Current Directions In California Obsidian Studies

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CURRENT DIRECTIONS IN CALIFORNIA OBSIDIAN STUDIES

Richard E. Hughes
Editor

With Contributions by

Mark E. Basgall, Robert L. Bettinger, Jonathon E. Ericson, David A. Fredrickson,
M.C. Hall and R.J. Jackson, Richard E. Hughes, Thomas L. Jackson, Thomas M. Origer,
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Editor's Preface

Most of the papers in this volume were first presented at a symposium I organized and chaired at the annual meeting of the Society for California Archaeology in Santa Rosa, California, March 28, 1986. At my request, the authors subsequently revised and expanded their oral presentations to the versions appearing here. Although the paper by Bettinger was not presented at this symposium, it is included here because of its clear relevance to the "current directions" theme of the volume. My own contribution was revised and expanded from a paper first presented at the annual meeting of the Society for California Archaeology, held in Redding, California, March 25, 1988.

Several individuals offered assistance during the time these papers were being revised, reviewed, and prepared for publication. Clement Meighan, Irving Friedman and Fred Stross offered constructive comments on various papers and John Graham, former Coordinator of the Archaeological Research Facility, and its new Director, Kent Lightfoot, deserve thanks for providing technical support crucial to completing the volume. Marie Floyd, Publications Manager, Institute of Urban and Regional Development, University of California, Berkeley, skillfully transformed the manuscripts into monograph form.

I would like particularly to acknowledge the generous assistance of Don Frazier for helping us to bring this volume to publication. Don has a long-term interest in, and enthusiasm for, western North American prehistory (the Great Basin in particular), and I am pleased to express thanks and gratitude for his unfailing support.

Finally, I extend very special thanks to Suzanne Sundholm, formerly of the Archaeological Research Facility, for all manner of assistance during the time these papers were being revised and finalized for publication. Throughout our long association, Suzanne's organizational and editorial skills, and facility with the English language, have transformed many a rough manuscript into a polished piece of work. This time was no exception. Thanks.

R.E. Hughes
December 1989

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A NEW LOOK AT MONO BASIN OBSIDIANS

Richard E. Hughes

INTRODUCTION

Over the past decade, archaeologists in the Far West have made tremendous strides toward understanding the prehistoric uses of obsidian. This understanding, however, did not derive solely from within archaeology, but is best understood as a highly beneficial consequence of a partnership forged between archaeology and the physical sciences- in particular geology, chemistry and physics. Geochemical studies of obsidian have provided the data base from which inferences about the existence of long distance conveyance networks and differences in source use by artifact function have been advanced. Such studies have received well deserved notoriety, and I believe that several of these avenues of research have taught us things about the past that we could not have learned any other way.

However laudable, many of these descriptive and interpretive papers prepared by archaeologists have relied on older geochemical studies that have been superceded by current work. For example, some of the artifact-to-source attributions made in Jack's (1976) pioneering study of prehistoric California obsidian use were in error- partly because the source inventory for certain parts of the state was much less complete than it is today, and partly because the artifact analyses in those days were not reported quantitatively in international measurement units (i.e. in parts per million [ppm] and weight percent composition). Aside from the issue of interlaboratory comparison, it is now widely recognized that quantitative data are indispensable for distinguishing among certain varieties of chemically similar obsidians, and that quantitative data are sometimes the only way researchers can identify and separate glasses from different geographic sources that have superficially similar geochemical "profiles". While these facts are well known to the few specialists currently involved in archaeometric studies of volcanic glasses, such information has not filtered to the large number of archaeologists who routinely use older data for interpretive purposes. Consequently, the results of older work becomes conventionalized in the archaeological literature, and it is only rarely that older results are subjected to critical scrutiny or re-evaluation. Although it has been argued that archaeologists should be concerned with developing research strategies to address what we don't know (Binford 1986), I have suggested that it is equally important to critically evaluate assumptions that may never have been subjected to serious scrutiny but that, through repetition, have become embedded as conventional knowledge (Hughes 1988a). It is only by engaging in such critical exercises that incorrect conventions can be exposed and replaced by results obtained through more exacting methods.

For the past year or so, I have been involved in field and laboratory studies of the geochemistry of obsidians from the Coso volcanic field and, more recently, obsidians from the Mono Basin (see Figure 1). At first blush, there would appear to be little reason for spending one's time studying either of these two places since the trace element geochemistry of Coso obsidian and Mono Basin obsidians has been in print for more than a decade (Jack and Carmichael 1969; Jack 1976). However, my choice of these research sites was guided by a concern for reexamination of convention; specifically, those conventions derived from early trace element work that have come to influence the way archaeologists use the terms "Coso" and "Mono Basin" obsidians. My Coso research (Hughes 1988a) showed that orthodox views about this "source" were in error; specifically, four geochemically distinct obsidians suitable for toolstone manufacture were exploited prehistorically in the Coso volcanic field and environs- not the single "Coso" variety assumed by previous workers. In addition, major and minor element chemical data indicated that each of these glass types should hydrate at a slightly different rate (Hughes 1988a; see Stevenson and Scheetz [this volume], and Ericson [this volume]). In light of the Coso results, it seemed appropriate to extend the re-examination of convention to the Mono Basin; specifically, the Mono Craters and Mono Glass Mountain obsidian sources of central eastern California.

BACKGROUND

In California, no study of geochemical characterization of obsidian use can proceed without reference to the pioneering work of Robert Jack (1976; Jack and Carmichael 1969). In the first significant pilot study of California obsidians, Jack and Carmichael (1969) employed wavelength dispersive x-ray fluorescence analysis to identify unique trace element signatures for nearly all the volcanic glasses they examined except for

> "..... two groups of samples which are virtually indistinguishable from one another; these are the extrusive materials of Mono Craters and those of (Mono) Glass Mountain 20 or so miles toward the east in the Mono basin" (Jack and Carmichael 1969: 22).

Their conclusion was that "no really definite trace-element criteria can be found to distinguish the acid lavas from the two (Mono Craters/Mono Glass Mountain) centers" (ibid.; my addition).

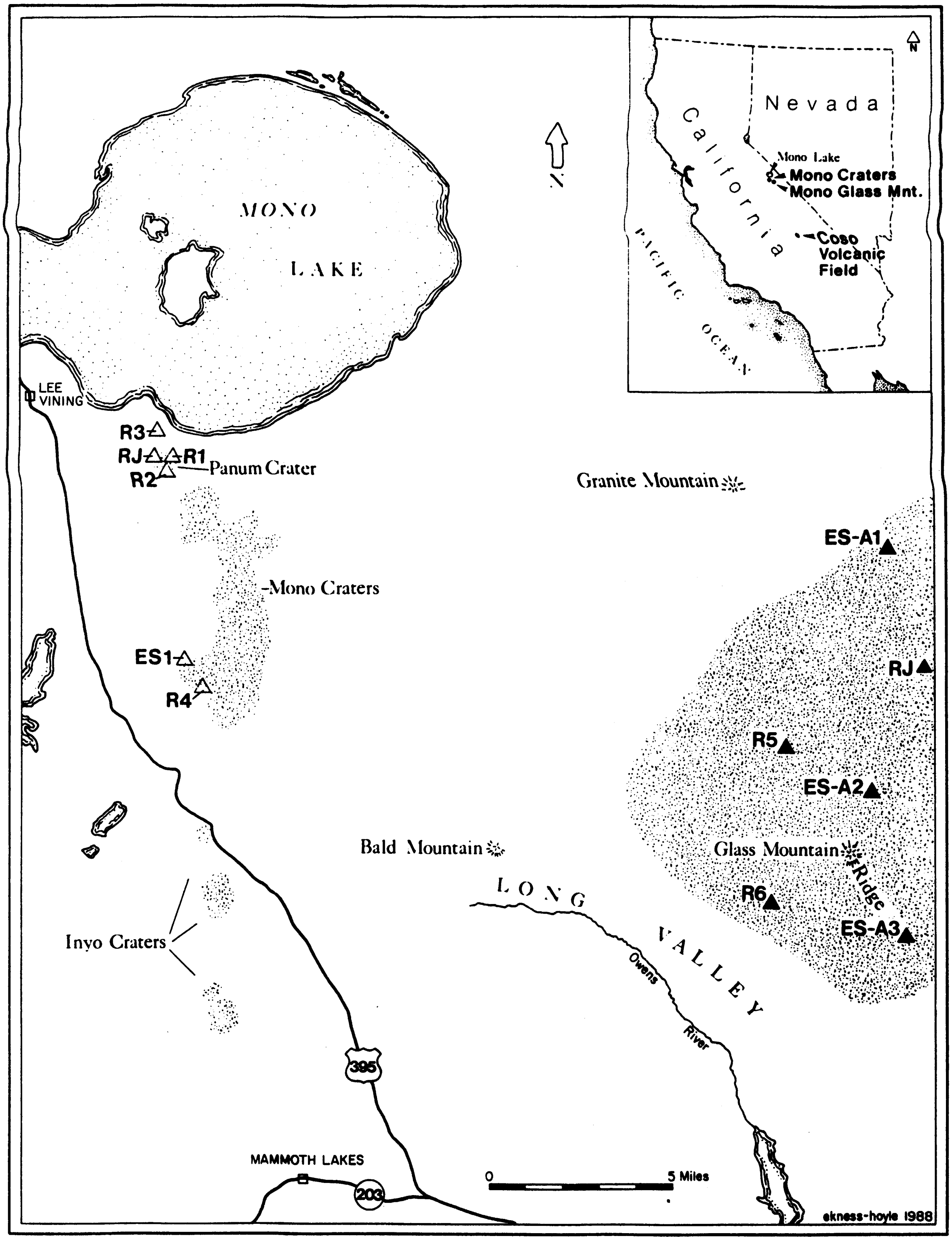
In a later study employing larger numbers of powdered geological obsidian samples from Mono Craters and Mono Glass Mountain, Jack (1976: 191, 203) was able to recognize geochemical distinctions between these sources. However, the non-quantitative, rapid-scan (i.e., semi-quantitative) technique he employed to study artifacts was unsuccessful in replicating the distinctions generated from quantitative analyses of powdered obsidian source samples. In short, the quantitative data (generated from analyses of crushed and powdered obsidian samples) provided a separation between these two sources, but the semi-quantitative (i.e., peak ratios generated from unmodified artifacts) data could not. Through subsequent experimentation, Jack found that Fe Kα / Mn Kβ intensity ratios (semi-quantitative data) effectively separated geological obsidian samples from the two sources, so this non-destructive technique was applied to archaeological specimens (see Jack 1976: 212). Despite Jack's apparent success in drawing meaningful distinctions between these two sources using non-destructive Fe/Mn ratios, Jackson (1974: 13-14, 77)- using the same x-ray fluorescence system and analytical conditions- found that this ratio did not unambiguously separate Mono Craters from Mono Glass Mountain obsidian at archaeological sites around June Lake.

To put this in perspective, it is important to remember that this x-ray work was conducted more than 15 years ago, well before the advent of energy dispersive x-ray fluorescence spectrometers employing microcomputer-based software capable of generating quantitative estimates of certain minor, trace, and rare earth elements non-destructively. The point here is that since no substantive archaeometric research has been undertaken on the problem since 1974, it is understandable that archaeologists repeat the convention that "Mono Craters obsidian is often chemically indistinguishable from Mono Glass Mountain" (cf. T. Jackson 1974: 50 with R. Jackson 1985: 106; Hull 1988: 172).

THE PROBLEM

From the present standpoint, the question was whether or not it was possible to identify quantitatively significant contrasts- using current state-of-the-art instrumentation- that would separate Mono Craters from Mono Glass Mountain obsidians non-destructively. While Jack had demonstrated that these glass types could be separated geochemically, his results applied strictly to crushed and powdered samples (i.e., the contrasts were identified using a destructive form of analysis). Thus, despite the demonstrated ability to partition Mono Craters from Mono Glass Mountain glasses, Jack's results are of limited archaeological

FIGURE 1
LOCATION OF THE STUDY AREA IN CENTRAL EASTERN CALIFORNIA (INSET), SHOWING OBSIDIAN COLLECTION AREAS



utility because the contrasts were determined using a technique which required sacrificing some portion of the specimen for analysis. The present study has an explicit bias toward identifying elemental contrasts that can be applied to archaeological specimens without sacrificing <u>any</u> portion of an irreplaceable archaeological artifact (see also Hughes 1986, 1988b). The question, then, is whether artifacts manufactured from Mono Craters obsidian are distinguishable geochemically from specimens fashioned from Mono Glass Mountain material.

To address this issue, it was first necessary to collect and analyze geological samples from several areas at both sources. Obviously, if geochemical distinctions could not be recognized between source specimens, it would be pointless to extend the study to an analysis of artifacts. The principal bias attending sample collection was that the obsidian had to be of toolstone caliber; loci containing obsidians charged with abundant phenocrysts and spherulites were not included in this study. The presence of prehistoric knapping stations associated with several of the collection locations made it readily apparent that they contained obsidian suitable for analysis.

