, demonstrating that hydration thickness variance between lots was much greater than that within burial lots. The results of Clark's analysis led him to propose a general hydration rate for central California obsidian that differed from Friedman and Smith's (1960) general diffusion rate ($x=kt^{1/2}$). Clark's (1961, 1964) work set the stage for the ongoing controversy over the appropriateness of a universally applicable diffusion equation. Perhaps the most important of Clark's (1961) contributions was the discovery of the potentially profound effect intersource chemical variation may have on the hydration rate of rhyolitic obsidians. Unfortunately, this observation was largely ignored by archaeologists, many of whom became disenchanted with obsidian hydration due to inconsistencies and anomalies in hdyration data.

Discouraged by the problems with using obsidian hydration as an absolute dating technique, Michels (1965) investigated its potential as a relative dating tool. Michels studied hydration on more than 450 artifacts from the Mammoth Junction site in Mammoth Lakes, California. Since Mammoth Junction was located in close proximity (ca. 100 meters) to abundant Casa Diablo obsidian deposits, all specimens were assumed to have been fashioned from this source material. Michel's (1965, 1967) research suggested numerous applications for hydration data, but also indicated the need for large numbers of measurements. Mammoth Junction data was subsequently used in attempts to develop an absolute hydration rate for Casa Diablo obsidian (Garfinkel 1980; Basgall 1983).

Recent Approaches

Archaeological applications of obsidian hdyration data have burgeoned since the mid-1960's, ranging from use of the method as a relative dating tool, to attempts to develop and apply absolute, source-specific hydration rates.

Different approaches to hydration rate formulation have also been made. One involves rate determination through archaeological assessment using radiocarbon, whereby obsidian in direct, datable archaeological contexts (such as hearths or burials) is subject to hydration analysis and geologic source determination and correlation between hydration and archaeological feature dates are used to construct hydration rate curves (Ericson 1975, 1977; Kimberlin 1971, 1976; Findlow et al. 1982; Origer 1982; and others). The chief problem with this approach is the limited available data upon which rates are constructed. Direct associations between datable carbon samples and obsidian artifacts are either rare, as in the case of hearth features, or increasingly inaccessible due to the current political climate (i.e. burial lots). Ericson (1977), for instance, attempted to evaluate existing obsidian hydration rate formulae for several California obsidian sources using radiocarbon dates and obsidian 'associations.' While his definitions of direct and stratigraphic association are nowhere clearly stated:

> The criteria of association was that an obsidian artifact to be included had to have the same unit-level provenience as a given radiocarbon date. Generally, units ranged from 5 x 5 to meter-square and levels ranged from 10 centimeters to 6 inches...If the stratigraphy was complex, inverted or disturbed as to cultural integrity or if the artifacts were "fire-burned" or other anomalies were observed, then the data were not included (Ericson 1977: 39).

Thus, he apparently considered a direct association to be one in which an obsidian specimen co-occurred with a radiocarbon sample in the same 10 cm level of an excavation unit. Such a definition of association falls beyond that accepted by many archaeologists. Examination of Ericson's data set reveals significant discrepancies between intrasource specimens obtained in this manner. For example, he associated Casa Diablo obsidian hydration values as disparate as 8.9 microns with a C14 date of 1440 A.D. and 1.07 microns with a date of 1425 A.D. (Ericson 1977: 350-369). Ericson derived means for several hydration values associated with specific radiocarbon dates, and while this procedure may have moderated the apparent discrepancies, it also may have distorted the hydration rates. Despite these problems, Ericson brought together and compared a large body of useful archaeological data and considered many important aspects of the hydration phenomena and its application.

An alternative technique seeks to develop hydration rates through the identification of specific major chemical constituents of each source, which are thought to either encourage or inhibit the rate of hydration (Friedman and Long 1976; Friedman and Trembour 1978; Michels and Tsong 1981; Michels 1982; and others). Development of rates based on physical principles may be the most theoretically satisfying approach, but these rates should be tested and assessed using archaeological data before they are accepted.

Obsidian hydration data also has been used as a relative dating tool with varying degrees of success. Michels' (1965) study was the first and remains today one of the most intensive applications of the method. He attempted to derive information on site stratigraphy and to seriate artifact assemblages on the basis of hydration data. Since Michels' (1965) Mammoth Junction (CA-Mno-382) hydration study is central to this paper, it will be discussed in greater detail below. Other approaches to relative dating with obsidian hydration data include Meighan and Haynes (1970), Layton (1970, 1973), Origer and Wickstrom (1981), and Jackson (1982, 1983a), among others.

Central-eastern California

A number of archaeological projects have been undertaken in central-eastern California in recent years. Bettinger (1982) and Jackson (1983b) have reviewed many of these.

Casa Diablo obsidian is the most common obsidian source from which stone tools were manufactured during prehistoric times in the Long Valley region, and obsidian hydration measurements from this source constitute the largest body of hydration data for central-eastern California. Many different hydration rates have been proposed for this source (Ericson 1977; Garfinkel 1980; Michels 1982; Findlow et al. 1982; Basgall 1983; Hall 1983; Jackson 1983).

Michels (1982) recently derived a rate of 3.51 μ^2/1000 years for Casa Diablo obsidian based on an induced hydration experiment. This rate places first occupation of sites in this region as early as 16,000-19,000 B.P., while the projectile point types from which these hydration measurements were obtained indicate a time depth no greater than 5000-6000 years (Hall 1983: 172). It is somewhat surprising that Michels accepts his experimentally derived rate, considering the spurious results it produces when applied to his own data from the Mammoth Junction site. This example suggests that there may be serious problems with at least some rates derived from induced experiments, and until the method can provide archaeologically meaningful results it should be regarded as no more accurate than other methods and should be rigorously tested against archaeological data.

The use of empirical archaeological data, on the other hand, does not automatically assure accuracy in hydration rate formulation. Obsidian hydration measurements obtained on Casa Diablo obsidian projectile points from Long Valley were used with several hydration rate formulae and variables presented by Ericson (1977: 51), and all were found lacking in precision (Basgall 1983: 131-132).

Most obsidian hydration analyses in central-eastern California have focused on the development of absolute obsidian hydration rates through the analysis of temporally diagnostic projectile points (Meighan 1981; Garfinkel and McGuire 1981; Garfinkel 1980; Basgall 1983; Hall 1983). This method involves the accumulation of source-specific hydration readings on temporally diagnostic projectile points, computation of the mean hydration value for each point type and correlation of mean hydration with the midpoint of the temporal period represented by that type. Hydration rates are then determined by mathematically modeling these data. Linear rates have been popular for use with Casa Diablo obsidian, though there are certain problems with all of the projectile point-based hydration studies. Garfinkel (1980) was the first to model Casa Diablo obsidian in this manner, using data from the Mammoth Junction site (Michels 1964, 1965; Sterud 1965). Like Michels, Garfinkel assumed that all of the recovered projectile points were manufactured from Casa Diablo obsidian, due to the site's proximity to local Casa Diablo obsidian quarries. Recent regional studies (Bettinger 1981; Hughes and Bettinger 1984; Basgall 1983; Hall 1983; Jackson 1983) indicate that projectile points are extremely mobile, and that assumptions concerning geologic origin based on proximity to source are unsound. Garfinkel also may have misidentified examples of particular projectile point types (Basgall 1983: 133) but despite these problems, his model has proven to be a fairly good predicator of age when applied to other data sets from different sites in the region.

Basgall (1983) recently re-evaluated the Mammoth Junction data, correcting what he perceived to be Garfinkel's typological problems, and derived a slightly different linear rate. Although Basgall's study, too, ignored potential differences in the geologic origin of the points, his formula produced results quite similar to Garfinkel's (1980).

Hall (1983) constructed an empirical obsidian hydration rate based largely on CA-Mno-561 data, using only projectile point hydration data geochemically determined by x-ray fluorescence to be Casa Diablo obsidian. He further restricted his study to projectile points recovered from subsurface contexts. Hall's (1983) rate is similar to those derived by Garfinkel (1980) and Basgall (1983), and brings the number of proposed Casa Diablo hydration rate formulae to at least thirteen.

California and western Great Basin archaeologists may be loathe to learn of yet another source-specific hydration rate for Casa Diablo obsidian, but a new rate shall be discussed. Data used in the formulation of this 'new' Casa Diablo hydration rate were obtained under the following guidelines: 1) all projectile points had to be manufactured from Casa Diablo obsidian, as determined by trace element analysis; 2) all specimens used in the study must include certain diagnostic elements so that typological schemes similar to those used by Thomas (1981) or Jackson and Bettinger (1983) could be applied repeatedly with similar results; and 3) all projectile points must have been recovered from the same geographic region to minimize potential environmental and cultural differences.

Much of the data used in the present study was obtained by the author during an archaeological reconnaissance of Inyo National Forest timber tracts in Long Valley and Glass Mountain Ridge, several miles east of Mammoth Lakes, California. The survey covered more than 26,000 acres, and resulted in the identification of 176 archaeological sites and numerous isolated finds. Eighty-eight temporally diagnostic projectile points were recovered during the survey, but only 39 of these were Casa Diablo obsidian. Obsidian hydration rim measurements on these artifacts was conducted by the author at the University of California, Davis, Obsidian Hydration Lab.

Projectile point data from the Mammoth Junction site (CA-Mno-382) also was incorporated in the study. Unfortunately, only 80 of the original 138 projectile points recovered from the site were available for study. Obsidian hydration data were obtained from 42 of the diagnostic points determined by x-ray fluorescence to be Casa Diablo obsidian.

The third large data set consisted of obsidian hydration rim measurements on CA-Mno-561 projectile points excavated by Hall (1983). Thirty-seven of these points met requirements for the present analysis. Additional obsidian hydration data on projectile points fashioned from Casa Diablo obsidian was obtained from CA-Mno-389 on Sherwin Grade (Garfinkel and Cook 1979; n=3), CA-Mno-446 near Lee Vining (Bettinger 1981; n=4), and CA-Mno-529 in Mammoth Lakes (Basgall 1983; n=5).

Western Great Basin projectile point types were used to impose time control in hydration rate determination (cf. Lanning 1963; Bettinger and Taylor 1974). Thomas (1981) has described and presented quantitative means of type determination for most of the forms. However, several minor modifications were made to Thomas' scheme based on regional data (Jackson and Bettinger 1983). Hall's (1983) projectile points were unavailable for examination, but his categories and classification criteria were assumed to be equivalent to those employed here.

The distribution of hydration values according to projectile point type is illustrated in Figure 3. Overlap in hydration measurements on points supposedly representing different temporal periods may have resulted from any (or all) of several sources of error including the degree of accuracy and comparability of interlaboratory obsidian hydration measurements, poorly understood variables affecting hydration rate, the attributes chosen for projectile point type designation, and processes of cultural change.

The approach used by Garfinkel (1980), Basgall (1983), and Hall (1983) for hydration rate determination has recently come under criticism by Singleton (1983), who points out that this method assumes that particular point type frequencies approximate normal distributions with a mid-point close to the mid-point of the temporal span associated with that type. He also notes that this procedure assumes that given types were equally numerous during their use. These assumptions may be particularly dangerous if data from single sites is taken to represent entire temporal periods of projectile point type use, as in the case of CA-Mno-382 (Garfinkel 1980; Basgall 1983) or CA-Mno-561 (Hall 1983). Examination of Figure 3 reveals distinct differences between the major data sets (sites) used in the present analysis. The Rose Spring/Eastgate inter-site hydration values are strikingly different, though this may be a result of small sample size. Variation in hydration distribution between the three Elko data sets also is pronounced, and may reflect differences in times of occupation within the Newberry period, though variability introduced in the measurement process by different technicians, procedures, and laboratories cannot be ruled out. It is interesting to note that the greatest similarity in range and mean values for Elko points occurs between surface points collected on the survey and subsurface points from CA-Mno-561. These data suggest that significant differences in the rate of hydration may not obtain between surface and subsurface occurrences in this particular region.

The degree of overlap between point types argues against correlation of endpoint hydration values with beginning or terminal dates for projectile point types. Use of mean values is, at present, probably the most practical method of deriving absolute, source specific hydration rates.

Hydration Rate Determination

Mean hydration values for four projectile point series were used in two regression exercises (see Table 1).

Table 1: Projectile Point/Hydration Data Used For
Casa Diablo Obsidian Hydration Rate Determination.

Type and Midpoint Date (B.P.)	Mean (μ) & S.D.	Range (μ)	Sample Size
Desert Side-notched, Cottonwood Triangular (405 B.P.)	1.88 ± .4	1.2 - 2.7	10
Rose Spring/Eastgate (1030 B.P.)	3.21 ± .8	1.8 - 4.2	10
Elko (2280 B.P.)	4.18 ± .7	2.9 - 5.8	40
Little Lake (4580 B.P.)	5.97 ± 1.0	4.8 - 6.9	7

Two anomalously large hydration values for Cottonwood Triangular points (which may represent 'Rosegate' preforms) were excluded from the sample, as were two extremely small readings on Little Lake points (Figure 1). Mean hydration values were correlated with the midpoints of dates for the periods during which those point types are thought to have been used (cf. Bettinger and Taylor 1974). Thomas (1981) suggests slightly different dates for Monitor Valley, Nevada point types, but his estimates generally are in agreement (plus or minus 100 years) with those used here. It is likely that some degree of regional temporal variation existed for either or both sequences. Dating for the terminal use of Little Lake and earliest appearance of Elko projectile points is by no means agreed upon (cf. Bettinger and Taylor 1974; Warren 1980). Alternative dating schemes for these points vary by several hundred years, which would dramatically alter hydration rate results derived from regressions based on projectile point hydration data. Such rate formulae should be adjusted accordingly if regional chronological relationships are found to differ. Absolute hydration rate formulae can be no more accurate than the chronological references (in this case, projectile point time spans) to which they are calibrated.

Least squares regression was performed on sourced, time sensitive projectile points from Long Valley, resulting in a rate of Y=743.256 (x) = 599.015, with a coefficient of determination (r^2) value of .905. However, the problem with a linear formula is that is does not intersect the X,Y intercept at 0 and, as a result, it will yield erroneous future dates for late prehistoric archaeological specimens. This suggests that the hydration phenomenon does not proceed in a strict linear fashion, even though such formulae may produce seemingly reasonable results for "intermediate" (neither very early nor very late) archaeological specimens. Ericson (1977) also suggested that non-linear rates best describe the hydration rate of obsidian.

Many regression models are applied to hydration data regardless of whether the hydration process proceeds according to such mathematical models. Meighan (1983: 603) has made the point that apparent high correlation coefficients for many different source-specific models often result because of the paucity of data points from which regressions are derived (i.e. Ericson 1977: 69). A best-fit power function regression was applied to the Casa Diablo data, resulting in the formula $y=229.002(x^{1.475})$ with (r^2) of .9988 (Figure 2). However, because relatively few clustered observations were used to derive the regression, a high correlation coefficient could be expected (cf. Meighan 1983). Nonetheless, application of this power function rate to a wide range of hydration values yields results in line with archaeological expectations. Table 2 presents the age determinations that result from the application of various projectile point based hydration rates proposed for Casa Diablo obsidian.

Table 2: Comparison of age estimates based on projectile point-based, Casa Diablo obsidian hydration rate formulae.