THE STUDY AREA

Mono Craters and Mono Glass Mountain (see Figure 1) have attracted the attention of geologists for more than a century, beginning with I.C. Russell's (1889) pioneering work in the Mono Valley area. Glass Mountain erupted silicic rhyolite (obsidian) sporadically during between ca. 2.1-1.2 million years ago (m.y.a.) and 1.1-0.8 m.y.a. (Metz and Mahood 1985). Mono Craters glasses are much younger- the earliest are Holocene in age, but some researchers believe that aphyric glasses erupted rather late in the sequence, perhaps within the past 2,000 years (Friedman 1968; Wood 1984). Obsidian at Mono Craters was erupted as recently as ca. 600 years ago, about the same time as obsidian at Inyo Craters ca. 20 km to the south (Sampson 1987; Sampson and Cameron 1987). Interested researchers should consult the recent geological literature (e.g., Gilbert et al. 1968; Loney 1968; Noble et al. 1972; Bailey, Dalrymple, and Lanphere 1976; Wood 1977; Hildreth 1979; Miller 1985; Metz and Mahood 1985; Sieh and Bursik 1986; Sampson and Cameron 1987) on the Mono Craters, Mono Glass Mountain and the Inyo volcanic chain for detailed discussion of the complex eruptive history in the Mono Lake/Long Valley area an environs.

ANALYSIS AND RESULTS: GEOLOGIC SOURCE SPECIMENS

Samples analyzed in the present study were collected at nine different loci at Mono Craters and Mono Glass Mountain (see Figure 1), and each group of specimens was subjected to x-ray fluorescence analysis to determine quantitative composition of ten minor, trace, and rare earth elements (see Table 1). All of these measurements were determined non-destructively on unmodified flakes and chunks with suitably flat surfaces. The analytical technique and calibration procedure employed for the x-ray analyses have been described elsewhere (Hughes 1988a). Although quantitative values for the element barium (Ba) have proved extremely useful for distinguishing between some chemically similar obsidians (e.g. Bodie Hills vs. Pine Grove Hills [see Hughes 1985], and Franz Valley vs. Napa Valley [see Jackson, this volume]), Ba occurs in both Mono Craters and Mono Glass Mountain obsidians in concentrations below the detection limit (< 14 ppm) of the x-ray fluorescence instrument employed here (see Hughes 1988a). Consequently, Ba concentrations were not measured for either Mono Craters nor Mono Glass Mountain source standards.

Table 1 presents the selected minor and trace element measurements determined for obsidian samples from each sampling locus. Initially, each locus from each source was treated as a separate unit. However, a one-way analysis of variance (ANOVA) test performed on the six best measured elements from Mono Craters and Mono Glass Mountain showed no significant departure from randomness at the 0.05 alpha level. The sole exception was the element rubidium (Rb) with shows relative depletion in Mono Glass Mountain sampling loci R5 and R6 (see Table 1). Noble and Hedge (1970) observed a similar situation with Rb in their Mono Glass Mountain samples, attributing the observed differences to "small variations in the degree of late-stage crystal fractionation" [in the parent magma] (Noble et al. 1972:1180; my addition). This finding of intra-source homogeniety is congruent with the results of other researchers (e.g. Loney 1968; Jack and Carmichael 1969:19), and the elemental data generated here are in excellent agreement with those published by previous analysts (see Table 2). Figure 2 illustrates the agreement between the non-destructive, quantitative measurements generated herein with the previous x-ray fluorescence work of Jack. Samples OS-9 and OS-10 represent, respectively, powdered obsidian samples from Mono Craters and Mono Glass Mountain (cf. Table 2).

TABLE 1

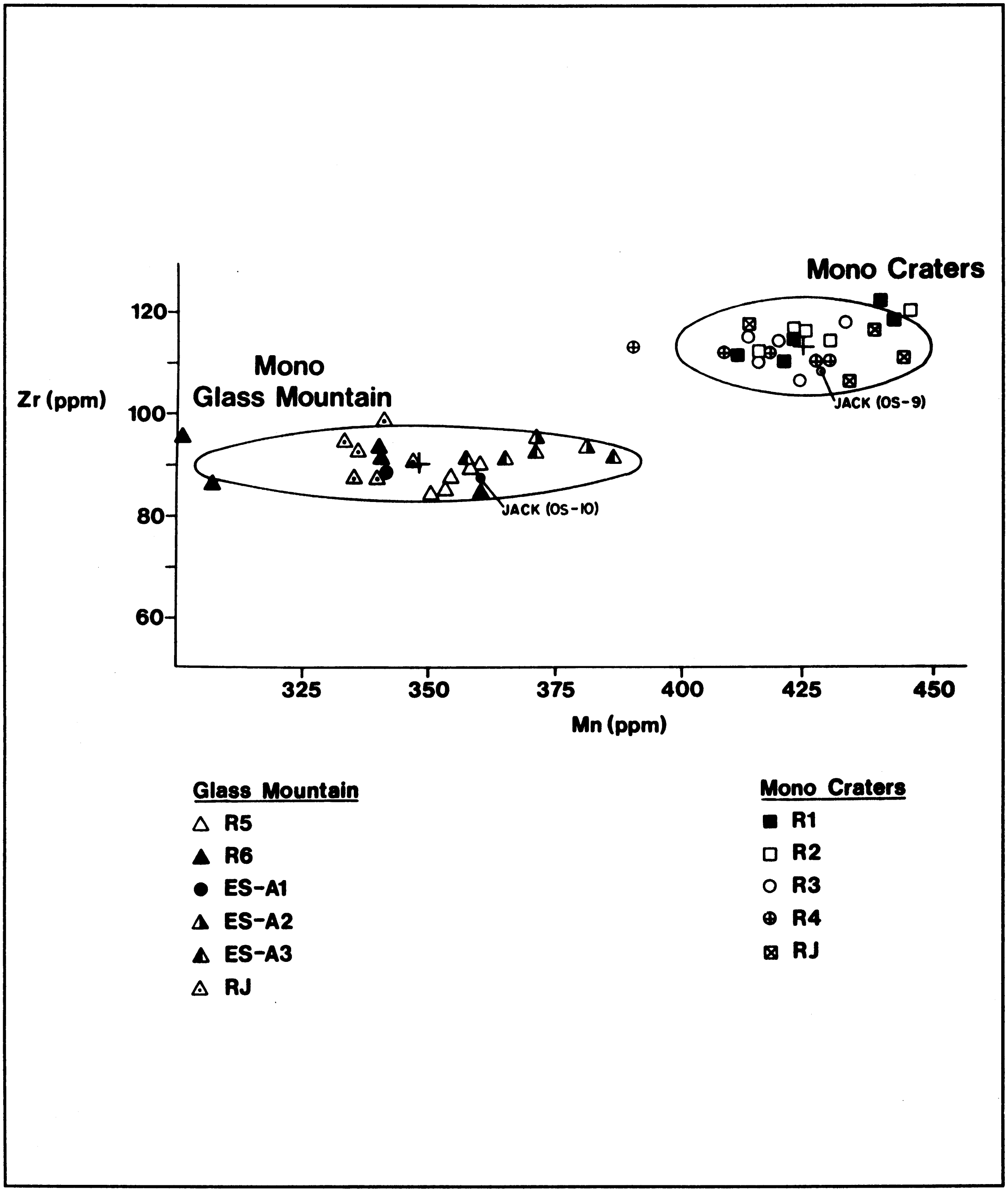
MINOR AND TRACE ELEMENT COMPOSITION OF OBSIDIAN FROM EIGHT SAMPLING LOCATIONS AT MONO CRATERS AND MONO GLASS MOUNTAIN BY ENERGY DISPERSIVE X-RAY FLUORESCENCE SPECTROMETRY

		MONO CRATERS				MONO GLASS MOUNTAIN			
Element		R1 (n=5)	R2 (n=5)	R3 (n=5)	R4 (n=5)	R5 (n=5)	R6 (n=5)	RJ (n=6)	ES A2 + A3 (n=4)
Ti	x	401	425	406	449	511	539	484	469
	S.D.	9	15	26	37	29	62	16	12
	CV%	2	4	6	8	6	12	3	3
Mn	x	426	426	420	414	355	322	339	370
	S.D.	12	10	8	17	4	27	5	10
	CV%	3	2	2	4	1	9	2	3
$Fe_2O_3{}^T$	x	1.24	1.27	1.27	1.23	.84	.84	.84	.84
	S.D.	.04	.03	.03	.04	.02	.03	.01	.02
	CV%	3	2	2	3	3	4	1	3
Zn	x	53	52	54	54	44	41	45	41
	S.D.	2	3	2	5	4	8	4	4
	CV%	4	7	4	8	9	20	9	10
Ga	x	19	14	20	20	17	17	17	20
	S.D.	3	7	3	4	2	4	4	2
	CV%	17	48	13	18	9	20	24	9
Rb	x	179	180	178	177	148	155	176	182
	S.D.	7	6	11	7	6	9	5	7
	CV%	4	3	6	4	4	6	3	4
Sr	x	9	10	9	10	7	7	6	5
	S.D.	1	1	1	1	1	1	1	1
	CV%	7	8	10	13	8	22	10	16
Y	x	28	28	28	27	22	25	26	29
	S.D.	2	1	1	2	2	1	1	3
	CV%	6	4	4	7	10	5	4	10
Zr	x	115	116	112	111	87	90	92	92
	S.D.	5	4	5	2	3	4	4	2
	CV%	4	3	4	2	3	5	5	2
Nb	x	20	21	22	22	23	21	23	27
	S.D.	3	3	3	3	3	2	2	1
	CV%	16	15	12	11	12	9	10	5

Collection localities correspond to locations specified in Figure 1; x= sample mean; S.D.= sample standard deviation; CV=coefficient of variation; all values in parts per million (ppm) except iron, which is expressed as total iron ($Fe_2O_3{}^T$) in weight percent. The specific geographic locations for each collection locus are- R1 and R2: T1N, R27E, NE 1/4 of SW 1/4, Section 19; R3: T1N, R27E, SW 1/4 of SW 1/4, Section 18; R4: T1S, R27E, SE 1/4 of SW 1/4, Section 20; R5: T1S, R29E, SW 1/4 of NW 1/4, Section 36; R6: T2S, R29E, SE 1/4 of SW 1/4, Section 23; RJ: T1S, R30E, SW 1/4 of Section 14, SE 1/4 of Section 15, NW 1/4 of Section 22; ES A2: T2S, R30E, SE 1/4 of SW 1/4, Section 5; ES A3: T2S, R30E, N 1/2 of SE 1/4, Section 28.

FIGURE 2

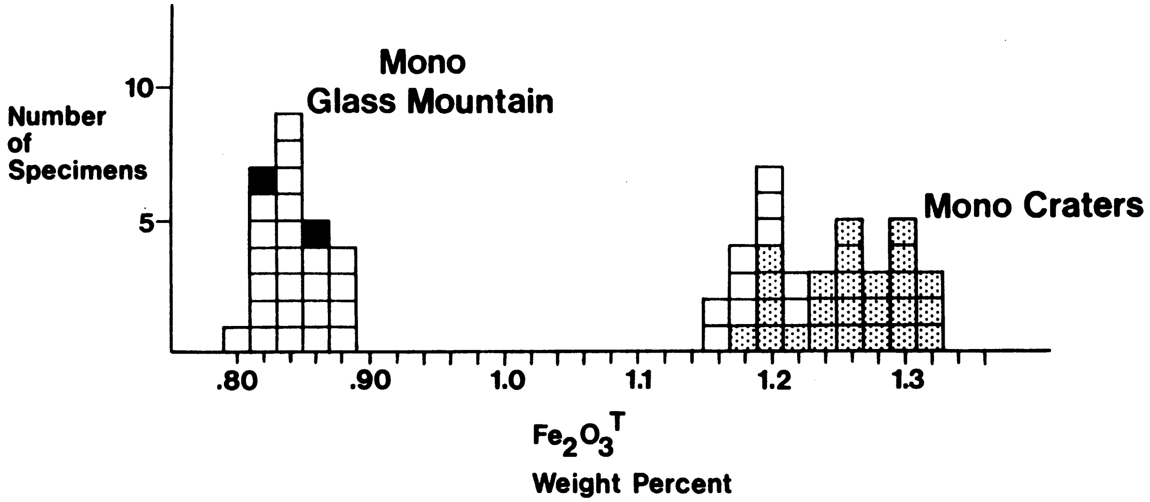
SCATTER DIAGRAM OF ZR VS. MN COMPOSITION FOR GEOLOGIC SOURCE SPECIMENS FROM MONO GLASS MOUNTAIN AND MONO CRATERS, WITH 95% CONFIDENCE INTERVAL ELLIPSE OVERLAYS



Different symbols represent values for obsidians collected from locations specified in Figure 1.

FIGURE 3

HISTOGRAM OF TOTAL IRON ($FE_2O_3^T$) COMPOSITION OF MONO GLASS MOUNTAIN AND MONO CRATERS OBSIDIANS COMPARED TO ARTIFACTS FROM LEE VINING (CA-MNO-446) AND FORT MOUNTAIN ROCKSHELTER (CA-CAL-991)



Open squares to the left of the figure represent Mono Glass Mountain source specimens, while filled squares are values for artifacts L-305 and L-405 from Mno-446. Stippled squares at the right of the figure represent Mono Craters source specimens, while open squares are values for eight samples from Mno-446 (L-72a, -72b, -93a, -93b, -395, -435, -516b, -530b) and two from Cal-991 (389-138 and -178).

The results of the x-ray analyses can be seen in Figure 2, plotting the concentration of Zr against Mn. I selected these two elements because they help draw the clearest contrasts between these two sources. Each symbol represents a group of specimens sampled from loci specified on Figure 1. The ellipses express the 95% confidence limits for Zr and Mn for each source (see Pires-Ferreira [1975] and Hughes [1988a] for discussion of probability ellipses). It is clear from this figure that Mono Glass Mountain obsidian contains lower concentrations of both Zr and Mn than Mono Craters, and that Mono Glass Mountain is more variable in Mn composition. Perhaps the sharpest contrast between these sources can be illustrated by comparing their total iron ($Fe_2O_3^T$) concentrations (Figure 3). Again, Mono Glass Mountain contains considerably less total iron than Mono Craters. This difference is particularly noteworthy since the iron results are expressed here in weight percent units, not parts per million; thus each increment on this graph (Figure 3) represents 200 ppm.

ANALYSIS AND RESULTS: OBSIDIAN ARTIFACTS

While the elemental data reviewed above support the position that geological samples of Mono Craters obsidian can be distinguished non-destructively from those occurring at Mono Glass Mountain, there remains the issue of whether or not these distinctions can be applied productively to archaeological research. To address the archaeological issue, I selected a small group of specimens from two archaeological collections; the Lee Vining site (Mno-446) and Fort Mountain Rockshelter (Cal-991). I had previously analyzed specimens from both of these sites (Hughes 1981, 1988c), and was unable to attribute them with confidence to either Mono Craters or Mono Glass Mountain using the criteria proposed by Jack (1976). While it would be desirable to reanalyze all of the specimens originally attributed by Jack (1976) to Mono Craters/

TABLE 2

ELEMENTAL COMPOSITION OF PRESSED OBSIDIAN POWDERS FROM MONO CRATERS AND MONO GLASS MOUNTAIN BY WAVELENGTH DISPERSIVE X-RAY FLUORESCENCE SPECTROMETRY

	MONO CRATERS					MONO GLASS MOUNTAIN				
Element	OS-9	CAM-104	CAM-105	CAM-108	CAM-110	OS-10	CAM-139	CAM-141	CAM-144	679-406
Ti	403	375 (386)	390 (401)	390 (402)	395 (407)	458	440 (451)	505 (522)	480 (494)	475 (488)
Mn	441	445 (461)	450 (465)	450 (469)	455 (471)	378	390 (403)	305 (318)	295 (304)	360 (374)
Zn	46	40 (60)	40 (58)	40 (60)	35 (57)	33	25 (38)	20 (33)	20 (32)	35 (54)
Ga	17	15 (24)	15 (23)	15 (24)	15 (21)	15	15 (21)	15 (22)	15 (23)	15 (23)
Rb	195	190 (199)	195 (206)	190 (201)	195 (203)	201	195 (204)	170 (180)	170 (181)	190 (201)
Sr	3	5 (6)	5 (6)	5 (5)	5 (6)	3	< 5 (2)	< 5 (2)	< 5 (2)	< 5 -
Y	21	30 (29)	25 (27)	25 (25)	25 (26)	14	25 (24)	20 (20)	25 (27)	30 (30)
Zr	115	110 (112)	105 (109)	105 (110)	105 (110)	89	85 (90)	90 (97)	90 (97)	95 (98)
Nb	21	20 (20)	20 (20)	20 (20)	30 (30)	18	30 (30)	20 (20)	25 (25)	25 (25)
Ba	17	10 (14)	20 (18)	20 (20)	20 (20)	-	30 (< 10)	10 (14)	10 (< 10)	20 (22)

Samples OS-9 and -10 from C.W. Chesterman collection; OS-9 from Mono Craters, T1S, R27E, Section 19; OS-10 from Mono Glass Mountain, T2S, R30E, SW1/4 of Section 21. Values for all CAM samples, and 679-406, from Jack and Carmichael (1969: 27-28). Measurements enclosed in parentheses are analyses of the same samples by R.N. Jack, subsumed in Jack (1976: Table 11.4). Unpublished measurements for samples OS-9 and -10 also courtesy of R.N. Jack.

Mono Glass Mountain, the present sample from Mno-446 and Cal-991 illustrates the archaeological utility of these quantitative data.

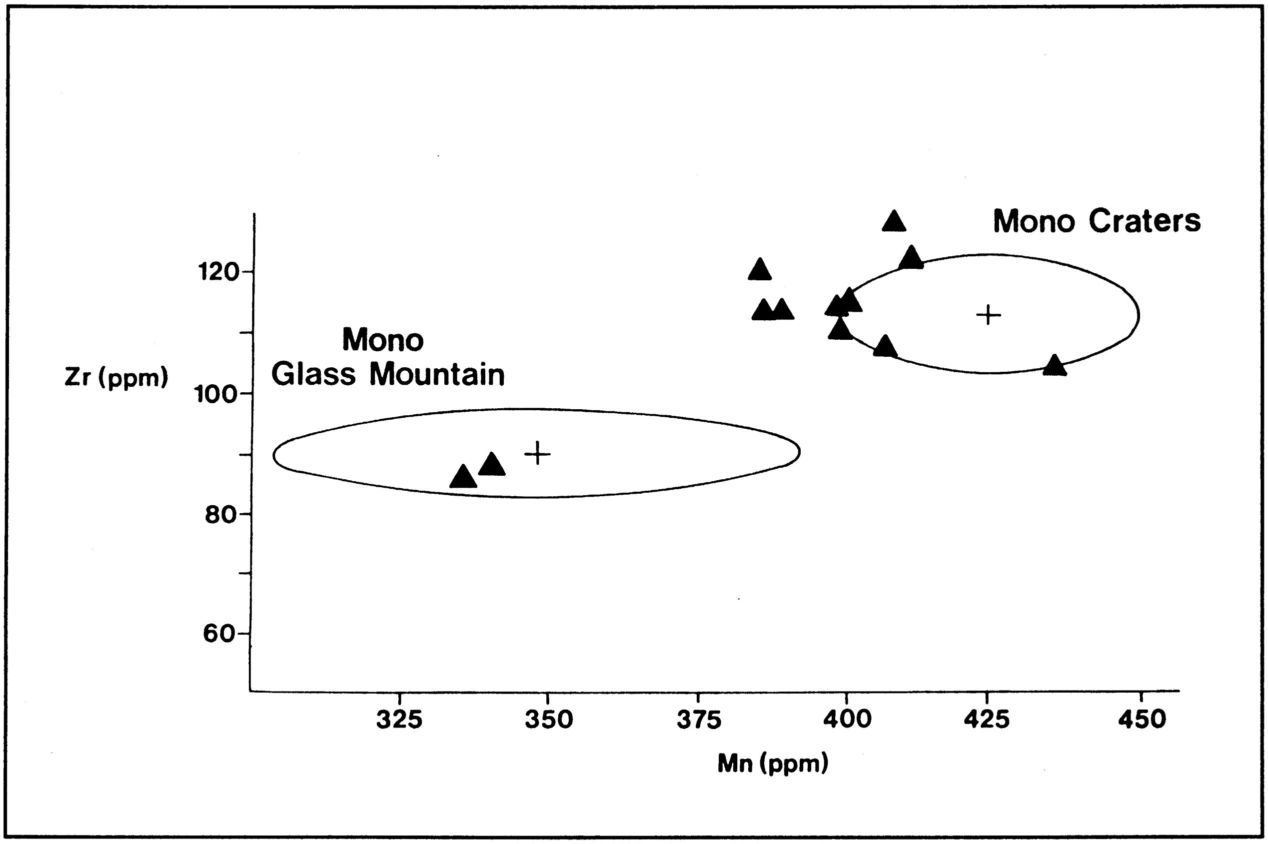
Figure 4 shows the Zr and Mn concentrations for artifacts from Lee Vining (Mno-446) and Fort Mountain Rockshelter (Cal-991) in relation to 95% probability ellipses for each source. Although there is some scatter along the Mn axis for Mono Craters specimens, it is no more extreme statistically than that observed in source samples. Figure 3 illustrates the total iron composition of the Mno-446 and Cal-991 artifacts plotted in relation to Mono Craters and Mono Glass Mountain source standards.

DISCUSSION

It is worth considering briefly why iron and manganese values were used successfully here to separate Mono Craters and Mono Glass Mountain non-destructively, when previous attempts were largely unsuccessful. Previous workers dealing with geology/archaeology issues were not able to present **quantitative** measurements for iron due, in part, to the inherent technological limitations of microcomputerless x-ray spectrometry in the early-late 1970's. Although Mn values generated from analysis of powdered obsidian samples were published (Jack (1976: Tables

FIGURE 4

SCATTER DIAGRAM SHOWING 95% CONFIDENCE INTERVAL ELLIPSES FOR ZR AND MN COMPOSITION IN OBSIDIAN SOURCE SPECIMENS FROM MONO GLASS MOUNTAIN AND MONO CRATERS COMPARED WITH VALUES FOR ARTIFACTS (FILLED TRIANGLES)



Zr and Mn values for both artifacts within the Mono Glass Mountain ellipse were generated for specimens L-305 and -405 from Mno-446 (see legend for Figure 3); values for artifacts corresponding with the Mono Craters ellipse are the same ten specified in the legend for Figure 3, above.

TABLE 3

CHEMICAL INDEX VALUES FOR MONO GLASS MOUNTAIN AND MONO CRATERS OBSIDIAN

Source sample number	n obsidian samples	Obsidian Source (Geochemical Type)	Chemical Index
GM-2	1	Mono Glass Mountain	53
GM-4	1	Mono Glass Mountain	53
MO-3B	1	Mono Craters	46
A	1	Mono Craters	44

Determined from data presented in Noble et al. (1972: Table 1).

11.1-11.5; Jack and Carmichael 1969: Table 1), Jack's only use of iron was **semi-quantitative** (peak intensity counts; see Jack 1976: 188). In the Mono Craters/ Mono Glass Mountain case, the difficulty with employing semi-quantitative data (peak intensity count ratios) is that values for iron and manganese vary in the **same direction**; Mono Glass Mountain contains less manganese and iron than Mono Craters. Consequently, despite differences in absolute concentrations, ratios of these values (Fe and Mn) will be quite similar. I suspect that if iron composition had been reported quantitatively, the prevailing convention that Mono Craters and Mono Glass Mountain cannot be clearly distinguished would never have come into existence.

Implications for Obsidian Hydration Studies

This study has been concerned specifically with using trace element geochemistry to segregate Mono Craters and Mono Glass Mountain obsidian nondestructively, but it is relevant to discuss some of the implications of these findings for obsidian hydration dating. It is widely known that although variability in trace element composition is the most practical way to "fingerprint" obsidian sources and artifacts, it is the variability in major and certain minor constituents of volcanic glass which appear to directly influence the obsidian hydration process (Friedman and Long 1976). So, while these trace element data show distinctions between sources, they are not directly relevant to determining potential differences in hydration rates.

Fortunately, the major and minor element composition for obsidian from Mono Craters and Mono Glass Mountain has been published (Carmichael 1967: Table 5; Noble et al. 1972: Table 1), so it was possible to derive the chemical index values for each glass type (cf. Friedman and Long 1976: 347) to see whether or not significant differences obtained. Table 3 shows that Mono Craters obsidian has chemical index values of 44-46, while Mono Glass Mountain has a value of 53. These differences support the position that Mono Glass Mountain and Mono Craters obsidian should hydrate at slightly different rates- but whether these differences are of sufficient magnitude to effect obsidian hydration dating studies is somewhat more difficult to address with data presently at hand.

To illustrate the current difficulty in extrapolating from chemistry to chronometrics, consider current studies in the Coso volcanic field. Stevenson and Scheetz' (this volume) induced hydration research with two varieties of Coso volcanic field obsidian shows an agreement between chemical index values and induced hydration estimates for one source (Sugarloaf Mountain), while the induced rate for the other (West Sugarloaf) is slightly slower than that predicted by the chemical index. On the other hand, Ericson's (this volume) induced hydration work with the same two glasses indicates no significant difference in hydration rates between the two flows. The implications for the Mono Craters/Mono Glass Mountain case are correspondingly contradictory; following Ericson's lead, the differences in chemical indexes between Mono Craters and Mono Glass Mountain might well convert to insignificant differences in hydration rate. Alternatively, extrapolation from Stevenson and Scheetz' results would support the position that potentially significant hydration rate differences may obtain between the two sources. In any event, it is clear that actual induced hydration experiments will have to be conducted on source samples from Mono Craters and Mono Glass Mountain before further speculation is warranted. Outside the laboratory, of course, archaeologically relevant hydration rate calculations must include consideration of a host of affective variables (see Ericson [this volume]) including effective hydration temperature (EHT) extant in particular burial environments, as well as potential changes in these through time.