	Years (B.P.) by Formula			
Hydration (Microns)	Garfinkel (1980)	Basgall (1983)	Hall (1983)	Jackson (this study)
0	*-745	-933	-637	0
1	-79	-234	32	229
2	585	466	700	637
3	1251	1166	1368	1157
4	1917	1866	2037	1770
5	2582	2566	2705	2459
6	3247	3266	3374	3218
7	3913	3966	4042	4040
8	4578	4666	4711	4919
9	5243	5366	5380	5853
10	5909	6066	6048	6837

* ("-" symbol means years in the future)

Only the power function formula (last column) produces consistently reasonable age estimates for late prehistoric materials. Other formulae yield dates far in the future when hydration rinds are lacking, and two of the three rates yield future dates for hydration values up to one micron. Examination of the other end of the hydration spectrum using these linear rates suggests that the most ancient Little Lake point is no older than 2500 B.C., even though there is general agreement that the oldest Little Lake points in the western Great Basin are considerably older (Bettinger and Taylor 1974; Warren 1980). These linear rates also suggest that Silver Lake, Lake Mohave, and Parman forms were manufactured during the Little Lake time period (ca. 3500-1200 B.C.). Although the power function rate also indicates many Silver Lake points were fashioned during the Little Lake period, the largest hydration measurements obtained from these point types yielded age estimates older than 3500 B.C.

The power function rate proposed in this paper provides the best empirical fit to archaeological data, though I suspect that it also yields age estimates that are too recent for obsidian artifacts with hydration rims thicker than about seven microns. Additional projectile points of Little Lake vintage and older, as well as control of effective hydration temperature (see Trembour and Friedman, this volume) may provide significant improvement in absolute hydration rate calculations. The paucity of numerous and well-associated radiocarbon dates, an incomplete understanding of the inception, use and abandonment of specific projectile point series, and disagreement over the most accurate Casa Diablo hydration rate leaves the door open to potential error in all previous rate determinations, including the power function rate.

Relative dating is an alternative approach to the application of hydration data which can yield meaningful chronologic and cultural information.

Relative Dating with Obsidian Hydration Data

The wide range of overlap in hydration values between temporally adjacent projectile point series (Figure 1) suggests that some, if not all, of the previously mentioned agents of variabliity may be operative. In addition, the timing of cultural change (the introduction of projectile point styles) may not be either sudden or accurately determined for the Long Valley area.

Perhaps obsidian hydration data could best be regarded in terms of a loose analogy. Consider the scatter of buckshot from a shotgun blast as similar to the plotted patterning of obsidian hydration measurements. The spread of buckshot near the barrel of the gun (the present) is relatively tight, but as the distance from the blast increases (increasing antiquity), the scatter widens for any number of reasons that may not be precisely identifiable. These factors may include the specific gravity and dimensions of the buckshot, air or wind currents, etc., which would be analogous to hydration variables such as air temperature; obsidian, soil and water chemistry; and surface exposure. To carry the analogy one step further, imagine two adjacent targets at a firing range, placed at different distances from the gun. In our analogy these targets represent specific but different time periods. A few pellets from shots fired at each target may stray from their intended target (normally predictable hydration ages) and strike the adjacent target. Holes in the wrong target (hydration values) may be difficult to distinguish from the buckshot striking the intended target. Similarly, obsidian hydration measurements may appear scattered and extend beyond the distribution expected from the length or time of prehistoric occupation. Hence, obsidian hydration may best be viewed as a "shotgun" approach. The hydration measurement for any single artifact, then, becomes much less important than aggregate hydration data. The larger the sample size, the more accurately we can distinguish the 'scatter' from the major occupational period(s).

As described elsewhere in this volume, Owens Valley data used in an interlaboratory hydration study (see Jackson, this volume) resulted in a poor correlation between hydration measurements on the same slide specimens examined by two different labs. The variation in absolute micron readings observed in the sample would argue against attempting to derive chronometric hydration rates from these data, and would discourage dependence on single samples for accurate absolute or relative dates.

Temporal periods in the western Great Basin have been established largely by association of projectile point styles, though other cultural features have been gradually added to the inventory (cf. Lanning 1963; Thomas 1971; Bettinger 1973; among others). To the extent that projectile points monitor larger cultural patterns and adaptive strategies with corresponding temporal and spatial limits, site occupation can be correlated with cultural patterns.

While there may be problems with assuming broad cultural patterns based on projectile point styles, these problems are general archaeological ones that cannot be addressed with hydration data. Furthermore, exclusive dependence on projectile points for dating archaeological sites presents additional problems. Projectile points are not found at every archaeological site, and conversely, the presence of one or even several projectile points of a specific temporal type at a site does not insure that site occupation coincided with point deposition, though points are commonly used to date sites (Bettinger 1975, 1977; Hall 1980). It is possible that site <u>function at a given time</u> determines the nature of deposition, and that site function can vary both synchronically and diachronically (cf. Binford 1982). The same argument pertains to any single cultural material class, including flaking debitage.

Methods

All prehistoric sites thus far identified in the Long Valley area appear to share one attribute; the presence of obsidian flaking debitage, often from the Casa Diablo obsidian source. In the present study, obsidian hydration analysis was used to derive relative dates for aboriginal sites by comparing hydration rim thicknesses on Casa Diablo tools and debitage with hydration values for temporally diagnostic projectile points.

In order to derive a useful hydration thickness range for each recognized cultural (projectile point) period, it was necessary to minimize hydration overlap in projectile point type distributions (consistent with the "shotgun" model). This was accomplished in some instances by simply excluding divergent and aberrant projectile point readings, as discussed above.

Hydration ranges for projectile point series were established by the use of variance around means (excluding the previously discussed specimens). Hydration measurements for each point series were averaged and the resulting values taken as the midpoint of the hydration range for each series. While this approach has been criticized for single site studies (Singleton 1983), the accumulation of projectile point collections from various sites throughout the Long Valley region minimized potential intra-period temporal bias. One standard deviation for sampled populations was then derived for each series (Table 1), which was added to and subtracted from point series means. The resulting values were considered endpoints in projectile point/cultural period hydration ranges (Figure 3, top). This procedure had the effect of 'tightening' the hydration range by minimizing the importance of extreme values. Series endpoints represent the <u>common</u> early and terminal use of projectile point series and, by extension, delineate cultural periods. Hydration values falling in or very near areas of overlap between projectile point series (cultural periods) are considered transitional. Only hydration rinds exclusive to specific projectile point series are equated with single cultural periods. Correlations between hydration values and cultural periods appear in Figure 3.

Despite the use of standard deviations, significant overlap in hydration values is evident in Figure 3, particularly between Rose Spring/Eastgate and Elko series points, as well as Little Lake and Stemmed points. Considering the relatively distinct separation between certain point series (i.e. Desert Side-notched/Cottonwood and Rose Spring/Eastgate; as well as Elko and Little Lake; Figure 3, top) the overlap in the aforementioned series may reflect the operation of factors such as slow transmutation or replacement of one series by another, or poor archaeological distinctions between series due to fundamental morphological similarities.

Two fundamental and crucial assumptions were used in this approach to hydration dating: 1) obsidian artifacts and debitage collected on site surfaces reflect all, or at least major occupational periods or events; and 2) that obsidian debitage attends most, of not all, site occupations other than incidental or special task activities involving only a few hours to perhaps a day. These assumptions have not been blindly accepted, but detailed consideration is beyond the scope of this paper (see Jackson 1983b).

Sample sizes adequate for addressing site-specific archaeological questions on the basis of flaking debitage will vary according to the nature of the specific research questions and site attributes. Several dozen hydration specimens are often required to accurately determine the total temporal range of site occupation, the degree of stratigraphic integrity, intra-site variability, and other questions. The sample sizes used for each site in the present study were woefully small, so the scope and detail of archaeological questions which can be addressed from these data are correspondingly limited. The goals of this particular hydration study, therefore, were primarily to obtain a rough notion of when major site activity may have taken place. A secondary and complementary goal involved obtaining information on the degrees of site complexity with regard to the duration, periodicity, or intensity of site occupation. In some cases, it is possible to determine very rough temporal data (i.e. major site occupational periods) using only a few hydration rim measurements.

Examples of the relative dating method, applied to archaeological sites in the Long Valley area, are presented in Figure 3. All analyzed obsidian is thought to derive from the Casa Diablo source, as determined by well tested techniques of visual identification (see Bettinger, Delacorte and Jackson, this volume).

The mean hydration value (age) of each site was calculated by deriving the mean for clustered hydration measurements. Determination of clustering and exclusion of data points was performed on a strictly intuitive basis, which was deemed appropriate in light of the very limited sample size and collection techniques. A more rigorous approach would certainly be recommended for future analyses with better controlled sample sizes. The importance or implications of values excluded from site dating is unclear in light of the limited sample size. Additional hydration analysis would be necessary to determine if such values represent minor site occupations of different time periods or simply aberrant hydration measurements. The purpose of this paper is not to explore the specific data, but rather to consider methods of deriving such data. However, hydration rim measurements and their distribution at each site provides valuable information on the cultural period(s) of occupation, site function and structure.

Summary

Determination of accurate, source-specific obsidian hydration rates is a desirable, long-term goal of hydration research, but there are many extant problems to overcome (i.e. poorly understood affective variables to the hydration process, preparation and measurement problems, etc.; see R. Jackson, this volume). The prospects of overcoming these problems in the near future, or perhaps more importantly that absolute hydration rates will find general agreement among archaeologists in the near future, are rather bleak.

Until we have overcome these problems, alternative interim dating applications using obsidian hydration are needed. This paper has presented one such application, using temporally diagnostic projectile points to determine the 'hydration ages' for prehistoric cultural periods.

Regardless of the successful application of this approach in the Long Valley area, the relative dating approach may not be appropriate for many areas. It is important that applications of obsidian hydration data be tailored to the archaeological research questions and physical circumstances of specific regions. Some regions lack projectile point forms as temporally sensitive as those of the Great Basin, or their temporal significance has not yet been worked out. Other areas may not contain obsidian in the source-specific abundance necessary for application of the approach. In such instances determination and application of 'absolute' rates may be more appropriate, but such formulations should be tested against other forms of archaeological data. In conclusion, there is no "right" approach to the use of obsidian hydration. Innovative applications should be pursued and developed on the road to absolute, source specific hydration rates.

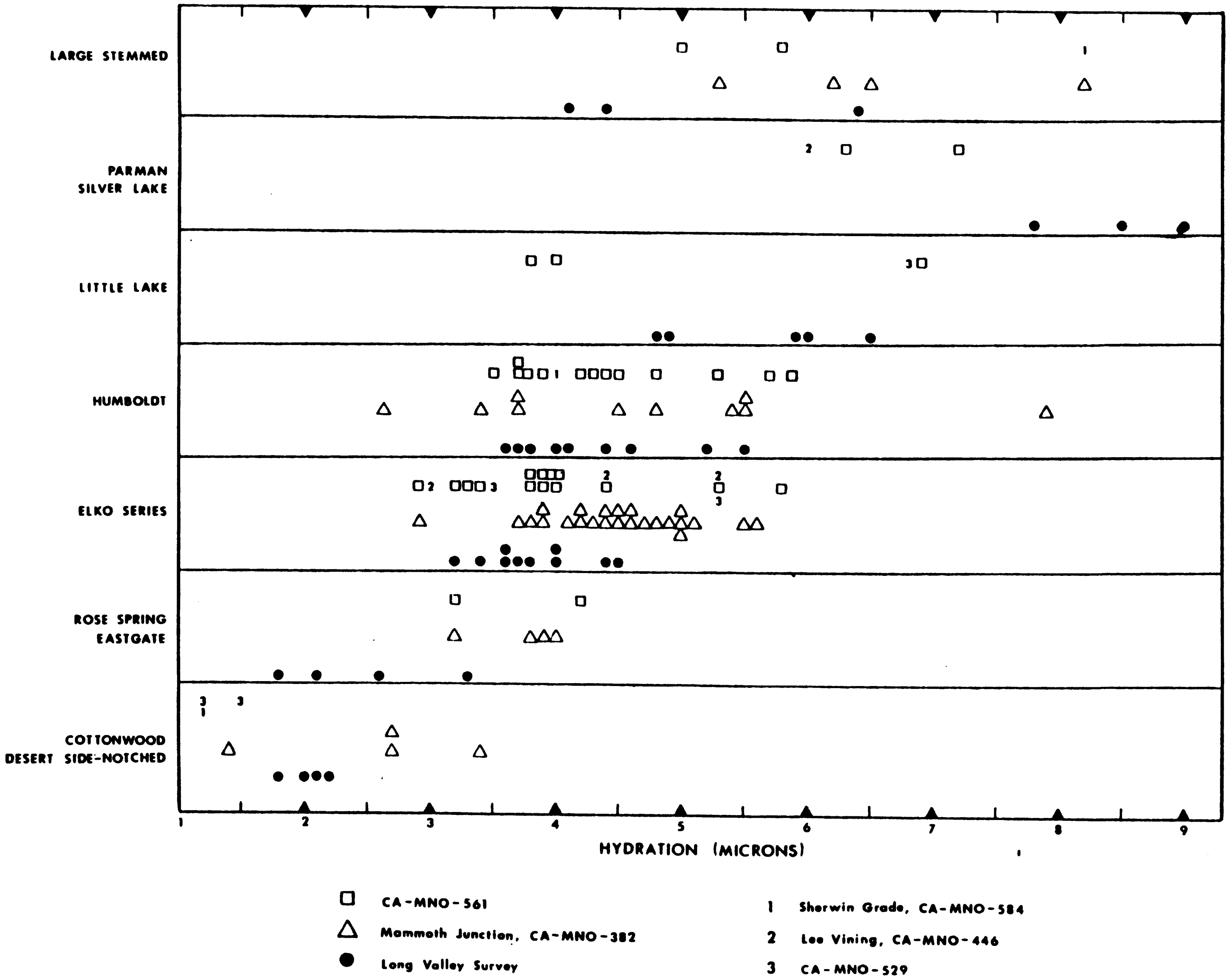

Figure 1. Obsidian hydration rim readings by projectile point type.

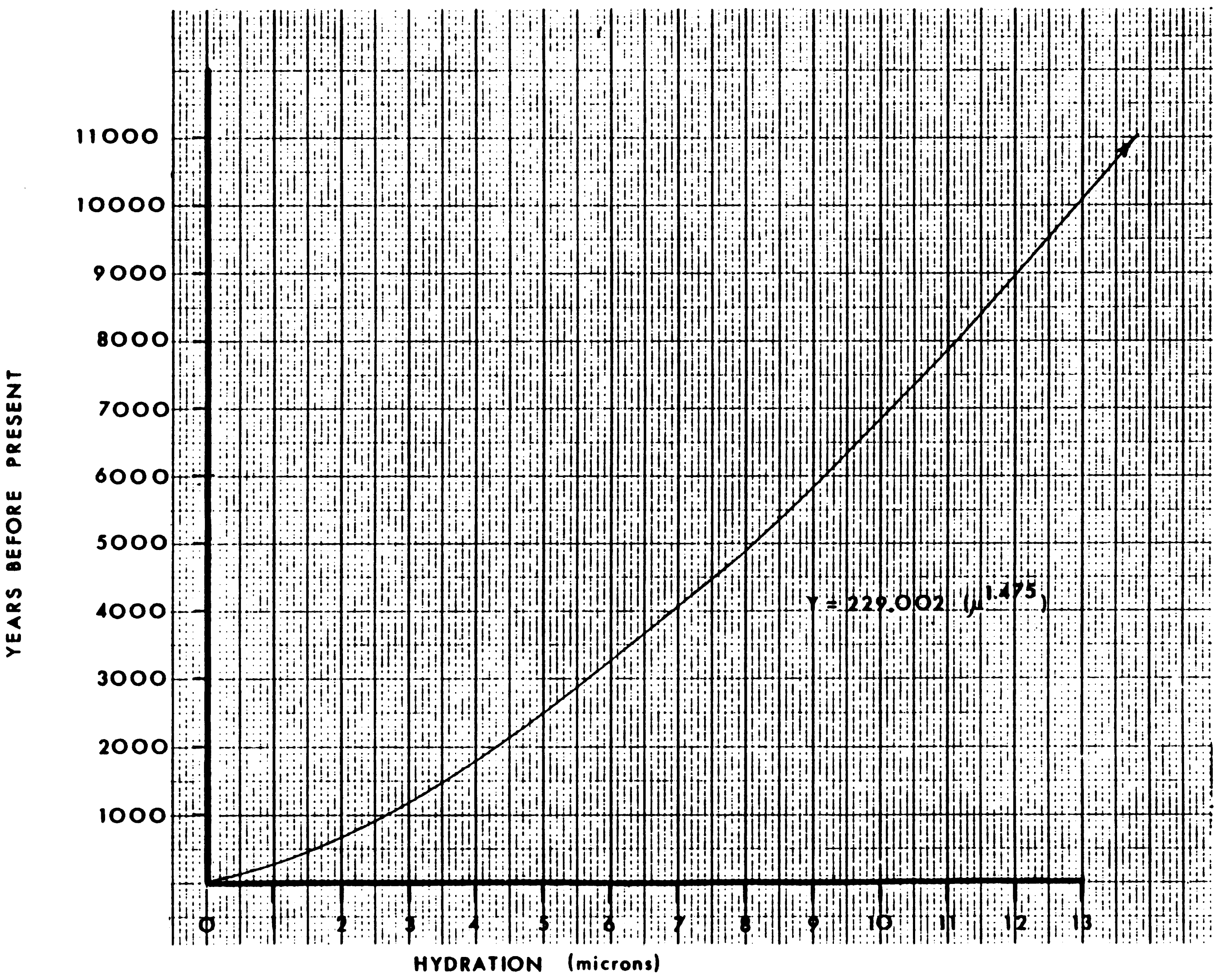

FIGURE 2: Source-specific hydration rate – Casa Diablo obsidian

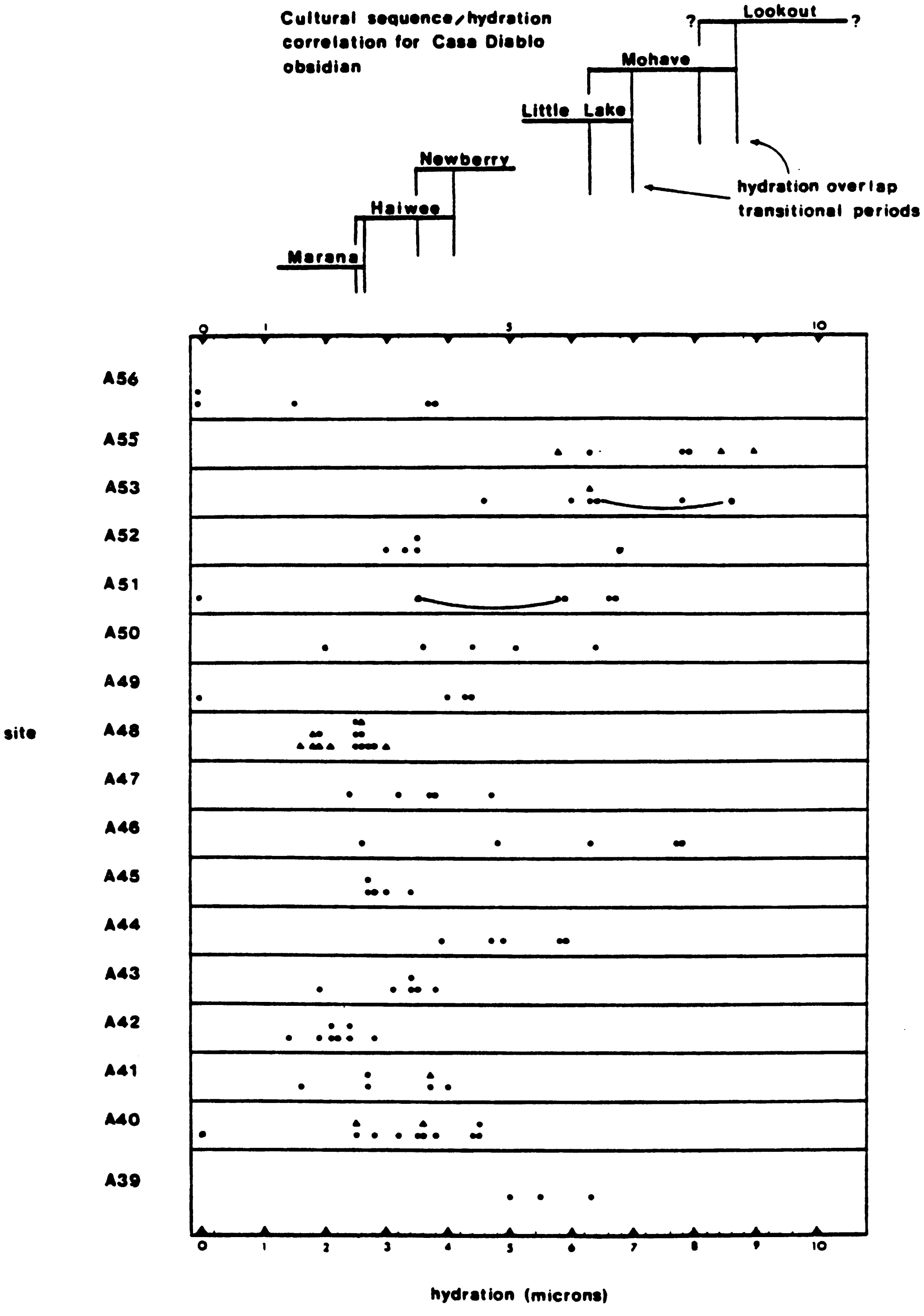

FIGURE 3: SITE-SPECIFIC OBSIDIAN HYDRATION DATA

- • debitage
- ▲ projectile points

•—• two hydration bands

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IMPLICATIONS OF OBSIDIAN HYDRATION READINGS AND SOURCE DETERMINATIONS FOR 28 PRESUMED "EARLY MAN" POINTS FROM NEVADA

Donald R. Tuohy

Introduction

More than a decade ago, Tom Layton stimulated my interest in obsidian hydration dating (see Layton 1970, 1972a, 1972b, 1973, 1979). At that time, I submitted 88 artifacts to Susan Moriarty and Harvey Crew at the University of California, Davis for obsidian hydration rim readings. The bulk of the hydration data derived from the excavated projectile points from Pyramid Lake has been published (Tuohy 1980). The latter publication, however, suffered because these specimens were not chemically characterized, a deficiency presently being remedied by Richard Hughes of the University of California, Davis.

As a residual bonus from the early 1970s, I also accumulated in my files rim readings made by Harvey Crew on what I perceive to be "Early Man" projectile point types recovered in the western Great Basin. All were surface finds made by a variety of persons, under a variety of circumstances, mostly uncontrolled. Richard Hughes, again, has helped to contribute some order to these circumstances by sourcing these 28 bifaces using x-ray fluorescence (XRF) analysis (see Hughes 1983a, 1983b for technical conditions of the study).

After these 28 points had been sourced, a decision was made to cut five of the points not previously subjected to obsidian hydration analysis. These specimens, numbers 1-5 in Table 3, were severely wind-blasted, and had not been analyzed previously because of the obvious, visible abrasion damage to the chipped surfaces on all of them. The obsidian hydration study of these five points was made by Thomas Kaufman, Obsidian Technology Services, Los Angeles, California. Results of this analysis will be presented below.

Meighan's (1981: 200-214) determination of differences between average readings on Little Lake "Pinto" points and those from my studies (Tuohy 1980) at Pyramid Lake suggest a significant variation in the hydration rates of obsidian in different parts of the Great Basin. This variability probably derives, in part, from geochemical differences between the obsidian sources, resulting in the probable existence of "slower" hydration rates for some of the northern and eastern parts of the Great Basin when compared to the rate proposed for the southern Great Basin (Meighan 1981: 212). With this in mind, one might question the wisdom of trying to draw together disparate hydration data on typologically disparate bifaces made from obsidians from disparate sources. When one realizes the one of the murkiest and most maligned of our knowledge pools in the Great Basin is the "Early Man" swimming hole, then I hope to float conclusions in this paper that, at best, will be disparate, not desperate.

Typology

Despite the best modern day efforts of persons such as Earl H. Swanson, Jr., who summoned the "First Conference of Western Archaeologists on Problems of Point Typology" over 20 years ago (Swanson and Butler 1962) and the recent contributions to typological systematics by Thomas (1970, 1981), Holmer (1978), and Holmer and

Weder (1980), among others, there is still much confusion among Great Basin archaeologists about morphological and technological projectile point "types" (Rouse 1960). Unfortunately, although confusion appears less prevalent among presumed pre-Archaic projectile point typologists, there are enough disagreements expressed in print to propose a Second Conference on Problems of Point Typology.

For present purposes, I follow Meighan (1981: 205) in applying the concept of a projectile point "series," defined by Hester and Heizer (1973: 1) as a group of related point "types," for discussing the sample of 28 points reported herein. Therefore, I will discuss "Clovis" series, "Haskett" series and "Great Basin Stemmed" series as if they were truly established instead of mostly postulated entities. Other named types are insufficiently represented in the sample to be of concern, but there are minor variations in morphology found among them. As an example, the so-called "Scottsbluff" point in this Nevada sample is quite similar to its Plains counterpart, although its flaking scars evince less care in their placement and regularity (Figure 2h).

I should also mention that there seems to be developing a kind of Great Basin Mason-Dixon line, where a southern "Pinto" becomes a northern "Elko," or a southern "Silver Lake" becomes a northern "Parman," or a southern "Great Basin Stemmed" becomes a northern "Windust Phase" point as reported in the Snake River country (Rice 1972). Significant differences between eastern and western Great Basin point typologists also have been noted (Thomas 1981: 10), particularly with reference to a "long" chronology in the east for some point types as opposed to a "short" chronology in the west. While there may be valid reasons for grouping "Eastgate" and "Rose Spring" series points under the name "Rosegate," or for integrating "Elko Contracting Stem" points and Pinto series points into a "Gatecliff series" (Thomas 1981: 19-22), the disappearance of "Pinto" series points and "Gypsum Cave" points from the roster of Great Basin point types violates my sense of continuity in Great Basin typology studies, as I have already noted (Tuohy 1982: 83).

Regardless of the point terminology one uses, however, presumed pre-Mazama and "Early Man" point series or types simply are not to be found in later sequences such as the well known ones in Monitor Valley or in Gatecliff Shelter where stratigraphic evidence suggests the oldest forms are concave base points (Thomas 1981: 13). Pre-Mazama occupants of the Great Basin possibly flourished better under the stars, or in brush or skin tents rather than under some natural rockshelter or in a cave, and this postulate, one surmises, may be the reason that the presumed early point types we do have are nearly all surface finds from open sites.

The Projectile Point Sample

As suggested, the selection of the "early" projectile point types for obsidian hydration analysis was somewhat casual. This paper, therefore, represents only a beginning tally of rim readings and sources for presumed "early" point types from western Nevada. Of course, other hydration studies containing "early" point types have been published (Layton 1972a, 1972b; McGonagle 1979; Tuohy 1980), or are awaiting publication (Layton 1983; Green 1982; Rusco and Davis 1982), so some comparative data are available. The only recent Great

Basin studies which present both obsidian hydration rim readings and sourcing data on "early" point types, however, are the studies by Hughes (1983a, 1983b), Rusco and Davis (1982) and Layton (1983).

It seems appropriate here to discuss the point sample and to identify both the typologists and the criteria used to classify the points. A summary of this information is shown in Table 1 which also presents the dimensions, weight, typology, and the original point identifications with a list of published references or type descriptions. Gross morphology and technological attributes of stoneworking were used to classify the points not previously classified. As noted in Table 1, at least three of the points are not truly "early" types, but are respectively, a Humboldt concave base point (Figure 2e), an "Elko" series point (Figure 2g), a thinned and fluted, plano-convex flake (Figure 3i), both of the former more than likely of Archaic persuasion. Still other forms in the sample (Figure 6o and 8y) are stems from Great Basin Stemmed series points reworked into drills or gravers. One such Great Basin Stemmed series point (Figure 7v) has been resharpened with a burinated tip, a technique for reworking stems described elsewhere (Tuohy 1974).

Chronology

There are at least two ways to arrive at relative age estimates for the "early" points in this study. The first is through comparative typology, and the second is through use of the obsidian hydration dating method.

Comparative Typology. Since the Nevada sample includes points classified as examples of Clovis, Great Basin Stemmed, Parman, Haskett, Lake Mohave and Silver Lake types, a perusal of the published literature on the chronology of these points should provide data for suggesting age estimates on the basis of comparative typology.

At the Lindenmeier site in northern Colorado, Wilmsen and Roberts (1978: 175) have shown that Clovis and Folsom points are coeval at least to 11,200±400 years B.P., and unfluted (Concave-base) points also found there have an antiquity comparable to that of the fluted points. In the Desert West, which includes Utah, Nevada, and parts of southern California, Idaho and Oregon, Clovis fluted points are widely distributed as surface finds (Davis and Shutler 1969; Tuohy 1977; Aikens 1978), but none has been directly dated. On the Great Plains and in the Southwest culture areas, however, Clovis points date within the 11,500 - 11,000 B.P. time range (Haynes 1971: 10). Such a temporal range seems reasonable for the western Great Basin Clovis samples.

The Great Basin Stemmed series points were first defined by Tuohy and Layton (1977: 1-5). Prior to 1977, Bedwell (1973: 142) published the earliest radiocarbon date (13,200±720 B.P.) on a stemmed (Lake Mohave) type of point associated with a concave base point (termed an unfinished point or a blank by Fagan 1975). This date still stands as the oldest for any stemmed series point.

Hester (1973: 47, 62-68) compiled data on stemmed points as part of the Western Pluvial Lakes Tradition in the Great Basin, and Hester's data and conclusions have been amplified by Bryan (1980). Bryan (1979: 186-190) reports stratigraphic evidence and ten radiocarbon dates from Smith Creek Cave, eastern Nevada -- evidence that seems to indicate stemmed points recovered there (Mt. Moriah variants) date from 12,000 - 10,000 B.P. These points are believed by Bryan to be fully contemporaneous with Clovis and Folsom kill sites on the Great Plains. Some Great Basin archaeologists perceive these stemmed points to be younger, possible post-dating fluted points by ca. 2,000 years (see Aikens 1978: 148).

Parman projectile points were first described by Layton (1970, 1972a, 1972b), who later incorporated them in the stemmed series (Layton 1979). Parman points are well dated, having been recovered in both the basal cultural levels at Hanging Rock Shelter (Layton 1972b) and Last Supper Cave (Layton and Davis 1978) as well as at pluvial Lake Parman (Layton 1979, 1983). The assemblage of 50 Cougar Mountain and Parman variants recovered in the stratigraphically controlled cave excavations were dated by four radiocarbon assays (on shell and charcoal) to 9,140 - 8,170 B.P. -- dates which Layton (1979: 47) rounds off to 9,000 - 8,000 B.P. Based on this evidence, the Parman varieties of stemmed series points from the northwestern Great Basin appear to be younger than the Mt. Moriah variants from the eastern Great Basin.

Haskett projectile points were first described by Butler (1965, 1967), and although both Clovis and Folsom points were recovered by amateurs from the same field as the Haskett points, they were not recorded *in situ* (Butler 1978: 64). The Haskett point style was not dated in Idaho until Sargeant (1973) reported radiocarbon dates of 9,860±300 and 10,000±300 on Haskett points and blanks from the earliest levels in Redfish Overhang, central Idaho. Butler has assigned the Haskett type to the "Plano" period in Idaho, ca. 11,000 - 8,000 B.P.