CONCLUDING COMMENTS

The results of this study show that non-destructive energy dispersive x-ray fluorescence spectrometry is capable of identifying comparatively fine-grained disinctions between the geochemical compositions of acid lavas from Mono Craters and Mono Glass Mountain, and that these distinctions are directly applicable to the study of archaeological collections.

These Mono Craters/Mono Glass Mountain results, along with those generated independently in the Coso volcanic field (Hughes 1988a), will hopefully stimulate renewed interest and research on other obsidian "sources" assumed to represent indivisible geochemical types. Such research might prove fruitful elsewhere in the Mono Basin area; specifically, at the Casa Diablo source where rhyolitic flows of different ages have been identified (Bailey 1989) which may have produced obsidians with contrasting trace element geochemistries.

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TOWARD FLOW-SPECIFIC OBSIDIAN HYDRATION RATES: COSO VOLCANIC FIELD, INYO COUNTY, CALIFORNIA

Jonathon E. Ericson

INTRODUCTION

As a result of research conducted under proprietary contract in 1981-83, it was observed that the hydration measurements among Coso obsidian artifacts showed definable clusters which correlated to chemical groups. The trace element values for Coso obsidian artifacts determined by x-ray fluorescence analysis, following techniques presented by Jack (1976), appeared to be concentrated in three centroids, which were nominally called Coso A, B and C. After testing petrographic characterization, it was determined there was significant clustering of crystal fabric among the three sub-groups so these data, along with chemical characerization data, were used to discriminate sub-groups (see Hughes 1988). In the course of this research, what appeared to be flow-specific hydration rates among the *different* Coso flows were observed. This paper presents results verifying these observations. It is now apparent that the next development in the refinement of obsidian hydration dating will require the formulation of flow-specific hydration rates in complex volcanic fields, such as the Coso volcanic field.

When Friedman and Smith (1960) first introduced obsidian hydration dating, they suggested that rhyolitic glasses would hydrate at different rates than basaltic glasses, but they did not suggest that the chemical and physical variability among different rhyolitic sources would change hydration rates significantly. Three data sets indicated that hydration rates would vary among rhyolitic obsidian sources. Aiello (1969) observed differential hydration associated with changes of bulk chemical composition of a single artifact from Grimes Canyon fused shale, and bimodality in hydration and bulk chemistry composition were indicated for one cache from Oregon and one stratigraphic layer form Amapa, Mexico (Ericson, MacKenzie, and Berger 1976). These preliminary findings provided the justification for further research to study the relationships among the chemical and physical properties of obsidians and their rates of hydration (Ericson 1977; 1981a, b).

In response to these findings, California archaeologists have incorporated obsidian hydration dating and chemical characterization as part of their research strategies. As a consequence there have been a number of empirical obsidian hydration rates formulated with available archaeological data. The Coso obsidian source is one of the better examples of the variation of rate determinations (Ericson 1978; Meighan 1978; 1981; 1983; Friedman and Obradovich 1981; Findlow et al. 1982; Michels 1983; Elston and Zeier 1984; Koerper et al. 1986). This variation is now a cause for concern among practicing field archaeologists.

There are a number of plausible explanations which may account for the number of hydration rates for the Coso source. Each condition may act singly or in concert with other conditions to produce the observed variation of rates; 1) errors introduced using relative chronological markers to formulate a hydration rate; 2) misidentification of obsidian source during the chemical characterization process (type II error); 3) non-standardization of hydration measurements among laboratories; 4) lack of true temporal association between obsidian artifacts and associated chronological samples; 5) different effective temperatures among different study areas; 6) the affects of unidentified environmental (soil) variables among different study areas; and 7) the affects of different chemical and physical variables among different flows within a single source of obsidian. The last point is a major focus of this paper. Hopefully, all of these effects will become the focus of future studies and reexamination of earlier research.

At this point, it is important to define terminology. The term, source, as employed in source-specific hydration rates (Ericson 1977; 1981), refers to one or more eruptive events within a volcanic field which have valid geochemical entity relative to other sources. For example, Coso (Ericson 1977; 1981) refers to both West Sugarloaf and Sugarloaf which are geologically superimposed yet whose eruptions are separated by approximately 100,000 years (Bacon et al. 1981; Friedman and Obradovich 1981). From the standpoint of chemical characterization of obsidian artifacts by short half-life neutron activation analysis and x-ray fluorescence analysis, Coso is a viable geochemical source relative to other sources (Ericson and Kimberlin n.d.). Obsidian artifacts from Coso have been grouped together for purposes of rate formulation.

The term, flow, as used herein to refer to flow-specific hydration rates, refers to an eruptive event which provided a geological source of obsidian for prehistoric exploitation. The term flow may refer to a dome, a flow, or a primary deposit of ejecta (bombs, blocks, lapilli, etc.) or other structure. Thus, a flow-specific hydration rate is the average hydration rate for a particular geographical and geological structure. The use of geographical terms to further define the flow is the most preferable approach if available, e.g., West Sugarloaf flow-specific rate, Sugarloaf Mountain flow-specific rate, etc.

SCIENTIFIC BASIS FOR FLOW-SPECIFIC RATES

New evidence indicates that flow-specific hydration rates may lead to the refinement of obsidian hydration dating in California. The scope of the author's earlier research was limited to source-specific empirical obsidian hydration rates which combined artifacts from different flows as one source (Ericson 1977; 1981). New evidence presented herein indicates that most Pleistocene and recent volcanic fields in California have multiple flows and other volcanic structures which provided obsidian to prehistoric Indian groups (Ericson, Hagan and Chesterman 1976).

The scientific basis for flow-specific obsidian hydration rates within a single obsidian source can be documented by appeal to the effects of chemical and physical parameters on the rates of hydration (Ericson 1981). The reproducibility of the same chemical and physical parameters for each eruptive event within a volcanic field is considered to be relatively low — that was apparent from initial stages of field work noted in 1970 (Ericson, Hagan and Chesterman 1976). There may be important variations of properties among flows which may affect the hydration rates; 1) the intrinsic water content, a known variable of hydration (Ericson 1977; 1981a, b), may vary tremendously between within eruptive events; 2) chemical interaction of two magmatic melts such as rhyolitic and basaltic or rhyolitic and andesitic may cause changes in the chemistry, e.g., Modoc Glass Mountain; 3) differential remelting of different host rocks forming the magma chamber and vents may cause chemical variations; 4) phase separation by differential settling of crystals within the magma chamber or flow may cause variations in the chemistry between events; 5) the melting of the contact surface during eruption may change the obsidian chemistry of the flow. Each of these factors, uniquely or in combination with other factors, can alter the chemical composition of the obsidians within a volcanic field.

In addition, physical factors like viscosity and temperature of the melt may cause variations among obsidians. In this case, variations may occur as a reuslt of; 1) differential release of water from the obsidian structure; 2) differential crystallization both of the amount and type of crystals formed; 3) degree of annealing and degree of mechanical stress; 4) the amount and type of glass phase separation in the obsidian; 5) the conditions of cooling history of the obsidian.

It is to be expected that flow-specific obsidian hydration rates will vary, significantly in some cases, given the above chemical and physical parameters which will change the properties of obsidian flows within a volcanic field. The Coso volcanic field seemed to be a good target for further study given initial data.

TABLE 1
POTASSIUM-ARGON AGES OF OBSIDIAN FLOWS, COSO VOLCANIC FIELD, CALIFORNIA, REFERRED TO IN FIGURE 1

Flow No.	Flow Name	Age (Myrs.)	Location
2-1	West Sugarloaf	1.08 ± .06	Southern
2-2	Sugarloaf Mountain	0.044 ± .022	Southern
2-3		n.d.	Central
2-4		0.093 ± .026	Central
2-5		n.d.	Central
2-6		0.99 ± .12 or 0.244 ± .028	Western

RESEARCH DESIGN AND OBJECTIVE

For the objectives of this research- investigation of potential variability in the hydration rates for obsidian flows in the Coso volcanic field- the laboratory-induced hydration experiments were considered the best experimental approach to control temperature, pressure, and other variables of hydration. If significant differences were observed among the flows in the Coso volcanic field, it would support the development of a set of flow-specific hydration rates.

THE STUDY AREA AND THE SAMPLES

The Coso volcanic field has been the focus of the geological study for some time (Ross and Yates 1943; Chesterman 1956), and recently the volcanic field has been studied to establish its geothermal potential (Austin and Pringle 1970; Lanphere et al. 1975;Bacon et al. 1981; 1982). On the basis of a cursory petrographic examination without chemical analyses, Lanphere et al. (1975) suggest that a single rhyolitic magma of relatively homogeneous composition fed all domes. More recently, Bacon et al. (1981) indicate that seven geochemically distinctive eruptive episodes occurred within the Pleistocene of the Coso volcanic field. Granodiorite and quartz monzonite of the Sierra Nevada batholith form the bedrock of the Coso volcanic field (Lanphere et al. 1975; Duffield and Bacon 1981). The geologic ages of the domes and flows determined by potassium argon dating are presented in Table 1.

Several research trips were conducted in 1981-82 to resurvey the volcanos in the Coso area. Pilot Knob to the southeast of Coso and Jawbone Canyon to the southwest were surveyed without success in locating viable obsidian. Pilot Knob had altered to perlite and was too brittle for tool manufacture, and the Jawbone Canyon "obsidian" source reported by Ericson et al. (1976) was not relocated. Apache tears from Fort Irwin were provided by Mr. Russell Kaldenberg of the Bureau of Land Management . He mentioned that a new obsidian source had been found some distance away at Mid Hills, but this source was not investigated. A second trip (1982-1983) to the Coso volcanic field was more extensive than reported earlier (Ericson et al. 1976). Multiple sources of obsidian and prehistoric workshops were observed, and flow samples were collected for experimental purposes (see Figure 1). Dr. Kenneth Pringle, China Lake Naval Weapons Center and Clay A. Singer of Santa Monica, CA accompanied the author in the field. The flow of West Sugarloaf (Hughes 1988) is Flow 2-1. The dome of Sugarloaf (Hughes 1988) is Flow 2-2, which was sampled at two locations.

EXPERIMENTAL PROCEDURES

The obsidian samples were cut into 1 cm cubes with a lapidary diamond saw and assigned a random code for the double-blind experiments. Obsidian cubes were fractured into halves, labeled, weighed, washed in doubly deionized water, and placed upright at the base of a 23 ml Teflon container of a Parr reaction vessel.

For experiment 3, one-half cube of each obsidian sample was placed with 14 ml doubly deionized water in the Parr reaction vessel for the two-phase system test. Twenty-five Parr reaction vessels were loaded for each run. Each vessel was placed in at a predetermined shelf position in a programmable oven pre-set at 174 degrees ± 1 degree C for 137 hours. For experiment 5, the matched half cube was placed with approximately 5 drops of doubly deionized water, to provide a saturated vapor environment without excess water. The actual amount of water was pre-calculated from volume measurements of the sample and reaction vessel and weighted to ±0.00005 gm accuracy. The shelf position of the Parr reaction vessels, time of hydration and temperature were reproduced for experiments 3 and 5. Following the procedures outlined above, additional obsidian samples were hydrated in the oven at 174 ± 1 degree C for 88 hours and 240 hours.

The hydrated surface of the experimental samples was prepared by cutting a slice from the cube, grinding one cut surface with aluminum oxide grits (nos. 95 and 400) on glass plates, mounting the ground surface on a pre-labeled flat (pre-ground) petrographic glass slide with epoxy cement, grinding the surface down to 75 micron thickness using optical birefringence colors of crystal inclusions, and covering with cover glass and Canada balsam. Using these prepared slides, the hydration bands were measured for the induced hydration bands, which were measured on a Vickers split image system pre-calibrated with a stage micrometer mounted on a petrographic microscope. The results of the experiments are presented in Tables 2 and 3.

EXPERIMENTAL RESULTS AND ANALYSIS

The hydration measurement data, presented in Table 2, were used in a matched pairs difference test to determine whether there is a significant difference if the system is single-phase (saturated vapor only) or two-phase (liquid plus vapor). The null hypothesis of this statistical test was that the mean of the differences was zero or ($H_0 : \mu_d = 0$). The critical value of t for the two-tailed statistical test is 2.064 (at the 0.05 alpha-level) with 24 degrees of freedom. The matched pairs test was performed on the data. It was found that $t = 1.674$ where $d = 0.2972$, $n = 25$, and $S_d = 0.8876$. Thus, the t-test results were not significant, given these experimental data. It was concluded that the hydration process was not significantly different whether the system was single-phase (saturated vapor) or two-phase (vapor and liquid).

The data presented in Table 3 were grouped by flow. The standard errors of the means were calculated for each experiment for each flow. West Sugarloaf (Flow 2-1), Sugarloaf Mountain (Flow 2-2), the northerly flows (Flows 2-3 and 2-5) have standard errors below 16% and appear to have excellent internal consistency. Flows 2-4 and 2-6 to the north and northwest appear to have greater internal variability relative to hydration. Further research may reveal why this variability was observed.