On the basis of comparative typology the Lake Mohave point type appears to have been widespread in the Great Basin during an early time period (Hester 1973: 45). The Silver Lake type frequently encountered at sites yielding Lake Mohave points appears to be younger in age. In the southern Great Basin, the chronological periods outlined by Warren (1980) indicate that the Lake Mohave Period should be assigned a temporal range of 10,000 - 5,000 B.C, while the Pinto Period dates from 5,000 - 2,000 B.C.

Obsidian Hydration Studies. A concordance of the illustrated points with obsidian sourcing sample numbers, site designations, hydration laboratory numbers, figure numbers, hydration measurements, and sources appears in Table 2. The supplemental results of obsidian hydration analysis performed on the five wind blasted specimens sent to Obsidian Technology Service, Los Angeles, appear in Table 3. The latter analyses were conducted using standardized procedures employed by the UCLA Obsidian Laboratory (Kaufman 1983a). Dr. Kaufman (1983b) commented on these five specimens as follows:

> "Hydration readings were obtained for all five specimens. Specimens 1, 3 and 5 exhibited hydration bands on all surfaces. Specimen 2 had only 1 hydration band (on the surface indicated by you), the other apparently destroyed by abrasion. The surface of specimen 4 was highly abraded showing no measurable hydration. Instead a large hydration band was located along a crack in slide 2.

> Hydration readings made along external surfaces ranged from 2.1 to 9.8 microns. The crack inside specimen 4 measured 10.6 microns. Hydration bands in cracks were also located and measured on specimens 1 and 5. Crack readings are usually somewhat larger than external surface readings and these two specimens were no exception.
>
> While I do not have hydration rate data for most of these sources the hydration readings on specimens 1, 2 and 5 seem somewhat small for Paleo-Indian temporal affiliation. The 3.1 micron surface hydration reading on non-abraded Bodie Hills source specimen 5 is suggestive of a relatively late temporal placement. Although there are still some ambiguities in the relationship of crack vs. surface readings on the same specimen, the 3.5 micron crack reading for specimen 5 supports the visual observation that surface abrasion has not been very significant on this specimen. Spallation effects are still possible."

No attempt will be made to convert the hydration rim readings in Tables 2 and 3 into calendric years. It seems reasonable to suggest that the chronology implied by review of the comparative typology reflects the general temporal periods during which the points in the sample probably were made. Conversion to calendric years depends upon several factors (see R. Jackson, this volume) beyond the scope of this study and, in addition, there are too few points in the sample to yield meaningful source-specific hydration ranges. Meighan's (1981: 211) estimate, a "northern" rate of approximately 800 - 1200 years per micron, seems to be a reasonable estimate for those points in the sample originating at Mono Glass Mountain and at other sources farther to the north (Figure 10).

Clovis Points and Sources

As noted in Table 2, seven "Early Man" style points are classified as "Western Clovis." The find spots of four of them are clustered on the east shore of Washoe Lake (Figure 11, WL) in west-central Nevada. Suggested sources were given only for six Clovis specimens, however, as one was from an unknown source (Figure 1d). Each of the other six has a separate source according to XRF analysis. One source, Majuba Mountain, for specimen 2053-G-5 (Figure 1a) is located approximately 150 miles (241 km) north of Washoe Valley. The second source, for specimen 2053-G-4 (Figure 1b), is located not far away in Lyon County near Sutro Spring, while the third source for the deeply fluted and scratched Clovis point (Figure 41) is listed as Bodie Hills, the well-known source locality on the California-Nevada border about 100 miles (161 km) south of Washoe Lake (Singer adn Ericson 1977). Another point typed as a Humboldt concave base point (Figure 2e) also was recovered at Washoe Lake, and the obsidian originated from the Bodie Hills source.

The two remaining "Clovis" points (Figures 4k and 5m) and one concave base point (Figure 1c) were recovered at Lake Tonopah and Mud Lake, respectively. The find spots of the two Clovis points are located respectively about 20 miles (32 km) west and 20 miles (32 km) east of Tonopah, Nevada (Figure 11, LT and ML). The source for one specimen (Figure 4k) is located not too far away at Queen. The other specimen (Figure 5m) has the largest rind reading (15.7 microns) of any sample analyzed -- its source was identified as Coso Hot Springs. The concave base point (Figure 1c) recovered at Mud Lake about 18 miles (29 km) southeast of Tonopah has been attributed to the Crow Spring source located in southeastern Esmeralda County, no more than 20 miles (32 km) away. If the points of seeming "Clovis" persuasion are as old as comparative typology and hydration rims suggest, it then appears that several obsidian sources, such as Bodie Hills and Coso Hot Springs, were discovered quite early and utilized throughout millenia. If the Nevada Clovis points represent the continuation of a presumed older style point into more recent times, we should then perhaps expect the hydration rim readings to average lower than they do. Obviously, a larger number of samples and more sourcing data would help here.

Stemmed Points and Sources

Other than concave base points, "Clovis" points and the Archaic points already mentioned, three stemmed projectile points from the Mud Lake vicinity have been typed. Two of these were classified as Haskett fragments (Figure 3j and 6q), and the third was identified as a Silver Lake form (Figure 8x), although both of the latter could have been placed into the Silver Lake catagory. Like the so-called Clovis and concave base forms from Mud Lake and Lake Tonopah, the Stemmed Silver Lake and Haskett forms were fashioned from nearby source materials. The Haskett-like fragments came from Queen and Sarcobatus Flat [1] respectively, while the other specimen, the Silver Lake form (Figure 8x), came from an unknown source.

The largest group of stemmed points (n=9) was collected from one locality (and several discrete sites) in Churchill County known as Brady's Hot Springs (Figure 11, BHS). Two of the points, a Lake Mohave and a stemmed point (Figure 6p and 6r), have been sourced to Bodie Hills, while four (Figures 6o, 7s, 7v, and 8w) came from either Homecamp B or C or Massacre Lake/Guano Valley located in the opposite direction in northwestern Nevada (see Hughes 1983c: 6). Three other stemmed points (Figures 7t, 7u, and 9bb) from the Sadmat Site (Warren and Ranere 1968; Tuohy 1981) also were attributed to northwestern sources. The remaining three specimens (Figures 8y, 8z and 9aa) came from southern sources — Mt. Hicks, Sutro Springs and Queen. There is an abundance of local cryptocrystallines in the hills adjacent to the Sadmat site and it is therefore somewhat surprising to find northwestern Nevada sources indicated for the obsidian specimens. I suspect local sources, but obviously this is an area where more sourcing work ought to be done, particularly upon the obsidian points already in the Nevada State Museum collections. Taken at face value, the distribution of sources and find spots (Figure 11) may reflect the northwest-southeast trend of mountain ranges and passes or trade routes rather than specific production and exchange systems *per se*.

Comparisons

Starting in northern Nevada for comparisons, Layton's (1983) recent analysis of 26 obsidian projectile points from both Hanging Rock Shelter (n=13) and Last Supper Cave (n=13) includes the results of sourcing research conducted by Richard Hughes. Layton's selected sample included five series (Rosegate, Elko Eared,

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[1] Editor's note: although obsidian nodules occur at Sarcobatus Flat, these most likely were redeposited down Tolicha Wash from primary deposits in the vicinity of Obsidian Butte, Nevada.

Gatecliff Split Stem, Northern Side-notched, and Great Basin Stemmed). All but four of the Great Basin Stemmed series specimens, including those not sourced, had hydration rim readings between 5-10 microns (a higher total than all other types), and nearly all of them were recovered in stratigraphically "early" contexts at both sites. Thus, even though there appears to Layton (1983: 21) to be two periods of occupational hiatus evident in both Last Supper Cave and Hanging Rock Shelter, there was an apparent continuity of choice expressed by the occupants of both sites for local obsidian -- a continuity that apparently lasted through nine millennia!

Figure 11 shows the popularity of northwestern Nevada as a source area for the 28 points in this study. The figure also illustrates the multiplicity of sources for sites with the largest number of points (Brady's Hot Springs, Washoe Lake and Sadmat). Each of these sites not only received obsidians from northwestern Nevada, but southern sources are indicated as well.

Working in an area where little is known of the geochemistry of sources and hence of artifact-to-source assignments, Rusco and Davis (1982) reported a multiplicity of source assignments for 241 obsidian samples analyzed by R.L. Sappington. These were taken from three sites in the Rye Patch Reservoir area of west-central Nevada, two of which are Archaic and younger in age. Although a total of 15 obsidian sources were said to be represented at these three sites, one source area nearby (Mt. Majuba [sic]) provided 60.2% of obsidian for all sites while Pine Grove Hills, south of Walker Lake, provided an additional 14.9% (Rusco and Davis 1982).

Only one of the Rye Patch Reservoir sites (26Pe670), the Old Humboldt site, was assigned an "early" time span (12,000 - 7,000 B.P.) on the basis of the geomorphic position of soil profile which clearly indicates that the site is older than Mazama tephra (Davis 1982). This assigned age was supplemented by the cross-dating provided by hydration rim readings on Great Basin Stemmed series points from the site. The rim readings were made by Matthew C. Hall at the University of California, Riverside, and they ranged from 5.7 - 9.2 microns on at least nine Stemmed points and other obsidian preforms and other artifacts from the sites. The nine specimens that were studied in this group all were attributed by Sappington to a single local source, Majuba Canyon (Rusco and Davis 1982: 54).

In contrast to the predominance of single source areas for "early" Stemmed points from caves in the High Rock Country of northwestern Nevada (Layton 1983) and from one pre-Mazama open site in the Rye Patch Reservoir area of Pershing County, Nevada (Rusco and Davis 1982), Hughes (1983c) reported eight sources for obsidians found in Hidden Cave. The inhabitants of Hidden Cave, located in the Carson Sink, apparently received most of their obsidian from six sources located 100 to 200 km south of the site, and lesser amounts from two sources 150 km to the northwest (Hughes 1983c: 4). One of the earliest point types from Hidden Cave, the Humboldt Basal-notched point, was fashioned almost exclusively from Mono Basin source materials. Mono Basin obsidians may well have accompanied trans-Sierran shell bead and ornament trade into the Carson Sink between ca 3,000 and 1,000 B.C. As Hughes (1983c: 12) indicates, contacts with people in the Humboldt Sink to the northwest apparently were strongly expressed in Hidden Cave between 1,500 and 1,800 B.C. Thus, exchange routes established during Paleo-Indian times apparently persisted into the Archaic in western Nevada.

Conclusion

In summary, because of the small sample of points under consideration in this study, the relationship between find spots and obsidian sources is difficult to assess. Any conclusions drawn here must be stated as working hypotheses rather than anything else. The disparate nature of the data does not permit much interpretive latitude beyond low level inferences. These postulations should be tested by further hydration cuts and more sourcing studies on presumed "early" materials from Nevada.

E.L. Davis (1978) had noted the preference for materials other than obsidian for fashioning presumed Early Man tools in the Lake China Basin of California. The present review of a small, selected sample of obsidian points seems to indicate the opposite -- that obsidian often was chosen to make "early" points and that the sources for those points were well known to generations of later obsidian tool makers. At the time of contact, individual Washoe tool makers, for example, were known to travel at least 50 miles (81 km) south of Carson Valley to Topaz to get obsidian for stone flaking (Lee 1934: 22). This magnitude of travel may well have been the rule in remote archaeological time as well, yet trade in obsidians probably extended up to ten times that distance, to judge from the limited data we have at present. The high frequency of Great Basin lithic blank caches of bifaces recovered in western Nevada (Hanes and Botti 1981) also may indicate strong and viable trade routes as well as cultural preferences for specific obsidians. These preferences also appear to have deep roots, and source-to-user exchanges appear to have been made often along a northwestern-southeastern axis rather than along a trans-Sierran axis, at least prior to 3,500 years ago.

The fact that all of the finds reported here were surface artifacts from open sites surely has affected the hydration rim readings, making some of them larger because of the bifaces' long surface exposure, and conversely, reducing the rims of others because of aeolian erosion of chipped surfaces. Still, the range of micron readings from 5.2 - 16.3 suggests considerable age for the majority of specimens, as does the comparative typology.

The sourcing studies also seem to suggest that the few Clovis points in the sample were not exotic specimens, but they were made from well-known local obsidians. None of the points in the sample originated beyond the boundaries of the Great Basin. Most originated at sites on the eastern side of the Sierra Nevada. Surely trade routes to California were established on an "early" time level, but there are no trans-Sierran sources for the "early" points types in this sample. These and other problems await further study, along the lines suggested by Bettinger (1982). If pre-Archaic peoples of the Great Basin are to have their patterns of land and resource use defined, it is obvious that more thorough studies of this kind shall be required.

Acknowledgements

The author gratefully acknowledges the contributions of Harvey Crew, Thomas S. Kaufman, and Richard E. Hughes for providing the data on obsidian hydration analysis, and for the x-ray fluorescence analysis, respectively. The author also is indebted to Mary K. Rusco and Jonathan O. Davis, as well as to Thomas N. Layton for permission to cite their unpublished studies on obsidian hydration dating and sourcing in the western Great Basin. The line drawings of the 28 bifaces are the work of Shelly Moore. An earlier version of this paper was presented at the 1982 Great Basin Anthropological Conference, held in Reno, Nevada September 30 - October 2, 1982.

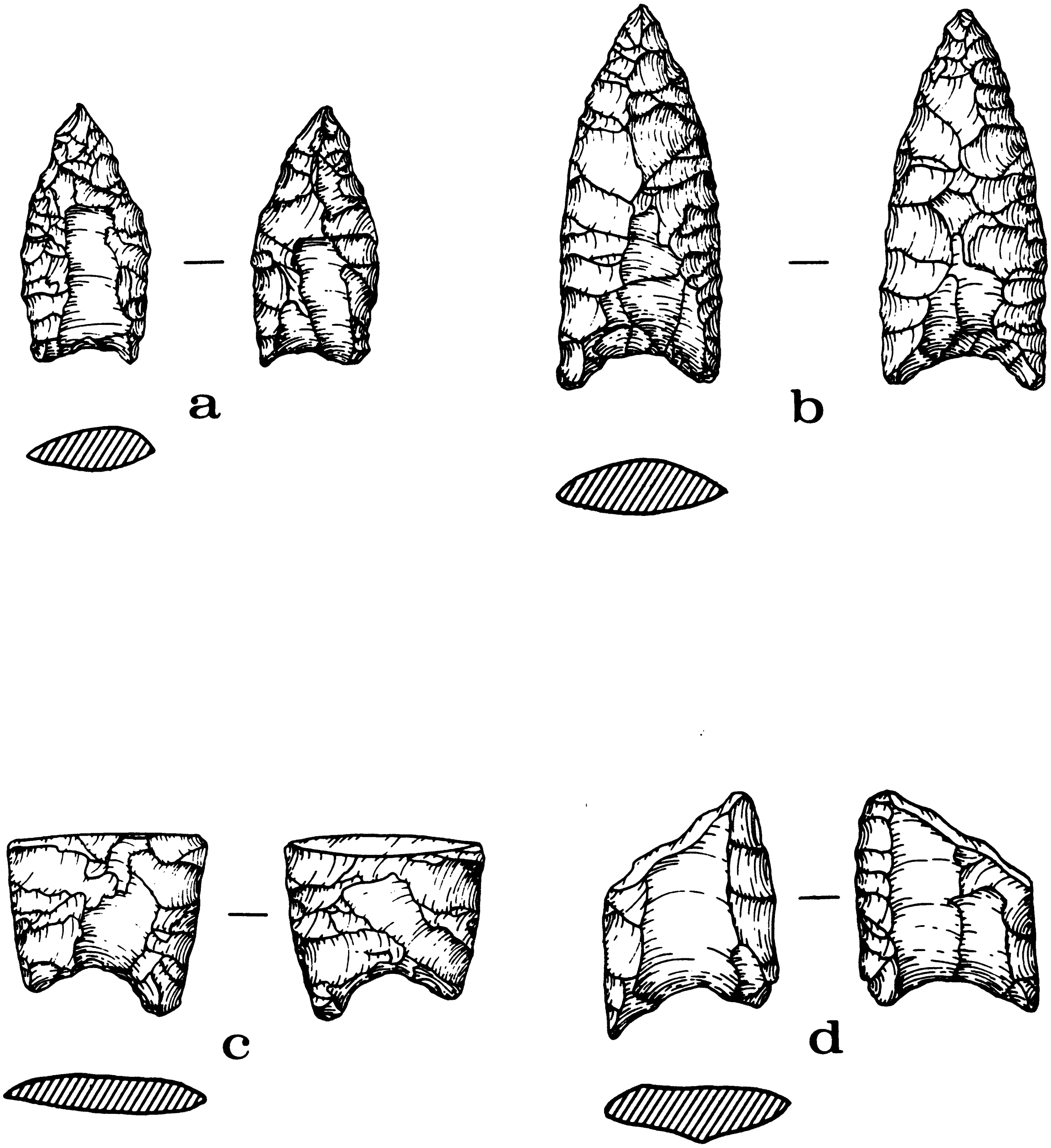

Figure 1a,b,c,d. Three "Clovis" points, a,b,d; and one Concave-base point, c.

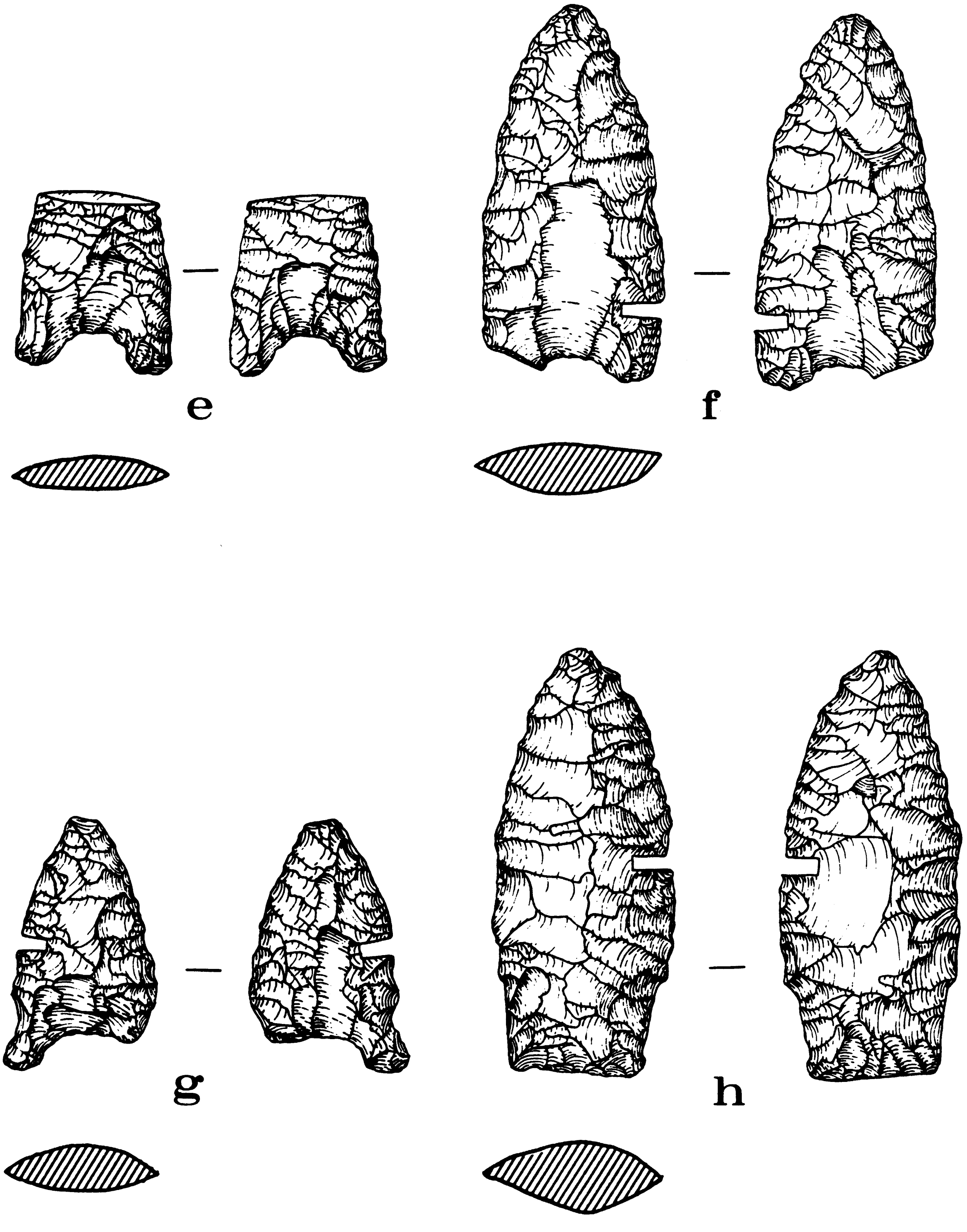

Figure 2e,f,g,h. A Humboldt Concave base point,e; a "Clovis" point, f; an Elko Eared point, g; and a "Scottsbluff" point, h.

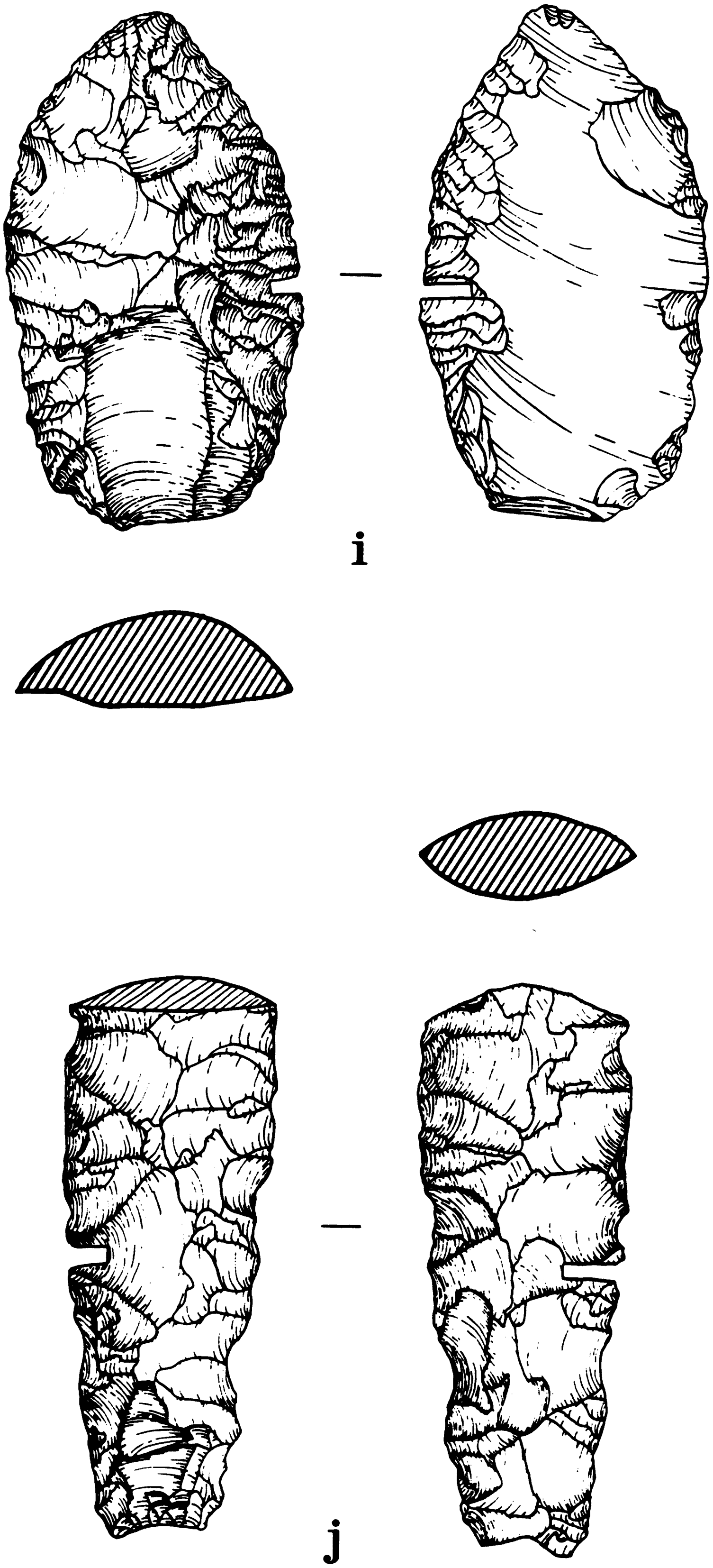

Figure 3i,j. Plano-convex flake, thinned, i; Haskett point fragment, j.

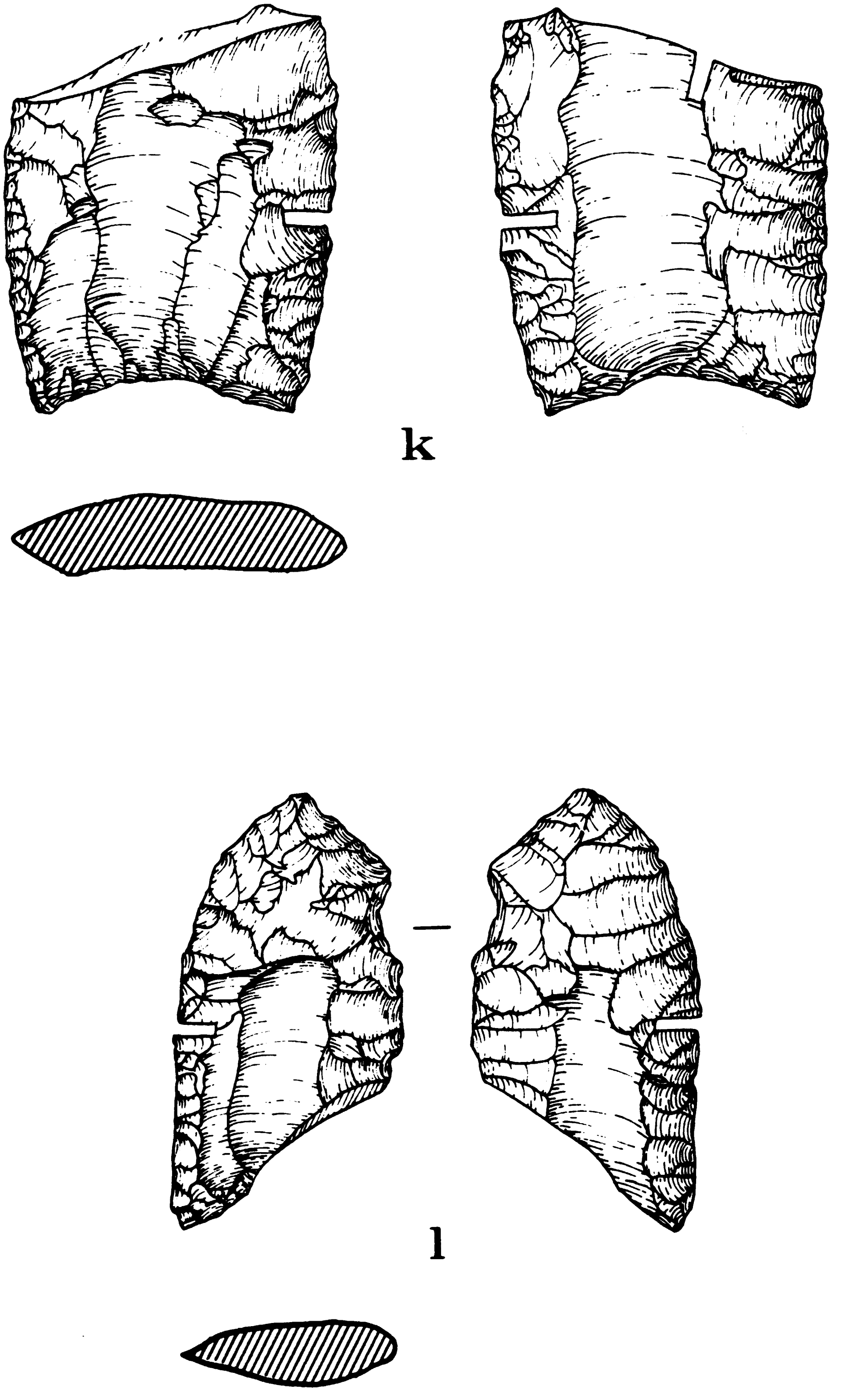

Figure 4k,l. Two "Clovis" points, k,l.

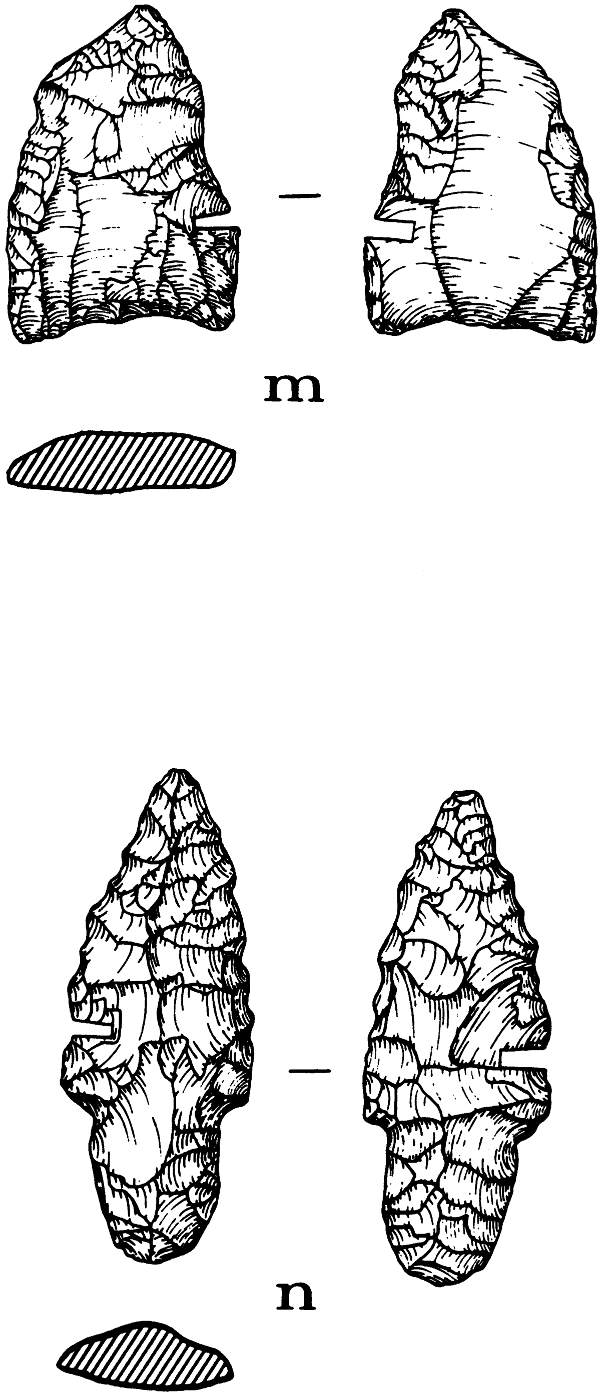

Figure 5m,n. A "Clovis" point, m; and a Parman point, n.