Hydration data were plotted in Figure 2. It is clear from this figure that the hydration rates for West Sugarloaf (Flow 2-1) and Sugarloaf Mountain (Flow 2-2) are very similar. Based on calculating chemical indexes (Friedman and Long 1976) derived from data provided by Bacon et al. 1981 (Table 1a-d), Hughes (1988) predicted that the rate of hydration for West Sugarloaf should be slower than Sugarloaf Mountain. However, the experimental data generated here do not support a significant difference in hydration rates between the two flows. The northerly flows (Flows 2-3 and 2-5) appear rather similar to each other, and their rates are approximately 40% faster than the West Sugarloaf and Sugarloaf Mountain rates. The northwesterly flows (Flow 2-4 and Flow 2-6), which appear to have more variable hydration rates, are intermediate between West Sugarloaf/Sugarloaf Mountain and the northerly flows (Flows 2-3 and 2-5).

DISCUSSION

Although the results of this research are preliminary, the findings are significant. It does appear that induced hydration experiments can be used to evaluate whether obsidians from different flows will hydrate at different rates. In cases where inter-flow variation is significant, flow-specific rates will have to be determined using archaeological data. Whether laboratory-induced hydration rates will be effective and accurate enough for archaeological application is conjecture at this point. Preliminary evaluation of the laboratory-induced hydration rates presented so far for Coso (Michels 1983; Stevenson and Scheetz [this volume]) suggests that discrepancies exist relative to archaeological data (Meighan 1981; 1983; Elston and Zeier 1984). The experimental results suggest that intra-flow variation of hydration can be evaluated, but it may be negotiable or variable depending on homogeneity of the obsidian.

TABLE 2

HYDRATION RESULTS IN MICRONS OF ISOTHERMAL MATCHED SAMPLE PAIRS IN SATURATED VAPOR AND VAPOR/LIQUID PHASES (174 DEGREES C)

Blind Code	Sample Field No.	Exp. 3 Vapor/Liquid	Exp. 5 Saturated Vapor
A	2-3-3-5	6.77 ± .14	7.41 ± .28
B	2-3-1-3	5.99 ± .06	5.63 ± .08
C	2-2-1-2	4.73 ± .06	4.52 ± .09
D	2-2-2-2	4.62 ± .08	5.40 ± .14
E	2-1-0-2	4.94 ± .16	4.63 ± .12
F	2-1-0-3	4.72 ± .11	5.94 ± .08
G	2-4-1-3	3.97 ± .09	3.34 ± .14
H	2-4-1-2	5.72 ± .09	4.86 ± .07
I	2-5-1-3	6.49 ± .06	6.73 ± .09
J	2-5-1-1	6.27 ± .08	7.00 ± .20
K	2-6-1-5	6.24 ± .08	7.55 ± .07
L	2-6-1-3	6.87 ± .08	6.78 ± .13
M	2-4-1-5	6.84 ± .08	6.83 ± .06
N	2-1-0-5	4.91 ± .15	5.64 ± .05
O	2-1-0-5	5.09 ± .11	5.31 ± .05
P	2-2-2-1	4.41 ± .09	4.26 ± .09
Q	2-2-1-3	4.97 ± .07	5.22 ± .04
R	2-6-1-1	6.24 ± .15	6.88 ± .19
S	2-6-1-2	5.78 ± .06	6.91 ± .10
T	2-5-1-2	7.93 ± .12	7.39 ± .05
U	2-5-1-5	7.17 ± .08	6.12 ± .10
V	2-3-1-4	6.19 ± .14	6.09 ± .08
W	2-3-2-5	6.28 ± .05	6.77 ± .07
X	2-3-2-4	6.86 ± .08	10.16 ± .23
Y	2-3-3-4	6.31 ± .07	6.37 ± .06

TABLE 3
OBSIDIAN HYDRATION MEASUREMENTS IN MICRONS GROUPED BY FLOW FOR THREE EXPERIMENTAL PERIODS FOR THE COSO VOLCANIC FIELD

Flow No.	Sample Members	Group Hydration (88 hours)	Coeff. Var.
2-1	O,E,F,N	3.72 ± 0.22	6.
2-2	C,Q,P,D	3.32 ± 0.53	16.
2-3	B,V,X,W,Y,A	5.12 ± 0.25	5.
2-4	H,G,M	4.12 ± 1.22	29.
2-5	J,T,I,U	5.04 ± 0.65	13.
2-6	R,S,L,K	4.34 ± 0.48	11.
Flow No.	Sample Members	Group Hydration (137 hours)	Coeff. Var.
2-1	O,E,F,N	4.92 ± 0.15	3.
2-2	C,Q,P,D	4.68 ± 0.23	5.
2-3	B,V,X,W,Y,A	6.40 ± 0.34	5.
2-4	H,G,M	5.51 ± 1.45	26.
2-5	J,T,I,U	6.97 ± 0.75	11.
2-6	R,S,L,K	6.28 ± 0.45	7.
Flow No.	Sample Members	Group Hydration (240 hours)	Coeff. Var.
2-1	O,E,F,N	6.49 ± 0.99	15.
2-2	C,Q,P,D	6.20 ± 0.33	5.
2-3	B,V,X,W,Y,A	9.24 ± 0.88	10.
2-4	H,G,M	6.77 ± 0.46	7.
2-5	J,T,I,U	8.63 ± 0.60	7.
2-6	R,S,L,K	7.15 ± 1.45	20.

FIGURE 1
THE STUDY AREA SHOWING SAMPLE LOCATIONS WITHIN THE COSO VOLCANIC FIELD (AFTER DUFFIELD AND BACON 1981)

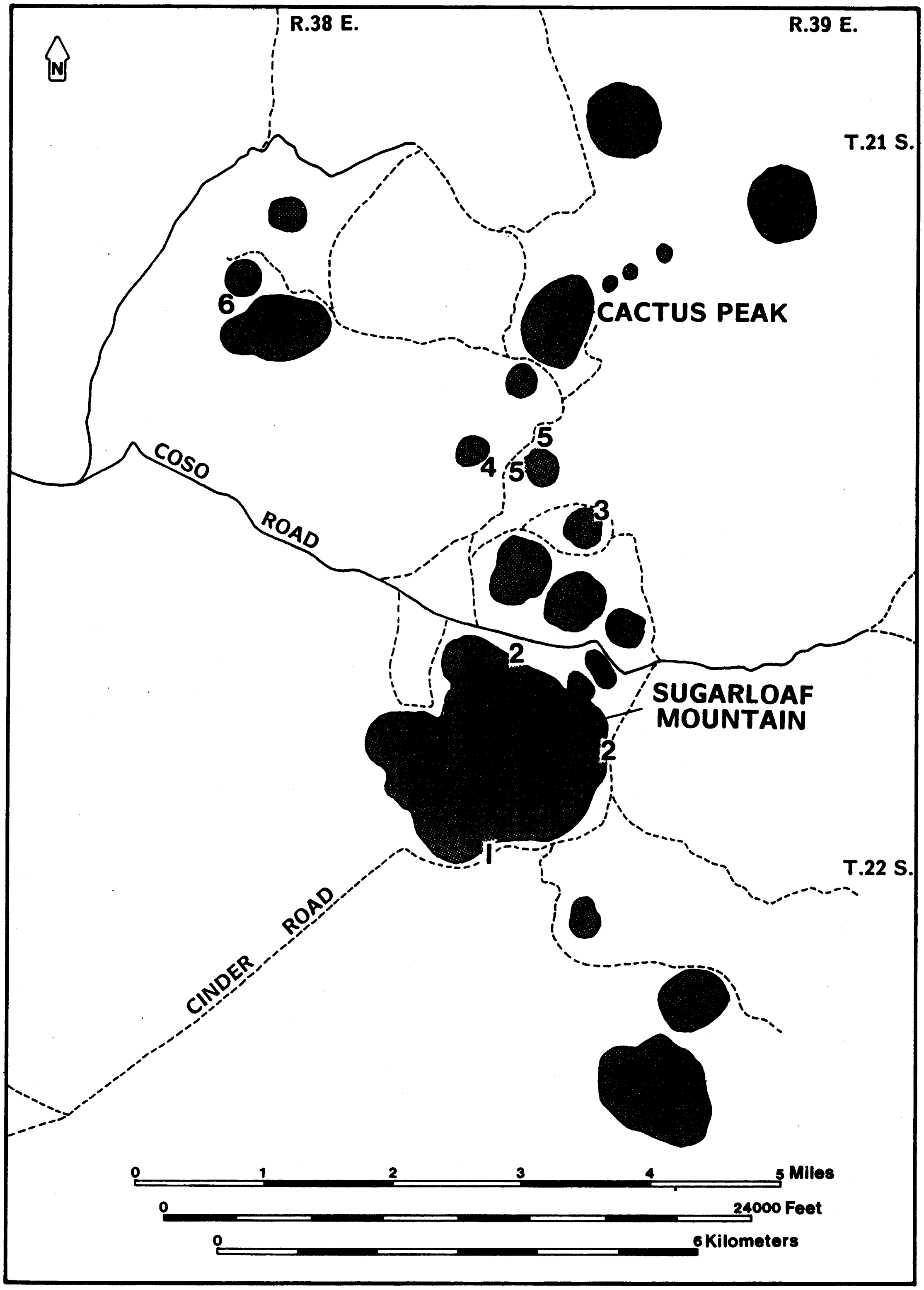
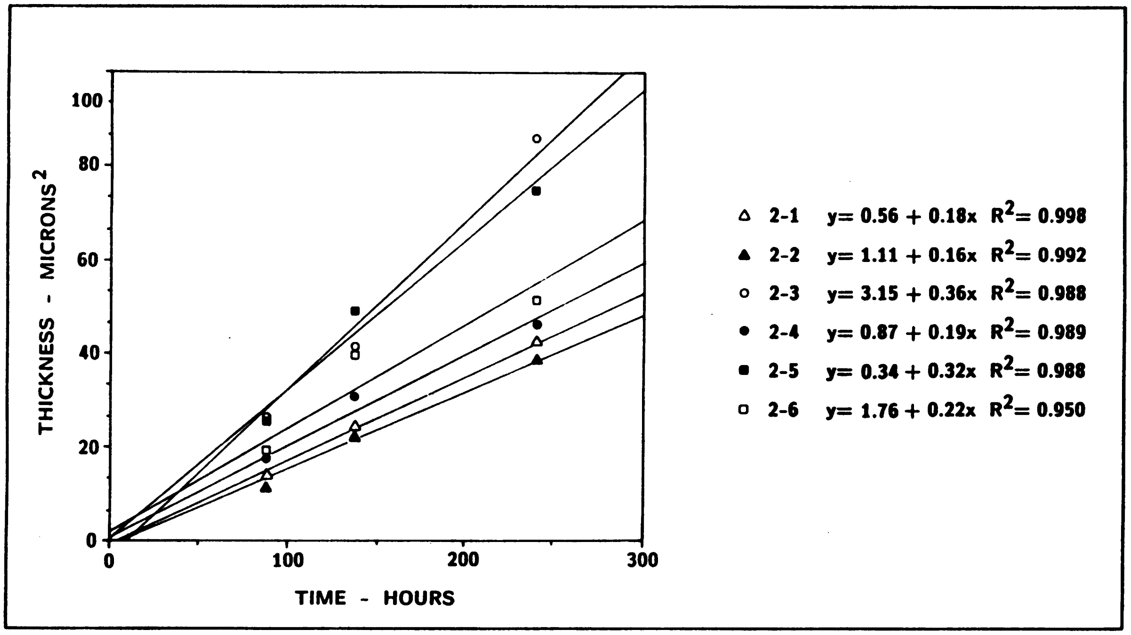


FIGURE 2

PLOTS OF FLOW-SPECIFIC HYDRATION MEASUREMENTS AND EXPERIMENTAL TIME



CONCLUSIONS AND RECOMENDATIONS

At present, researchers routinely apply source-specific hydration rates to obsidian artifacts whose source has been determined by chemical characterization. This preliminary study suggests that flow-specific rates may improve the accuracy of obsidian hydration dating for the Coso source; preliminary findings for the Coso volcanic field suggest that flow-specific rates may vary as much as 40%. There are numerous source-specific hydration rates for Coso obsidian in the literature, most derived from available archaeological data. These will have to be reevaluated, given these new findings. The variation of these published rates may, in part, be explained by combining data which should have been stratified, given the operation of flow-specific hydration rates. The role of environmental variables, other than effective temperature, in explaining variations of hydration rates, remains to be resolved. This paper is offered in the hope that the findings herein will lead to the refinement of obsidian hydration dating.