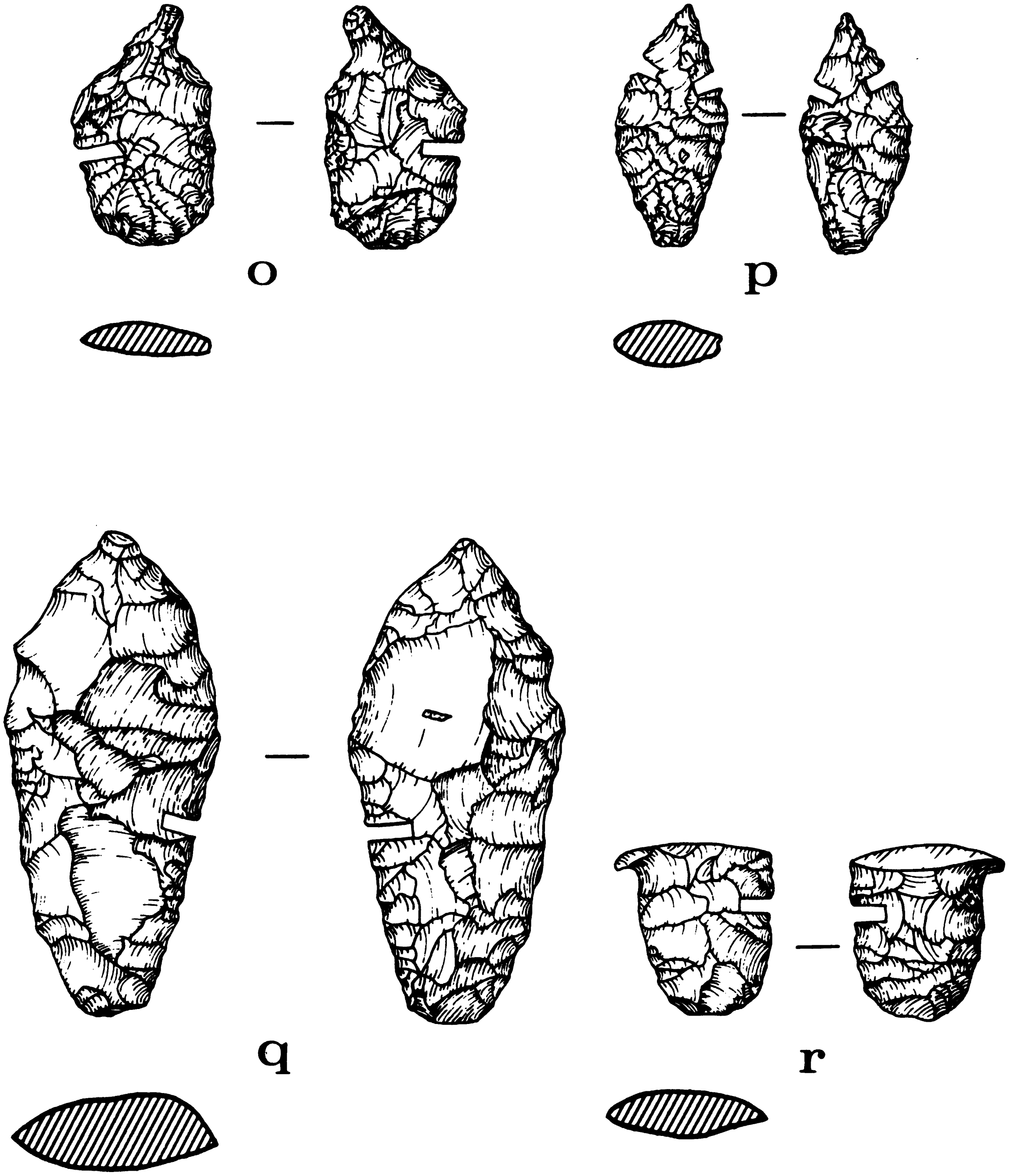

Figure 6o,p,q,r. A stemmed point made into a drill, o; a Lake Mohave variant, p; a Haskett point, q; a fragment of a Stemmed Series point, r.

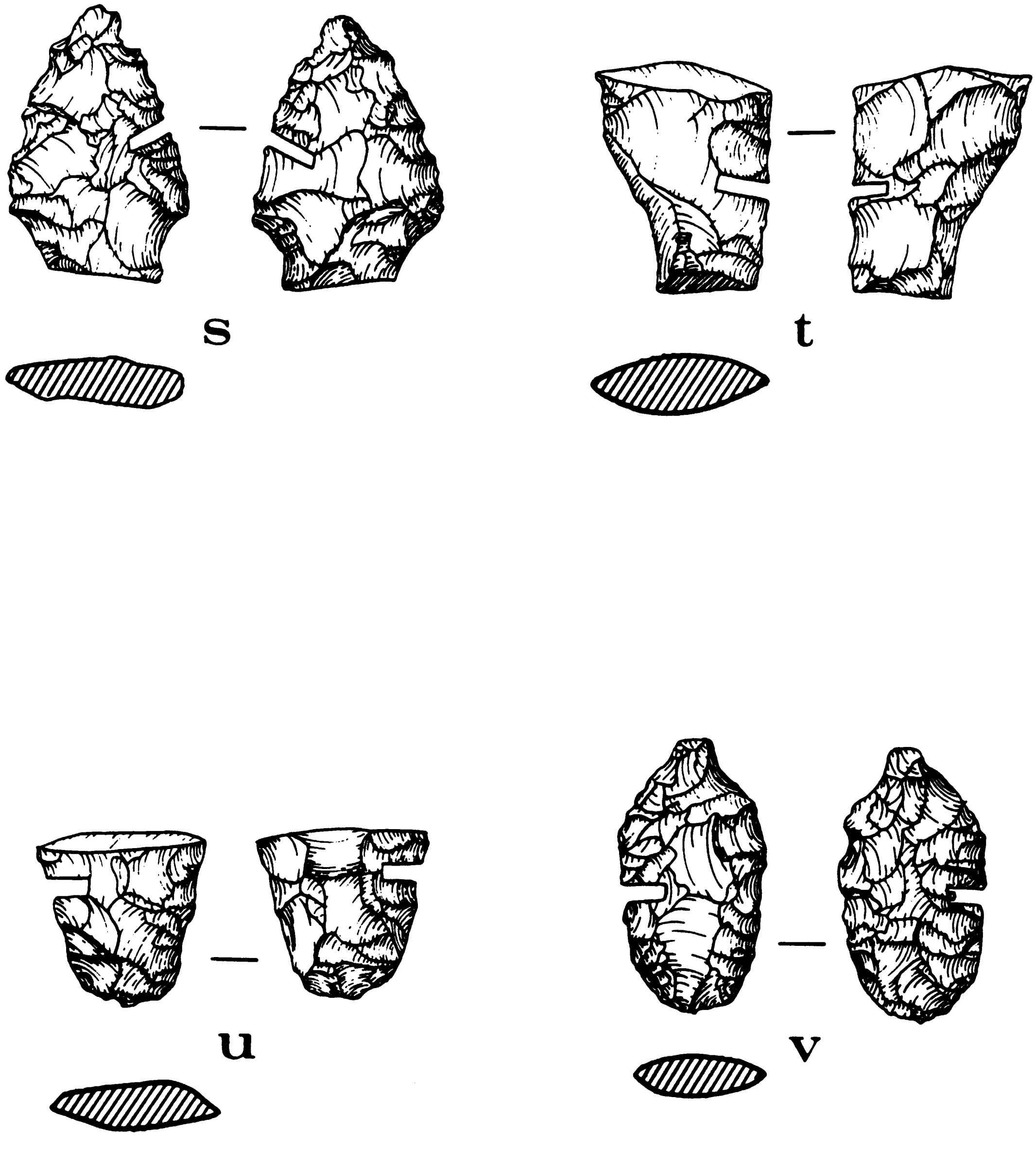

Figure 7s,t,u,v. Four fragments of Stemmed Series points, s,t,u,v.

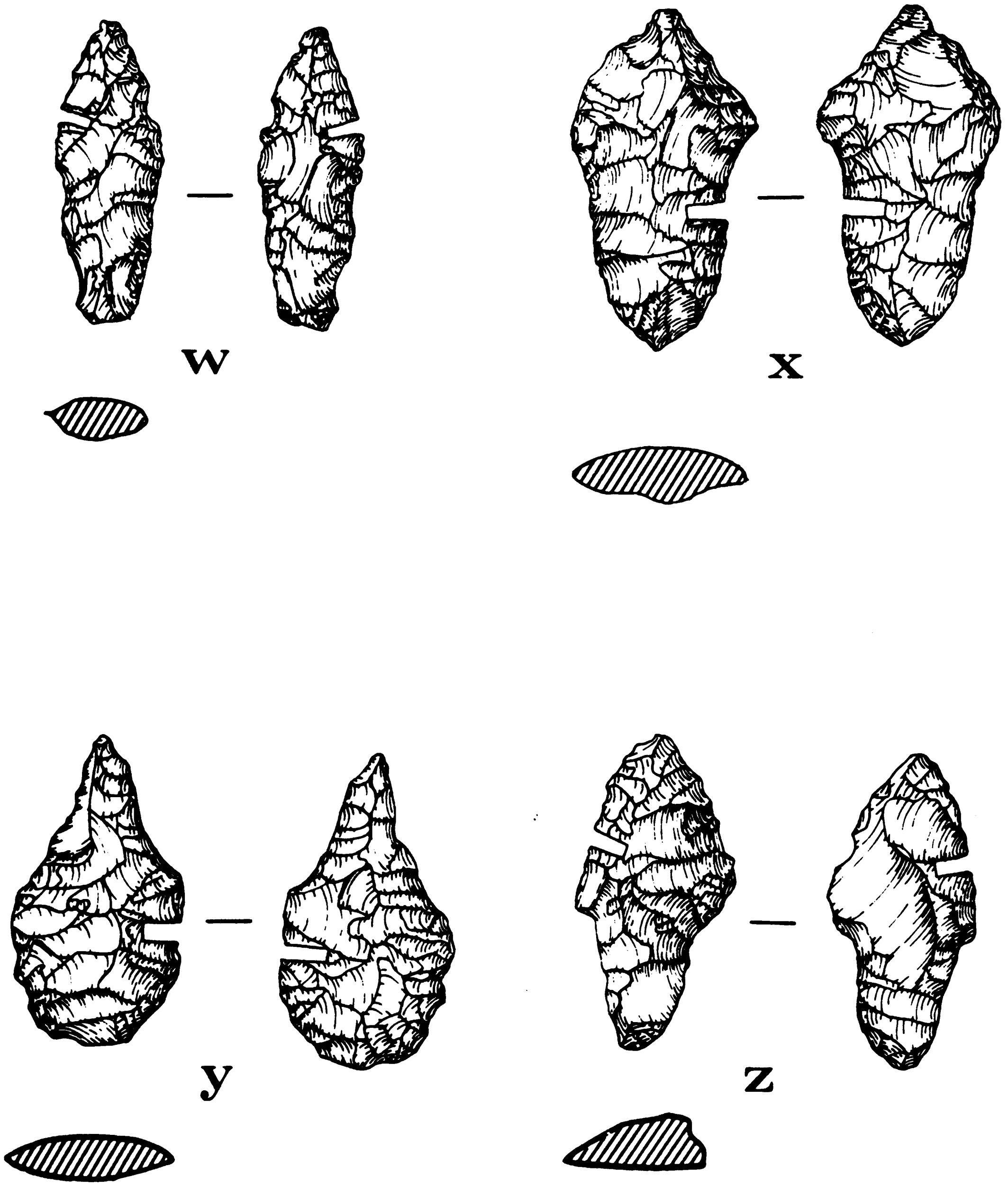

Figure 8w,x,y,z. A Lake Mohave point, w; a Silver Lake variant, x; a Stemmed Series point made into a drill, y; and a Stemmed Series point, z.

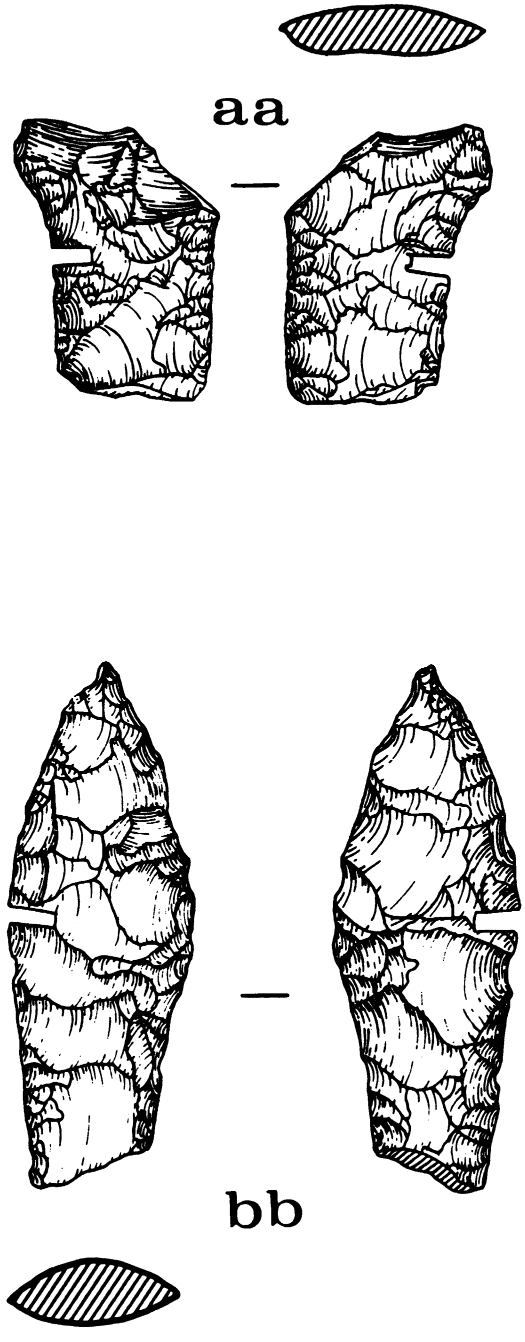

Figure 9aa,bb. A Stemmed Series point fragment, aa; and a Haskett point, bb.

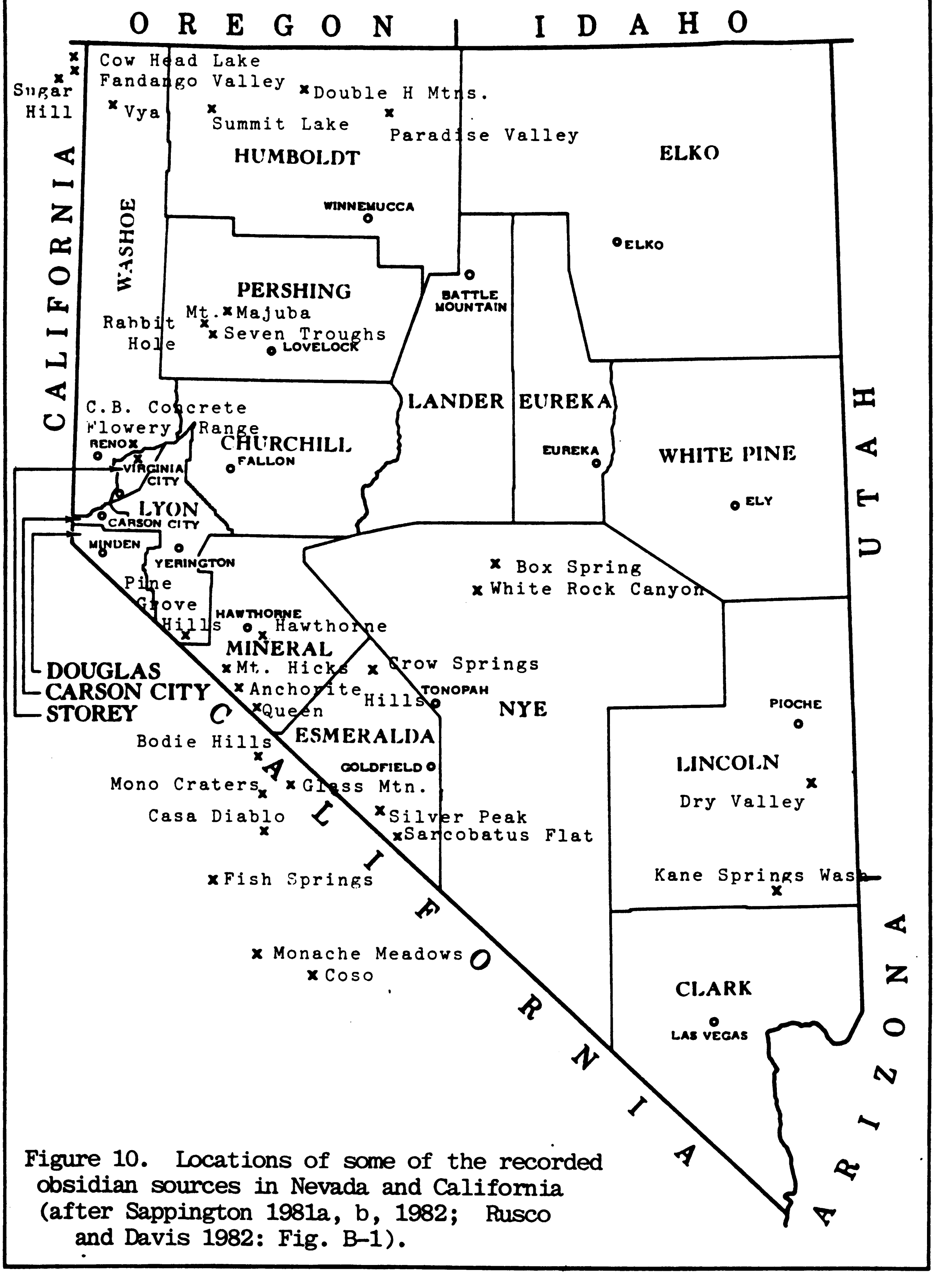

Figure 10. Locations of some of the recorded obsidian sources in Nevada and California (after Sappington 1981a, b, 1982; Rusco and Davis 1982: Fig. B-1).

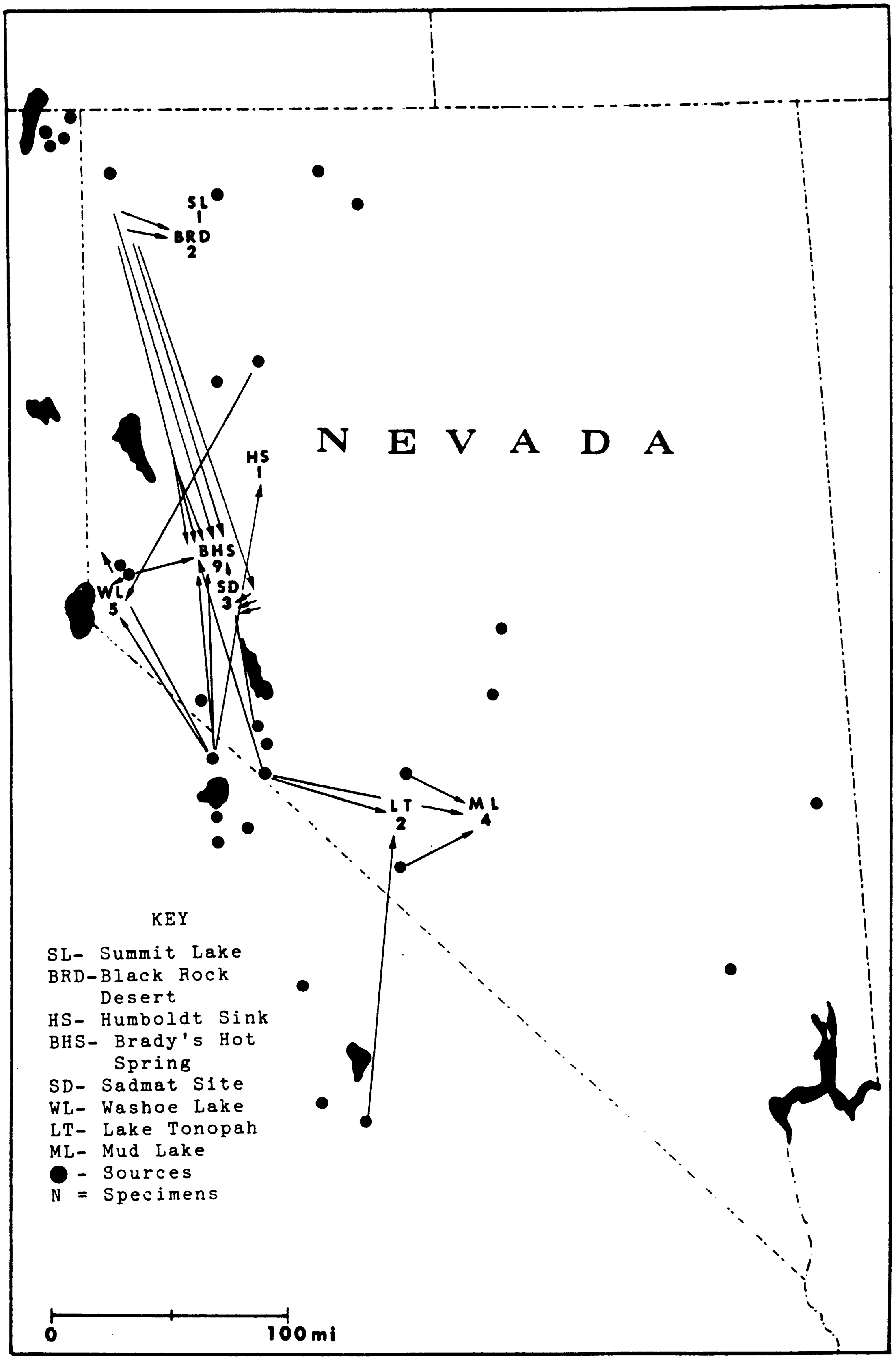

Figure 11. Map of Nevada showing the distribution of some of the well known sources (also shown in Figure 10), and sites and areas where the projectile points in the study sample were recovered.

Fig.	L (cm)	W (cm)	Th (cm)	Wt (g)	Type or Series	Previous Illustrations
1a	3.8	2.0	0.5	3.5	Clovis	Davis and Shutler (1969:166,Fig.4c)
1b	5.3	2.4	0.7	8.2	Clovis	Davis and Shutler (1969:166,Fig.4a)
1c	2.5+	2.8	0.5	4.0	Concave-base	Tuohy (1969b:172,Fig.61)
1d	2.9+	2.5	0.8	5.9	Clovis	Davis & Shutler (1969:167,Fig.5c)
2e	2.7+	2.4	0.4	3.5	Humboldt	Davis & Shutler (1969:166,Fig.4b)
2f	5.9	3.0	0.8	11.7	Clovis	--
2g	4.0	2.3	0.7	5.8	Elko	--
2h	6.7	2.9	1.2	22.3	Scottsbluff	Tuohy (1968:7,Fig.1)
3i	6.9	4.1	1.1	30.4	Plano-convex, thinned	
3j	7.6+	3.0	1.15	24.8	Haskett	Butler (1965, 1967)
4k	5.7+	4.8	1.0	31.0	Clovis	Tuohy (1969b:172,Fig.6z)
4l	6.2	3.3	0.85	16.1	Clovis	Tuohy (1969b:173,Fig.7x)
5m	4.2	3.0	0.7	8.7	Clovis	Tuohy (1969b:172,Fig.6v)
5n	11.0	2.5	0.8	11.0	Parman	--
6o	3.4+	2.1	0.5	3.5	Stemmed, made into drill	
6p	3.5	2.2	0.7	3.1	Lake Mohave variant	
6q	7.0	3.3	1.3	22.0	Haskett	Butler (1967:25,Fig.1);type;see also Butler (1965:19-20,Figs.9,10)
6r	2.4+	2.4	0.7	4.1	Stemmed	
7s	3.6+	2.5	0.6	5.0	Stemmed	--
7t	6.6+	2.4	0.9	6.5	Stemmed	--
7u	2.2+	2.2	0.7	3.4	Stemmed	--
7v	3.6	2.0	0.6	4.3	Stemmed, resharpened	
8w	4.1	1.5	0.6	3.1	Lake Mohave	
8x	7.0	2.5	0.7	7.0	Silver Lake	Tuohy (1969a:150,Fig.5c)
8y	4.1+	2.4	0.6	5.4	Stemmed, made into drill	
8z	4.2	2.2	0.7	5.0	Stemmed	
9aa	3.7+	2.7	0.65	6.1	Stemmed	
9bb	6.7+	2.5	0.9	13.0	Haskett	

Table 1. Dimensions, weight, and typology of the point sample.

Sample No.	Temp. Desig.	Type or Series	U.C.Davis Lab. No.	Fig. No.	Hydration (microns)	Source
1	2053-G-5	Clovis		1a	See Table 3	Majuba Mountain
2	2053-G-4	Clovis		1b	"	Sutro Springs
3	Lowe Coll.	Concave-base		1c	"	Crow Spring
4	Washoe Lake	Clovis		1d	"	Unknown
5	HCB-Shutler	Humboldt		2e	"	Bodie Hills
6	Summit Lake	Clovis		2f	"	Crane Creek
7	Shaber	Elko	39	2g	2.8	Bodie Hills
8	66B	Scottsbluff	VIII	2h	8.7	Massacre Lake/ Guano Valley
9	66A	Plano-Convex flake	65	3i	9.2	Homecamp
10	Lowe Coll.	Haskett	XI	3j	9.3	Queen
11	ES-2	Clovis	I	4k	5.2/ 9.3	Queen
12	2053-G-3	Clovis	II	4l	9.9/ 10.2	Bodie Hills
13	47 Mus.	Clovis	III	5m	15.7	Coso Hot Spring
14	333	Parman	XIII	5n	5.6	Unknown
15	CH4B	Stemmed (drill)	69	6o	7.0	Homecamp B
16	CH10	Lake Mohave	74	6p	8.3	Bodie Hills
17	I-IML	Haskett	XIV	6q	10.4	Sarcobatus Flat
18	CH4A	Stemmed	54	6r	11.9	Bodie Hills
19	CH4B	Stemmed	70	7s	11.0	Homecamp B
20	11-5	Stemmed		7t	11.5	Massacre Lake/ Guano Valley
21	11-9	Stemmed		7u	15.5	Homecamp C
22	CH4D	Stemmed	66	7v	9.5	Homecamp B
23	66H4	Lake Mohave	66	8w	12.7	Massacre Lake/ Guano Valley
24	VIII-M71	Silver Lake	VIII	8x	14.1	Unknown
25	CH4	Stemmed	67	8y	15.5	Mt. Hicks
26	CH4A1	Stemmed	X	8z	10.7	Sutro Springs
27	CH2A	Stemmed	IX	9aa	15.5	Queen
28	73	Haskett	73	9bb	16.2	Massacre Lake/ Guano Valley

Table 2. Concordance of illustrated points with sourcing sample numbers, hydration laboratory numbers, figure numbers, hydration measurements, and sources.

Specimen No.	OTS Lab No.	Fig. No.	Hydration (μ m)	Remarks
1 2053-G-5	2883	1a	5.4 surface/7.8 crack	varies, some abrasion
2 2053-G-4	2884	1b	5.5	good
3 Lowe	2885	1c	9.8 [1]	good, some abrasion
4 Washo	2886	1d	10.6 crack	crack reading only, no surface
5 Shtlr	2887	2e	3.1 surface/3.5 crack	good

[1] Hydration bands on both the medial break and bifacial surfaces are 9.8 μ m.

Table 3. Report of obsidian hdyration analysis of five points (all readings ±0.2 μm).

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SUMMARY COMMENTS

OBSIDIAN STUDIES IN 1984

Fred Stross

Twenty years have elapsed since the publication of the first papers showing that the sources of obsidian glass could be determined by physico-chemical methods. Since that time, the quality of the analytical determinations has improved, leading to real confidence in the source assignments; provenience determinations have been correlated with dating procedures, thus complementing archaeological information, and criteria have been suggested that allow those interested to assess the reliability of the determinations. Data banks representing detailed compositions of obsidian sources are being established in many regions and cost effective procedures are being developed which enable the user to reduce the cost of determining provenience. Attempts to use computer techniques to improve interpretation of results, or further to reduce the cost, continue to be made. Finally, other physical measurements have been developed which have contributed to the information desired, such as the measurement of obsidian hdyration to determine the time at which the obsidian was last worked. My specific comments on the papers in this volume will be restricted primarily to those dealing with obsidian source analysis, since obsidian hydration analysis is covered in detail in the following paper by Meighan.

Hughes' paper fittingly sets the tone by emphasizing that producing high quality data is more important than using sophisticated statistical, computerized methods for their interpretation. The statistics needed to make valid provenience assignments on the basis of high quality data are relatively simple; if the data are not sufficiently discriminating to make such assignments, this fact is normally quite obvious without the use of complex techniques. I think it was very worthwhile for Hughes to have gone to the trouble of pointing out in detail how treacherous it can be for the non-expert in statistics to use advanced methods and how, in the few ambiguous cases, mismatch by computer is at least as likely as mismatch on the basis of simpler calculations.

Nelson's article reflects careful work, and his data generally compare very well with data obtained by other workers on some of the same sources. They provide a useful addition to the data bank on Great Basin obsidian already available in the literature. However, given the reservations expressed by Nelson on page 29 of his paper, I am unsure why the author used discriminant analysis to distinguish between sources. In my estimation, computers are useful in obsidian analysis for cataloging data and for performing routine analytical calculating and evaluating functions, but in the interpretive techniques that have become so fashionable in this type of study, the pitfalls for many practitioners are far more significant than the benefits they are likely to gain, as noted previously by Hughes.

Hampel's paper is much to the point, concisely and competently discussing some problems in x-ray fluorescence analysis that are most commonly ignored in obsidian analytical studies.

Bettinger, Delacorte and Jackson explore the utility of visual sourcing. They make the point that in a limited geographic area, some obsidian sources can be recognized by visual inspection, aided by low power magnification. Given their success, one might consider recommending visual inspection as a first step, rough classification in sorting out a group of otherwise unsorted artifacts before subjecting them to formal geochemical analysis.

Discussion

Source data. It seems obvious (though not generally appreciated) that it is highly desirable to present data on source composition in absolute concentration units (i.e. parts per million or weight percent) and to report the abundances of the largest possible number of independently variable elements to allow users of different analytical methods some latitude in the use of the data bank. Well defined error limits should be recorded for the results, so that other workers may estimate the reliability of the data. Source composition data require much more complete, accurate and sensitive information than artifactual data, since the validity of the artifact-to-source assignments rests upon the reliability of the source composition data. Another advantage of high quality source information is the reduction in cost that may be achieved if detailed source data are available. It often is possible to reduce the number of elements needed for source assignment by an ability to focus on diagnostic elements, and to use more economical methods for determining them than used for the more complete source analysis. Generating high quality source data makes it possible to match analytical results on excavated artifacts against published source composition data, thus avoiding the cost and duplication of effort of determining source compositions in an area more than once.