The determination of flow-specific hydration rates can be implemented in three research phases: 1) laboratory-induced obsidian hydration experiments can identify the range of rates within complex volcanic fields with multiple flows or eruptive events. Whether these rates are accurate enough for chronological application will have to be determined by long-term archaeological evaluation; 2) if significant rate variations are found, chemical characterization will have to discriminate and identify the obsidian flow of each artifact. Here, recent refinements in chemical characterization by x-ray fluorescence analysis (Hughes 1988) and long half-life instrumental neutron activation analysis (Ericson and Kimberlin, n.d.) provide the techniques to identify specific flows within complex volcanic fields. Quarry analysis (Ericson and Purdy 1984) may reveal that a single flow was the sole source for obsidian in a complex volcanic field; 3) hydration measurements of obsidian artifacts from specific flows combined with associated radiocarbon dates can be used to determine flow-specific hydration rates. Even with the above controls, obsidian hydration rates may vary due to other environmental variables that have not been considered heretofore. Understanding these new variables may be the ultimate step in refinement of the obsidian hydration dating technique. A new protocol is being developed which will improve evaluation of environmental variation effects (Ericson 1988).

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INDUCED HYDRATION RATE DEVELOPMENT OF OBSIDIANS FROM THE COSO VOLCANIC FIELD: A COMPARISON OF EXPERIMENTAL PROCEDURES

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and
Barry E. Scheetz

ABSTRACT

In the present study, hydration rate determinations for obsidians from the Coso volcanic field have been developed at elevated temperature and pressure. The completion of the experiment resulted in a hydration rate of 10.9 μm^2/1000 years for West Sugarloaf and 28.5 μm^2/1000 years for Sugarloaf Mountain at an effective hydration temperature of 20 degrees C. A comparison of the hydration rate for Sugarloaf Mountain with other rates developed for the same glass indicated varying degrees of correspondence. Possible reasons for the differences in the hydration rate are discussed.

INTRODUCTION

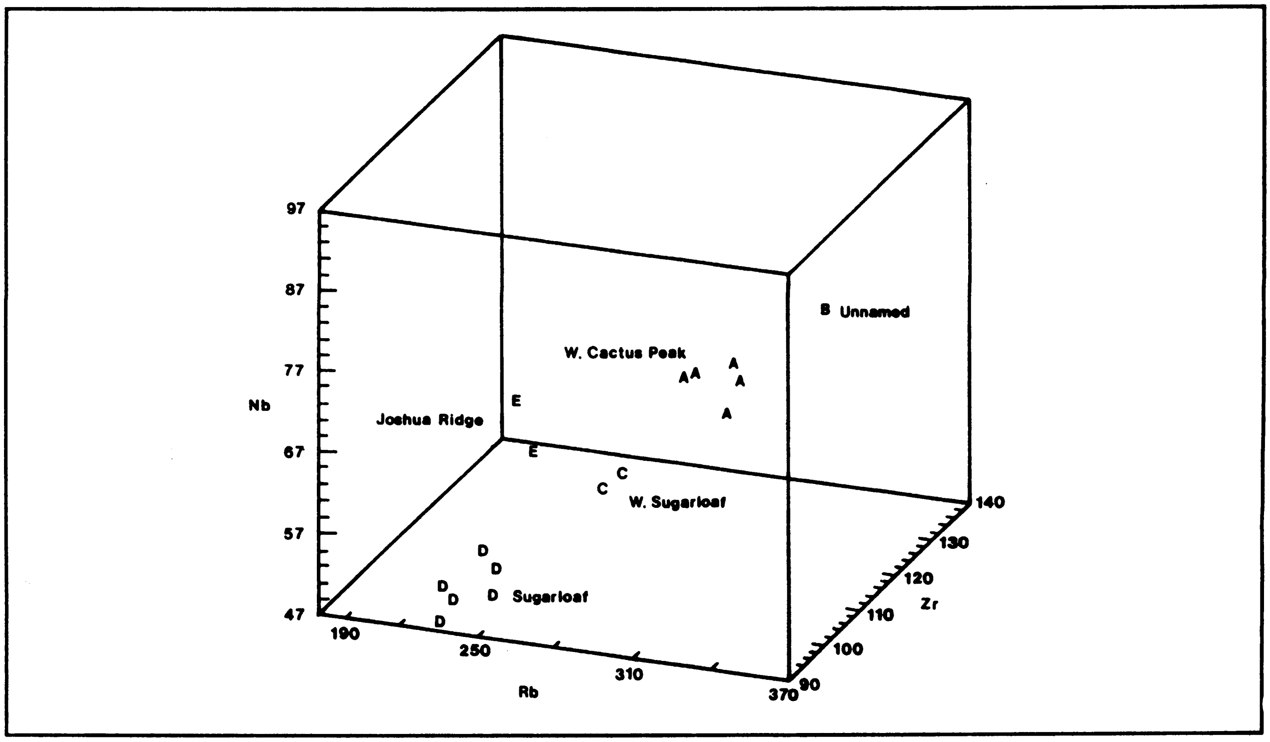
The Coso volcanic field is located at the southern extension of the Basin and Range province, immediately to the east of the Sierra Nevada. It is a region that has experienced active pre-Pleistocene volcanism that began approximately 6 m.y.a. with more active eruptive periods occuring between 4.0 and 2.5 m.y.a., and 2.0 and 1.8 m.y.a. (Duffield et al. 1980). Pleistocene volcanism (1.04 to 0.06 m.y.a.) resulted in the formation of nearly aphyric, high silica rhyolite domes and flows with accompanying basaltic flows (Bacon et al. 1981). The rapid quenching of the silica rich lava at the margins of these flows resulted in the formation of obsidian deposits. These sources of natural glass were exploited by prehistoric peoples in the manufacture of stone tools and therefore can be used to date archaeological sites by the obsidian hydration dating method. In this analysis, two samples of obsidian from the Coso volcanic field have been selected for the development of hydration rate constants.

Obsidian Sources in the Coso Volcanic Field

In their study of the petrogenic and eruptive history of the Coso volcanic field, Bacon et al. (1981) analyzed 39 silicic localities for their major, minor, and trace element constituents. Up to 44 element and oxide determinations were conducted on each sample. The suite of samples was then partitioned into seven compositional groups using the multivariate procedure of cluster analysis.

Sixteen of the characterized samples were obsidian fragments. An inspection of the cluster dendrogram of Bacon et al. (1981) indicates that five compositionally distinct groups of volcanic glass are present within the Coso field. Although highly similar on the basis on their major and minor elements they exhibit some variability in their trace element profiles. Eight trace elements were selected from the larger set of determinations and the samples were again partioned into groups using cluster analysis. An average link algorithm using an euclidian distance measure between unstandardized

FIGURE 1
CLUSTER ANALYSIS OF COSO OBSIDIAN



Graphical representation of the cluster analysis solution demonstrating Coso obsidian compositional types based on the parts per million concentration of trace elements.

values was used to determine if the the results of Bacon et al. (1981) could be replicated using a fewer number of attributes. The results of the cluster analysis (Figure 1) indicate that their analytical solution can be replicated using eight data points per sample instead of the forty-four used in the initial study.

A recent survey and geochemical analysis of the Coso volcanic field obsidian sources has been conducted by Hughes (1988). Based on a visual examination of the quality of the material at the source locations Hughes suggested that that only four obsidians of knappable quality are present within the Coso field. These sources have been named Sugarloaf Mountain, West Sugarloaf, Joshua Ridge, and West Cactus Peak (Hughes 1988: 258-260). X-ray fluorescence of samples from each of these sources indicated that the outcrops may be differentiated on the basis of their Zr/Rb concentration values.

The two samples provided by Wirth Environmental Services were selected from the southwest corner of Sugarloaf Mountain (Sample 1-1) and from a locality approximately 4 km to the northeast (Sample 4-1). X-ray fluorescence analysis of the samples by Hughes indicated that Sample 1-1 belongs to the West Sugarloaf Mountain source and that Sample 4-1 belongs to Sugarloaf Mountain. Sample 4-1 also corresponds to chemical Group 7 of Bacon et al. (1981).

THE HYDRATION PROCESS

The hydration of obsidian is controlled by the diffusion of atmospheric moisture into the core of the obsidian artifact. When a freshly fractured piece of obsidian is created, ambient water is attracted to the surface. Hydronium ions diffuse into the glass from the surface and exchange for alkali ions, notably sodium, within the alumino-slicate network. The alkali ions counter-diffuse to the surface and are removed. The replacement of sodium ions by hydronium ions results in a thin rim of residual stress which is manifested by optical birefringence when viewed in transmission with polarized light. The rate of hydration rim development (i.e. the hydration rate) is a function of glass composition and the thermal environment to which it has been exposed. It is therefore possible to accelerate the hydration process by raising the temperature of the hydration environment.

Archaeological studies of the hydration process and leaching studies conducted by individuals in the fields of glass science and nuclear waste management (Michels and Tsong 1980; Hench et al. 1980; Doremus 1979) have repeatedly demonstrated that the diffusion of water into glass follows the equation:

$$x=kt^{1/2} \qquad (1)$$

where: x=thickness of the hydration rim
k=a rate constant for each glass composition
t=time

HYDRATION RATE DEVELOPMENT

The diffusion of water into glass is a temperature dependent process that exhibits an Arrhenius relationship:

$$K= Ae^{E/RT} \qquad (2)$$

where: K=hydration rate (μm^2/1000 years)
A=preexponential (μm^2/day)
E=activation energy (J/mole)
R=universal gas constant (J/mole)
T=temperature (Kelvin)

The development of a hydration rate (K) requires that the activation energy (E) and the preexponential (A) be known. These values for a particular glass composition were determined at elevated temperature under the following experimental conditions.

Freshly fractured obsidian flakes were hydrated in a two liter Parr pressure reactor in 500 ml of distilled deionized water and 1.0 gm of amorphous silica. Powdered silica was added to bring the solution to saturation thereby preventing surface dissolution of the developing hydration rim. Eight separate reaction runs were completed. Temperature ranges for individual runs ranged between 130°C and 190°C for durations up to 18 days (Table 1). At the end of each reaction period, the flake was removed from the solution and a

TABLE 1
EXPERIMENTAL CONDITIONS AND RIM WIDTHS FOR THE INDUCED HYDRATION EXPERIMENT

Sample No.	Lab No.	Temperature(°C)	Duration	Rim Width(µm)	S.D.
		Sugarloaf Mountain (Sample 4-1)			
1	87-66	160	3 Day	3.72	0.11
2	87-60	160	6 Day	5.05	0.07
3	87-56	160	12 Day	6.90	0.09
4	87-50	160	18 Day	8.90	0.14
5	87-74	130	12 Day	2.95	0.06
6	87-164	140	12 Day	3.77	0.05
7	87-89	170	12 Day	8.76	0.13
8	87-96	190	12 Day	—Too Diffuse-	
		West Sugarloaf (Sample 1-1)			
1	87-67	160	3 Day	2.38	0.07
2	87-61	160	6 Day	3.58	0.08
3	87-55	160	12 Day	5.02	0.09
4	87-49	160	18 Day	5.34	0.07
5	87-73	130	12 Day	2.12	0.03
6	87-163	140	12 Day	2.41	0.05
7	87-88	170	12 Day	4.82	0.06
8	87-97	190	12 Day	—Too Diffuse-	

* Measurements made at 800x or 2000x

TABLE 2
HYDRATION RATE CONSTANTS FOR COSO OBSIDIANS

Obsidian *	Method	Preexponential	Activation Energy	Rate (20°C)
1) W. Sugarloaf	Induced	2.10 (160°C)	84170 J/mole	10.9
2) Sugarloaf	Induced	7.17 (200°C)	70450 J/mole	10.8
3) Sugarloaf ?	Induced	5.02 (172°C)	149781 J/mole	0.0014
4) Sugarloaf	Index	———	———	25-34
5) Sugarloaf	Induced	4.20 (160°C)	82201 J/mole	28.5
6) Coso Hot Springs	Induced	$3.0178x10^{15}$	80603 J/mole	13.4

* 1: This analysis; 2: Michels (1983); 3: Ericson (1981); 4: Friedman and Long (1976);
5: This analysis; 6: Friedman and Long (1976).

* ? - No compositional data available to confirm obsidian source assignment.

* The Coso Hot Springs source presented by Friedman and Long (1976) was referred to as "Cosco Hot Springs." This spelling is believed to be a typographical error.

period, the flake was removed from the solution and a petrographic thin section prepared. The artifically induced hydration rims were measured at 800x or 2000x under polarized light with a Watson image-splitting measurement instrument. Hydration rims were readily identified and could be measured using traditional measurement techniques on specimens that were hydrated at temperatures equal to or less than 180°C. At 190°C the diffusion front of the hydration rim became poorly defined and an exact boundary region could not be identified.

The hydration rate constants were then calculated for each glass. Samples 1 through 4 were used to calculate the preexponential (A) and Samples 3, 5, 6, and 7 were used to calculate the activation energy (E). This resulted in a preexponential value of 2.1 μm^2/day for West Sugarloaf and a value of 4.2 μm^2/day for Sugarloaf Mountain (Table 2). The activation energies were 84170 J/mole and 82201 J/mole respectively. Hydration rates were then calculated at 20°C for each obsidian. This resulted in a hydration rate of 10.9 μm^2/1000 years for West Sugarloaf (Sample 1-1) and a rate of 28.5 μm^2/1000 years for Sugarloaf Mountain (Sample 4-1).