Computer analysis. Since element composition data provide distinguishable patterns, such arrays of data seem eminently suitable for pattern recognition applications by computers. Although a host of papers have appeared which describe computer use for this purpose, the results of these projects have at times been disappointing. The first classification of artifact data often involves only a few elements, so that the greatest potential of computing techniques in this connection is not utilized. In fact, the labor of setting up and using the often complex programs may be greater than judicious use of a hand calculator. Worst of all, many workers are tempted to regard statistical computer methods as a substitute for careful analytical work. As Hughes has emphasized, the application of pattern recognition capabilities of the computer to inadequate analytical work may lead not only to incorrect results, but it also is difficult to recognize this defect because tha apparent rigor of the procedure engenders a false sense of security in both the unwary analyst and the reader. Obviously, the computer has its place in this work for many of the calculation procedures, but its benefits in pattern recognition applications in artifact sourcing have been overestimated; it is very pertinent that some of these shortcomings have been pointed out in this volume.

OVERVIEW OF GREAT BASIN OBSIDIAN STUDIES

Clement W. Meighan

The papers in this volume represent a considerable advance in both the amount of interest and the sophistication of the reports on obsidian studies. I recollect a national meeting only about 15 years ago at which a symposium on this subject was able to attract only five or six people -- the speakers were there but the audience was not. In contrast, the symposium reported here had a large and faithful audience which sat through an entire day of papers relating to obsidian studies. Archaeologists have clearly recognized by now the significance and the multiple applications of these studies to archaeological problems. Particularly in the Great Basin, there is greater appreciation of what these studies can do for archaeological understanding, since the Great Basin is characterized by many shallow (often surface only) archaeological sites, and often the commonest cultural material is obsidian artifacts and chipping waste, due to the multiplicity of obsidian sources in and around the Basin. With so many sites lacking samples datable by radiocarbon, and lacking physical stratigraphy, obsidian dating is often the best source of information on the age of the site, and obsidian sourcing is often the best source of information on trade relationships. Hence the relatively greater interest in obsidian studies from those who work in the Great Basin.

There are four papers here dealing with the important issue of determining the source from which obsidian came. In spite of the increasing attention to this problem, there are still numerous practical and intellectual matters to resolve. Hughes points out the difficulties in determining the sources of obsidian (through chemical analyses of varying kinds), and cautions that incorrect assignment to source may go undetected and unchallenged, leading to misinterpretation of trade routes. This may also lead to confusion in applying obsidian hydration dating, because it is becoming increasingly clear that different obsidian sources show formation of hydration bands at quite different rates.

Hampel also stresses the need to adhere to specific basic procedures in x-ray fluorescence (XRF) studies of obsidian sources, while pointing to refinements of the method. Nelson applies XRF methods and identifies the chemistry of many obsidian sources in the Great Basin. This is particularly valuable since most of the earlier source identifications were made on obsidian from California, at one edge of the Great Basin. Comparative data for Nevada, Oregon, Utah, and Idaho greatly expand knowledge of Great Basin sources and provide a much firmer basis for future studies of contact and obsidian trade.

Nelson observes that prehistoric people usually got their obsidian from the closest available source but that there are numerous instances where this practice was not followed -- hence the basis for study, and hopefully explanation, of long-distance trade in the past. That long-distance trade was very important can be seen in the great amounts of obsidian recovered in areas where there are few or no sources of this material, such as coastal southern California.

The possibility of avoiding the cost and difficulty of laboratory determinations of obsidian sources is considered by Bettinger, Delacorte, and Jackson, who have sorted obsidian on the basis of visual characteristics with reasonable success. This procedure is not without some error, but neither are XRF or other procedures. Obviously an in-depth study requires some chemical analyses to identify source, but once the sources are known the visual characteristics of the obsidian can be carefully tabulated and observed and it then becomes possible to recognize pieces from that source without a full chemical analysis of each piece. This is important because there is no possibility that chemical analyses can be performed on the many thousands of individual specimens that can be collected from even a single site. A judicious combination of chemistry and observation of known traits is probably the only practical way of dealing with large collections.

It may be noted that other "short-cut" methods are applicable as well. Some obsidian sources have aberrantly high or low amounts of specific trace elements, and it will be possible to get a pretty good idea of the source by testing merely for those elements. This requires more thorough knowledge of the chemistry of all the sources than is now available, but as the data base improves it will certainly become possible to identify some obsidian by looking for distinctive marker elements without the need for more detailed analysis. It has also been pointed out by Jonathon Ericson that in some cases the hydration rate for specific obsidian sources is very distinctive (exceptionally fast or exceptionally slow) and that in some archaeological contexts it is possible to know the source by knowing the applicable hydration rate.

All of these short-cut methods involve extrapolation from knowing part of the data to drawing conclusions about other parts of the data, a common-sense procedure which often works but is based on assumptions. All of us making use of such methods are obligated to make clear in our reports what statements are verified objectively and what statements are in fact assumptions or extrapolations from partial data.

These various studies of obsidian sources are aided by the apparent tendency of obsidian users to collect their obsidian from small areas, returning to the same spots (possible to the same ledge or outcrop) over many visits. This behavioral pattern tended to collect and distribute more uniform kinds of obsidian than would be the case if obsidian were gathered at random from every possible location on a given obsidian flow. In other words, the total chemical variability of an obsidian flow does not seem to be strongly reflected in the observed obsidian found in archaeological contexts. This fortunate circumstance of patterned collecting activity aids both chemical and visual identifications of source.

Three papers deal with obsidian hydration analysis. R.J. Jackson points out the methodological problems of hydration studies and makes the same plea for standardized and replicable procedures voiced by the sourcing specialists with respect to <u>their</u> methodology. Jackson provides interesting comparisons between obsidian hydration readings obtained on the same specimens by different laboratories. At least two other studies of this kind are in press or underway, and they provide objective evidence on replicability, margins of uncertainty, and other problems with making the slides and measuring the obsidian hydration bands. Cross-checking between laboratories becomes increasingly important as the number of technicians increases and differing optical and slide-preparation techniques are used. Some of the observed variability between laboratories may be due to measuring the obsidian hydration band at different locations, but whatever the cause we should all have a little humility about the accuracy of our hydration measurements.

I would like to add to Jackson's observations of variability my own plea for a) systematic publication of obsidian hydration readings, and b) systematic cataloging and preservation of the published slides. It is important to know who the technician was, how the work was done, and where the original slide can be obtained for checking and verification of the reading. It is equally important that the original data be made available; it is impossible to know what sites have been studied for obsidian hydration since the majority of the data are sequestered and are either never made public, or appear as an appendix to a site report many years after the readings were taken. It is my impression that the researchers on obsidian sources have done a much better job of publishing their basic data and making it available for comparative study. Only two of the existing obsidian hydration laboratories make systematic efforts to publish their readings, and only UCLA publishes all of its obsidian hydration readings and makes all of its slides available to scholars for re-examination when needed.

The two other articles in this section of the volume (Davis; Termbour and Friedman) deal with the important matter of the temperature variable in the rate of obsidian hydration. Davis presents a most ingenious way of determining effective hydration temperature in the past. Trembour and Friedman stress the importance of temperature in their calculations of hydration rate, with small differences in temperature having a large effect on the rate. They also stress the necessity of sorting out surface from buried pieces and the difficulties arising from obsidian exposed for even a short time to high temperatures (such as a cooking fire or brush fire). This is a formidable set of difficulties in archaeological collections. Not only does the temperature vary seasonally, but the period of hydration may span warmer and cooler climatic cycles. Any obsidian lying in chapparal areas has a high probability of exposure to brush-fires every 50 years or so if not more often. Pieces once on the surface get interred by ground squirrels, while the busy rodents are also bringing up buried pieces and depositing them in the surface sunshine. Finding the temperature in order to work out the hydration rate involves a number of unverifiable assumptions and may lead to the same kinds of difficulties encountered with amino-acid dating, in which incorrect assumptions about past temperatures lead to major dating errors. The system can be scientifically correct and internally consistent but still be wrong as to the age of the specimens due to unknown factors.

Because of these problems, working it the other way around -- that is, using hydration to determine effective annual temperature, seems to me a more promising approach. In many cases such findings would be immensely valuable, for the paleotemperature data would be indicative of other environmental variables relevant to the interpretation of archaeological sites.

Fortunately, the archaeologist has additional data which provide a check on both dating and temperature results. For chronology, these data include other chronological methods such as radiocarbon, stratigraphic placement, and "time markers" of known age in the artifact assemblage. Obsidian hydration dates are tested against these empirical data, and when there is serious lack of agreement, re-evaluation of the results is required. With regard to conclusions about ancient temperatures, many archaeological sites contain an abundance of climatic indicators in the form of pollen, floral, and faunal remains. Plant and animal remains reflect the climate and temperature of the time when the archaeological site was in use, so they can provide a separate line of evidence to evaluate paleotemperature calculations.

The final section includes four papers which apply the methodology to varying problems and use the source and hydration findings to move forward to archaeological explanations.

T.L. Jackson assesses aboriginal obsidian production from two eastern California sources, Bodie Hills and Casa Diablo. In a detailed review of the several exploratory studies done on obsidian hydration from these sources, including his own large sample of 800 pieces from Casa Diablo, it is made clear that "production" curves are only as believable as the supporting chronological evidence. For these two sources, understanding of the chronology (obsidian hydration rate) is still elusive, although the serious consideration given by Jackson should get us closer to understanding the hydration rate(s).

Bouey and Basgall look at trade relationships between the Great Basin and California, based on hydration dating and the model of "economic articulation" which proposes that a change in production and/or exchange in one area will have an observable repercussion in the other. As these authors point out, any general explanations applicable to such a large area are tentative because of the many scholars involved in collection of the data, plus differing interpretations of obsidian hydration rates. Nonetheless, an effort can be made to look at political and economic processes which might explain the observed pattern of obsidian distribution (in space and time). They conclude that Central California was a major consumer area, that the obsidian trade was linked, at least initially, to a demand for status goods, and that there was a production peak between 3000-1600 B.P. Other sub-regions are evaluated and some alternative models are also presented, including population replacement in local regions.

In examining the structure of obsidian exchange, Bouey and Basgall are getting a great deal of historical explanation out of trade in a single raw material: obsidian. Their suggestions go far beyond anything dreamed of by most of the diggers of an earlier era, who never anticipated that general conclusions of broad significance could come from their arrowheads and chipping waste. On one hand, it is encouraging to find that the dating and sourcing of obsidian can contribute to new ideas and that archaeologists are able to advance their field of study to new levels of sophistication. On the other hand, there is also the moral that careful field work, documentation, and preservation of the obsidian collections are increasingly essential. Shortcomings in the traditional archaeology will abort formulations of the new archaeology, and the two need to work hand in hand if the discipline is to move ahead intellectually.

The obsidian hydration paper by R.J. Jackson points out the value of using obsidian hydration for relative dating, and reminds us that obsidian hydration studies have important values whether or not they can be used for absolute dating. However, he cannot resist providing another suggested absolute chronology for Casa Diablo obsidian. This is worth brief general comment:

First, the four Casa Diablo hydration rates in Table 2 differ, but not substantially except for readings under 2 or over 10 microns, sizes that are quite rare in known archaeological collections of Casa Diablo obsidian. I would conclude that all of the proposed rates in Table 2 give reasonable age determinations, even though they were worked out in different ways by different people. It is distressing that we cannot support our formulae beyond question, but it should be encouraging that similar answers are determined independently. In the mid-range, for example, the four rates are within a span of 211 years for 3 microns of hydration, with a span of 156 years for 6 mircrons, and within 610 years for 9 microns. This strikes me as amazing consistency, the greatest variability being ± 12-20% of the true age, assuming the true age to be somewhere in the time range expressed by the four rates. This is certainly far better absolute dating than has been available for most Great Basin sites.

Assuming Jackson's rate to be the most valid, the time intervals between each micron of hydration (omitting the small bands) are:

Micron 2-3	520 years
Micron 3-4	613 years
Micron 4-5	689 years
Micron 5-6	759 years
Micron 6-7	822 years
Micron 7-8	879 years
Micron 9-8	934 years
Micron 9-10	984 years

It is extremely rare to have an archaeological context showing 2-10 microns of hydration, and often the range of hydration is only 3 or 4 microns in a given site or archaeological horizon. I have pointed out elsewhere (Meighan 1983) how this narrow range in a given context makes it impossible to verify an empirically-determined rate formule — there is just not enough variability in most archaeological collections to test the formula. Hence almost any formula can be made to yield acceptable answers. Assume, for example, a collection of Casa Diablo obsidian with a range of 7-10 microns of hydration. With a couple of radiocarbon dates, one might well propose a simple linear rate of 700 years per micron (average of Jackson's intervals for 7-10 microns). Such a rate would differ from Jackson's numbers by as little as 19 years and as much as 537 years (the latter in a Jackson age of 6837 years, or 8% of the age). The 700-year rate would not work at all for hydration bands of significantly larger or smaller size, but in our hypothetical collection it would be as close to the truth as any other rate, and it would be impossible to dispute by any archaeological evidence (including radiocarbon dating).

The rough and ready linear rates used for determining ages of particular assemblages are irritating to the purists, lack elegance, and are "wrong" in the laboratory or theoretical sense. But they work with the real data the archaeologist has at his disposal, and they do provide age determinations as close to the truth as we can measure.

When dealing with collections from a wide area and many sites, as Jackson does in this paper, the rough and ready methods can lead to some big mistakes. Jackson's relative dating chart (Figure 3) shows hydration measurements of 1-10 microns; here he avoids absolute dates but does provide the hydration sequence for six named Great Basin cultures. Since most of these cultures are defined primarily on the basis of surface finds, the objective sequencing is no mean accomplishment and provides a good basis for further analysis.

In the final paper, Tuohy applies obsidian dating to 38 "early man" points from Nevada, including examples of Clovis, Elko, and other types associated with earlier cultures. In this complex subject, Tuohy confronts the morass of typological confusion, varying obsidian sources, and related problems which make it difficult to go beyond tentative conclusions.

One situation observed here by Tuohy (and elsewhere by others) poses a considerable problem to users of obsidian hydration data. This is the confusion caused by abrasion or erosion of the surface of obsidian pieces. Exposure of obsidian to desert winds full of sand and silt can sand-blast the surface and alter the obsidian hydration band. This abrasion can sometimes be detected microscopically, and it is no problem if all the hydration layer is removed. But there is good evidence that abrasion can sometimes remove part of the hydration band and leave a fraction of it intact to be measured by the archaeologist. This shows most clearly when the surface of a specimen has a small hydration layer while a much larger layer is visible in cracks protected from surface abrasion. There does not appear to be any simple solution for this problem, but a large enough sample will usually detect anomalous readings and raise the suspicion that something has happened to the surface of the piece being studied.

On the whole, the papers in this volume represent a lot of brain power. In my view, Great Basin archaeology is put forward by these studies, which reflect the ever-present problem of getting more information out of the fragmentary evidence of past activity. It is a contribution to raise an intelligent question, and the authors of these papers have laid out a challenging agenda of relevant issues to be explored. There is, of course, much more to Great Basin archaeology than obsidian studies, but it is remarkable how studies of this ubiquitous raw material can throw light on multiple lines of investigation: chronology, trade and even social organization and social classes. The editor of this volume deserves much credit for organizing and presenting this set of papers; they will be essential references for future workers.

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