A COMPARISON OF HYDRATION RATE CONSTANTS

Obsidians from the Coso volcanic field have been the subject of several rate development studies. Induced hydration rate experiments have been conducted by Ericson (1981, [this volume]), Michels (1983), and Friedman and Long (1976). The compositional profiles published by Bacon et al. (1981) also permit hydration rate estimates using the Chemical Index of Friedman and Long (1976). The results of the rate development procedures from previous studies and the results of this study are compared and evaluated.

More than a decade ago, Friedman and Long (1976) introduced the induced hydration rate approach. Twelve chemically different obsidians were hydrated at elevated temperature in saturated steam for periods of up to three years. At the end of the experimental runs the activation energy (E) and the preexponential (A) for each source were calculated from the widths of the induced rims. The researchers then correlated the compositional profiles of the obsidians with their corresponding rates to produce the rate prediction equation which they named the Chemical Index:

$$\text{Chemical Index} = SiO_2 - 45(CaO + MgO) - 20(H_2O^+) \qquad (3)$$

A hydration rate at a particular temperature may then estimated from the conversion graphs provided by Friedman and Long (1976:351). Alternately, the hydration rate constants may be estimated from regression constants. Using the experimental data of Friedman and Long (1976), Smith (1977) computed the best fit line describing the relationship between the Chemical Index and each of the hydration rate constants (A, E). Using this method the preexponential and activation energy may be estimated for obsidians with a Chemical Index of 50 or less.

The compositional data for the Coso volcanic field developed by Bacon et al. (1981) permit hydration rate estimates for the five obsidian types defined by a cluster analysis of the trace element profiles (see also Hughes [1988: Table IV]). An examination of Table 3 indicates that the index values range between 45.75 and 59.25. The values of SiO_2, CaO, and MgO for all the samples are very similar. Variation in the index values are primarily a result of the larger range of values for H_2O^+.

Hydration rates for each glass were calculated at 20°C. The hydration rates for the five groups range between 12.76 μm^2/1000 years to approximately 38.0 μm^2/1000 years. The hydration rate for Sugarloaf Mountain ranges between 25 and 34 μm^2/1000 years (Table 3). It should be noted that the index values for almost all of the Coso obsidians are much higher than those used in the study by Friedman and Long (1976). The upper limit of the index values in that study was 48.9. Therefore, the rate estimates for the Coso glasses with a Chemical Index greater than 50 could not be

TABLE 3

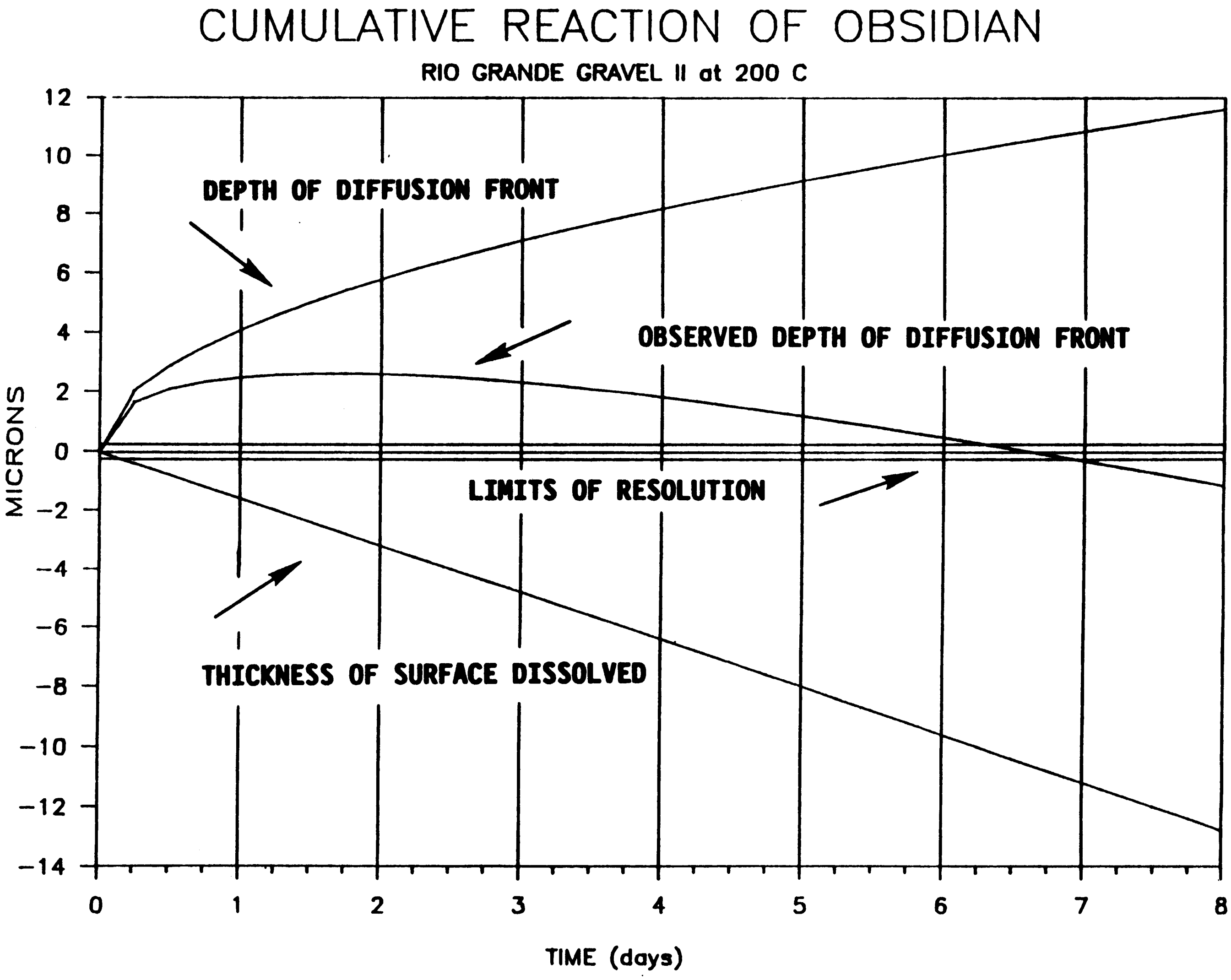
CHEMICAL INDEX VALUES AND ESTIMATED HYDRATION RATES FOR COSO VOLCANIC FIELD OBSIDIANS

Sample No.	Group	SiO_2	CaO	MgO	H_2O^+	Index	Rate(20°C)
13	3	76.9	0.35	0.01	0.19	56.9	35
10 West	3	76.9	0.39	0.01	0.21	54.7	31
14 Cactus	3	76.6	0.35	0.01	0.29	54.6	31
15 Peak	3	76.2	0.39	0.02	0.22	53.35	27
19	3	76.9	0.35	0.02	0.08	58.65	38
5	4	76.9	0.32	0.01	0.14	59.25	38
*16 West	5	76.2	0.43	0.02	0.51	45.75	12.76
*20 Sugarloaf	5	76.4	0.44	0.02	0.28	50.10	17.53
*24 Joshua	6	76.5	0.42	0.02	0.37	49.3	16.78
25 Ridge	6	76.7	0.41	0.02	0.19	53.55	27
4	7	77.0	0.31	0.02	0.23	57.55	34
6	7	76.6	0.36	0.01	0.11	57.75	34
27 Sugarloaf	7	77.0	0.38	0.03	0.27	53.15	27
17 Mountain	7	76.8	0.42	0.03	0.22	52.15	25
18	7	77.5	0.41	0.02	0.17	54.75	31
26	7	76.4	0.37	0.02	0.31	52.65	25

1) Sample Numbers, Group Numbers, and chemical data after Bacon et al. (1981); source names after Hughes (1988).

2) * Hydration rates for starred specimens have been calculated using the regression constants of Smith (1977). The hydration rates for all remaining specimens have been estimated from the conversion graphs of Friedman and Long (1976: 351).

FIGURE 2
OBSERVED THICKNESS OF THE HYDRATION RIM FOR SAMPLES REACTED IN DISTILLED DEIONIZED WATER



Graphical representation of the observed thickness of the hydration rim for samples reacted in distilled deionized water as a function of linear surface dissolution subtracted from hydration proceeding at the square root of time. the limit of optical resolution associated with the measurement of the hydration rim is 0.25 μm.

calculated from the regression constants of Smith (1977) and required large visual extrapolations from the rate estimation graphs. They should therefore be considered as only very general estimates of the hydration rate. A hydration rate for Sugarloaf Mountain of 10.8 μm²/1000 has also been developed by Michels (1983). A listing of all hydration rate determinations on Coso glasses is presented in Table 2.

The hydration rates range from quite slow (Michels) to very fast (this analysis). At this point in time it is difficult to provide an exact explanation as to why apparently similar experimental conditions should result in a wide range of rate constants. However, slight differences of the reaction vessel conditions and the methods of induced hydration rim measurement offer some insights into the problem.

The exchange of alkali ions for hydronium ions in obsidian will occur when moisture is present. However, the form of the water may significantly effect the hydration process. The samples of Friedman and Long (1976) were hydrated in saturated steam. Under these conditions alkali ions are removed from the glass without dissolving the surface of the glass (Doremus 1979). For obsidians hydrated in a bath of distilled deionized water, the reaction solution acts as a corrosive media and dissolves the surface of the glass until the water is saturated with silica (White 1983). Under these conditions the hydration rate develops at the square root of time while surface dissolution procedes linearly with time. Therefore, the resulting hydration rim does not reflect the true hydration history of the sample (Figure 2). Samples reacted by Michels (1983), for the Sugarloaf Mountain source in distilled deionized water may have experienced substantial surface dissolution at the higher temperature runs (200°C - 250°C). This may account for the slower rates compared to rates developed in this analysis and by Friedman and Long (Table 2).

The addition of amorphous (powdered) silica to the distilled deionized water will inhibit the corrosion of the experimental samples. The finely powdered silica will be preferentially dissolved until saturation of the solution is achieved, thereby allowing the hydration rim to develop. The hydration rates for the Coso samples 1-1 and 4-1 were developed in this manner. The rate for the Sugarloaf Mountain source, Sample 4-1, (28.5 μm²/1000 years) is comparable to that estimated from the Chemical Index (25-34 μm²/1000 years). The hydration rate for West Sugarloaf is slightly slower than that predicted by the Chemical Index.

A portion of the experimental error associated with the induced hydration rate experiment is also contributed by the optical measurement of the induced hydration rims. The accuracy and reproducibility of a measurement is related to the resolving power of the optical system, the instrument used in the measurement process, the clarity and definition of the diffusion front, and the focusing methods of the operator.

Resolution is the ability to distinguish between two closely spaced objects. Typical optical systems used in the measurement of hydration rims have a resolution of approximately 0.25 μm. Measurement instruments such as the filar screw are very susceptible to the limits of resolution because the wire is seen with more clarity that the image of the hydration rim. The error associated with each measurement cannot be less than 0.25 μm. In the computation of a hydration rate using the Arrhenius equation the measurement errors are compounded and can result in a total error of -30/+70% (Scheetz and Stevenson 1988).

The use of an image-splitting instrument can reduce the measurement error to less than 0.2 μm (Dyson 1960). The image-splitting measurement instrument was developed to measure the width of objects with identical or nearly identical opposite edges (i.e. blood cells, wires). When these objects are sheared the edges may be superimposed and very precise measurements achieved. For hydration rims however, these conditions are rarely met. The outer edge of the specimen has a sharp, well-defined boundary while the diffusion front is often represented by a grey band of finite width. As a result, no established stopping point is present and the inner boundary of the diffusion front is dependent upon the judgment of the operator. In spite of this problem measurement error associated with the image-splitting method is less than the resolution of the typical optical system.

Alternate techniques of focusing on the hydration rim can result in different hydration rim width determinations. An inter-laboratory blind test by Green (1986) indicated that substantially different rim with measurements on the same thin section may be provided by different laboratories. In other blind tests, the correspondence between laboratories has been quite close (Jackson 1984: 111-113; Kelly 1987). Where differences do occur they most probably stem from the techniques used to focus the hydration rim under high magnification. An operator may focus on the surface of the thin section or he may focus into the specimen which, in some cases, may better define the optical image. The problem with the latter approach is that the width of the hydration rim can significantly change with the depth of focus and that objective criteria (other than rim clarity) cannot be used to establish a stopping point. For measurements made on the surface of the thin section the objective is moved toward the specimen until the instant when the outer edge of the thin section becomes a sharp clear black line.

SUMMARY AND DISCUSSION

Recent geochemical studies of the Coso volcanic field have identified four chemically distinct obsidian sources used by prehistoric populations. These sources may be distinguished on the basis of their Zr/Rb concentrations (Hughes 1988). Hydration rates for Sugarloaf Mountain and West Sugarloaf have been developed under conditions of elevated temperature and pressure. The completion of the experiment resulted in a hydration rate of 10.9 μm^2/1000 years for West Sugarloaf and 28.5 μm^2/1000 years for Sugarloaf Mountain at an effective hydration temperature of 20 degrees C. A comparison of the hydration rate for Sugarloaf Mountain with other rates developed for the same glass indicated varying degrees of correspondence. The hydration rates for Sugarloaf Mountain and West Sugarloaf developed in this study are in general agreement with the hydration rates estimated by the Chemical Index. However, the rates developed by these methods are substantially faster than a hydration rate for Sugarloaf Mountain developed by Michels. The conditions within the reaction vessel and techniques of hydration rim measurement are suggested as possible explanations for the different rate determinations.

It is clear that additional criteria are needed to determine the best set of experimental methods used in rate development studies. A thorough and critical review of current rate development methods from the standpoints of optical microscopy and the diffusion kinetics is clearly needed to establish which sets of techniques contributes the least error and best replicates the natural hydration process. As a first step in establishing the preferred experimental procedure, a comparison of dates generated by the different rate constants with independent archaeological data should be completed.

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OBSIDIAN HYDRATION RATES IN CALIFORNIA

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IN SPITE OF LIMITED, OFTEN SKEPTICAL, INITIAL applications, both hydration and geologic-provenance analyses of obsidian artifacts are today relatively common facets of prehistoric hunter-gatherer archaeological investigations throughout California (Meighan 1983:600-601). Advances over the past quarter-century in hydration dating and the trace element chemical "fingerprinting" of geologic sources are enabling archaeologists to track obsidian procurement, tool production, and tool use on a diachronic basis (Hughes 1984a; Taylor 1976). Although systematic, problem-directed integration of hydration measurement and source determination data on a broad geographic basis remains in its infancy (cf. Bouey and Basgall 1984; Ericson 1977a; Hall 1984), obsidian studies have already provided insight into several outstanding, regional archaeological problems. These include the nature of prehistoric subsistence-settlement systems in northern and eastern California (Basgall and Hildebrandt 1987; Basgall and McGuire 1987; Fredrickson [this volume]; Hall n.d., 1983; Hughes 1986; R. Jackson 1985), the development and structure of trans-Sierra Nevada economic exchange networks (Bouey and Basgall 1984; Ericson 1977a, 1977b, 1982; Hall 1984; T. Jackson 1974; T. Jackson and Dietz 1984), patterns of sociopolitical organization and interaction (Bettinger 1982a; Hughes and Bettinger 1984; T. Jackson 1986, [this volume]), and processes of site formation and post-depositional stratigraphic transformations (Basgall, Hall, and Hildebrandt 1988; Bouey and Mikkelsen 1988; Weaver and Hall 1984).

It is also apparent, however, that as hydration and source analyses emerge as typical ingredients in archaeological research recipes in both California and other obsidian-bearing regions, there is a need for consumers of the resultant data to appreciate certain inherent technical and analytical issues. Among these are the comparability of results obtained on the same or similar samples by different laboratories (cf. Green 1986; Hughes 1984b, Stevenson et al. 1989), sampling strategies and methods of data manipulation appropriate to the research questions under examination, formats for reporting analytical results and, ideally, their standardization, and coordination of investigative efforts (Hall 1983, 1985; R. Jackson 1984a; Meighan 1983, 1984). For sourcing studies in particular, problems of note are intra-source chemical variability (cf. Hall 1983; Hughes 1988a) and identifying the geochemical signatures of lesser known, or small nodule, "pocket" sources. In eastern California and southwestern Nevada, for example, there are now more than a dozen major and minor obsidian sources, represented in archaeological deposits, that have been either physically located or inferred to exist based on the results of trace element chemical analyses (cf. Basgall [this volume]; Hall n.d.; Hughes 1988b).

Issues relating to hydration studies include: (1) the detection and measurement of very thin (1.0 microns or less) hydration bands (Findlow and DeAtley 1976; T. Jackson 1984; Origer [this volume]); (2) the possible error inherent in the measurement process (Scheetz and Stevenson 1988); (3) procedures that distinguish multiple, chronologically divergent bands on the same specimen, as opposed to a single, perhaps highly variable diffusion front (cf. Kaufman 1980); (4) depositional variables influencing the hydration process, such as geographic or stratigraphic differences in effective hydration temperature and soil chemistry (Ericson [this volume]; Friedman and Long 1976; Friedman and Trembour 1978; Kaufman 1980; Michels and Tsong 1980; Trembour and Friedman 1984); and (5) construction, evaluation, and use of source-specific hydration rates. It is this latter topic, rate derivation, that is of concern here although all of the problem areas mentioned are currently the subject of directed research. In the following discussion, emphasis is placed on the importance of "careful evaluation" (Ericson 1978:45) of rates prior to their interpretive application. By way of example, the use of temporally diagnostic obsidian artifact forms is also explored as an alternative strategy (cf. Basgall 1983; Hall 1983, 1984; R. Jackson 1984b) to the conventional rate-building methodology in which correlations are made between hydration measurements and radiocarbon assays obtained on stratigraphically "associated" sample materials.

OBSIDIAN HYDRATION RATES

There are three fundamental approaches to the derivation of obsidian hydration rates. On one hand, there are geophysicists and archaeologists who attempt to develop a rate based on the chemical properties of a particular glass or by experimentally inducing hydration and extrapolating a source-specific (even specimen-specific) rate (cf. Friedman and Long 1976; Friedman and Trembour 1978, 1983; Michels and Tsong 1980; Michels, Tsong, and Smith 1983; Stevenson [this volume]). In the long run, these efforts may well pay off handsomely; one can envision the availability, for a given obsidian type, of a "standard" rate which will yield acceptable absolute age estimates once adjustments are made for certain variables (e.g., effective hydration temperature). However, aside from technical matters in its implementation (cf. Sheetz and Stevenson 1988; Stevenson and Scheetz [this volume]), the problem with the induced approach has been — and continues to be — an at times glaring lack of concern on the part of some of its advocates with the need for comprehensive rate verification against archaeological materials of known (or indirectly well-established) age. All too often it seems, so-called "laboratory" rates are promulgated without any consideration of their cultural historical ramifications. Thus, for example, according to rates proposed by Michels (1982, 1983), initial human exploitation of the Casa Diablo and Coso obsidian sources in eastern California (based on typical hydration values of 10 and 18 microns, respectively, for early Holocene artifacts fashioned from these glasses) took place some 25,000-30,000 years ago — clearly erroneous estimates by most accounts (cf. Elston and Zeier 1984:136-137; Hall 1983:172; R. Jackson 1984b: 176). Moreover, just because a rate may result in a believable date for a given time interval or in one not so blatantly inconsistent with the known time-depth of human occupation does not mean that the date or rate are even roughly accurate. In terms of absolute-age conversion, without customized justification source-specific rates must be at least reasonably meaningful at either end of and throughout the cultural chronological continuum.

On the other hand, there are those archaeologists who, pending the development of laboratory-derived rates of demonstrable utility, construct hydration rates using available archaeological data. Assuming sufficient evidence of their relative reliability, so-called empirical or "rough and ready" (Meighan 1984:229) rates have the advantage of being immediately applicable in ongoing studies. One disadvantage of this third approach is the necessity of periodically upgrading a rate in light of new data. Archaeologists are, however, in the business of finding out precisely what happened when, and why, and these goals demand constant refinement of the chronological tools used to establish temporal frameworks.

As noted above, the empirical approach usually entails the correlation of hydration values and radiocarbon determinations obtained on respective sample materials found in presumed stratigraphic association. Major difficulties with this strategy are: (1) ensuring that such associations are, in fact, real; and (2) of those that are, having enough to provide a reasonable basis for rate calibration (cf. R. Jackson 1984b; Meighan 1983). Complex prehistoric site formation processes in California and the Great Basin preclude a simplistic assumption of association based on spatial co-occurrence (cf. Basgall, Hall, and Hildebrant 1988). Inadequate appreciation of this problem can easily lead to specious correlations and the computation of invalid hydration rates (Hall 1988). For example, Koerper et al. (1986) apparently did not consider the issue of sampling error with respect to the hydration/radiocarbon associations they used in constructing a logarithmic hydration rate for Coso obsidian. Five of the 17 "data points" employed by Koerper et al. (1986:51, Figs. 14-

15) in their calculations appear to represent the equating of ca. 8.5-8.0 microns of hydration with ca. 4500-2000 B.P. Given the unlikelihood that half of a micron of hydration on Coso glass (from later Holocene archaeological contexts) can be correlated with the passing of 2500 years, it seems highly probable that certain of the hydration/radiocarbon associations made by Koerper et al. (1986) are spurious. Not surprisingly, the Coso rate proposed by these authors yields age conversions grossly out-of-line with other forms of archaeological evidence; e.g., 9059 years for 10 microns, and 196,509 years for 18 microns.

RATE DERIVATION USING TIME-DIAGNOSTIC ARTIFACT FORMS: A CASE STUDY

Recognizing that the day when archaeologically verifiable and consistent laboratory-produced obsidian hydration rates are available may not arrive for some time, a modified version of the empirical approach is presented here in which temporally diagnostic obsidian artifact forms (specifically projectile points) are used to formulate a rate for the Casa Diablo source in east-central California. Described below are procedures that, hopefully, take some of the "rough" out of the "rough and ready" strategy of calibrating source-specific rate curves against archaeological data.

GEOLOGIC AND CULTURAL SETTING

The Casa Diablo obsidian source is located in the western portion of Long Valley, a massive, 17x32-km elliptically-shaped caldera at the base of the east-central Sierra Nevada. A cataclysmic eruption of more than 600 cu km of rhyolitic magma, and subsequent crustal subsidence, created the caldera approximately 700,000 years ago (Bailey, Dalrymple, and Lanphere 1976; Gilbert et al. 1968). Intracaldera volcanism resumed within 40,000 years after subsidence. Silica-rich, unusually fluid rhyolite tuffs and flows were emplaced in the west-central area of the caldera (Bailey, Dalrymple, and Lanphere 1976:732). These extrusions form a complex "resurgent dome" that at the close of magmatic activity ca. 600,000 B.P. had risen 500 m above the caldera floor (Smith and Bailey 1968:646; Bailey, Dalrymple, and Lanphere 1976:735). Obsidian flows and inclusions in the dome, manifested as more than 20 sq km of discontinuous outcrops and exposures, constitute the Casa Diablo obsidian source (Ericson, Hagan, and Chesterman 1976:226, Fig. 12.1).

According to some estimates (Ericson 1977a:209), Casa Diablo obsidian was supplied to hundreds of thousands of prehistoric hunter-gatherers in central California. At the time of Euroamerican penetration of the region, Long Valley does not appear to have supported a sizable, indigenous population and may have served as a general resource procurement area exploited by several, geographically distinct hunter-gatherer groups (cf. Bettinger 1977; Hall 1983; R. Jackson 1985). Considerable archaeological evidence attests to a long prehistory of extensive use of both the Casa Diablo obsidian source as well as surrounding environs (Basgall 1983, 1984; Bouscaren and Wilke 1987; Hall n.d., 1983, 1984; R. Jackson 1985; Michels 1965).

HYDRATION DATA ON PROJECTILE POINTS OF CASA DIABLO OBSIDIAN

The Casa Diablo obsidian hydration rate described below was derived in late 1984 on the basis of extant hydration values for 108 time-sensitive projectile point forms from 24 prehistoric sites in east-central California (Hall 1984). All of the points were fashioned from Casa Diablo glass, as determined by x-ray fluorescence spectroscopic trace element analysis. Expectably, archaeological work in the source area since 1984 has increased the number of points of Casa Diablo origin for which hydration measurements are available. Table 1 summarizes, as of this writing (1987), all currently reported hydration data for projectile points from east-central California attributed to the Casa Diablo source, including values obtained on point forms of unclear temporal affiliation (234 total specimens, 54 locations [all open-air]). For two reasons, however, the Hall (1984) rate is not revised here: first, substantial samples of Casa Diablo obsidian points are presently undergoing hydration analysis (e.g., Hall n.d.) and it would seem more practical to postpone rate refinement until these results can be incorporated; and second, a marginal upgrading of the rate may be inappropriate at this time given the wide acceptance it has won with practicing archaeologists in surrounding regions of California and the Great Basin.

There are, nonetheless, a few observations that should be made in light of the hydration measurements arrayed in Table 1. First, although these data were generated by several different technicians operating with optical equipment of varying quality and design, on the whole the compatibility in the range of values per projectile point form is both quite close and encouraging from a methodological perspective. Second, with respect to Casa Diablo glass, the surface versus subsurface provenience of obsidian samples would not seem to be as critical a hydration variable as has been advocated by some archaeologists (e.g., Bouscaren and Wilke 1987; cf. R. Jackson 1984a; Layton 1973). At issue here are the insolation and

TABLE 1
HYDRATION MESAUREMENTS ON OBSIDIAN PROJECTILE POINTS FROM EAST-CENTRAL CALIFORNIA CHEMICALLY ASCRIBED TO THE CASA DIABLO SOURCE

C-14 Age B.P.	PrPt	Hydration	Site	Elev	Provenience		84R	Ref
					Asp	Depth		
650-100	DSN	1.20	MNO-458*	2164	S	20-30	-	(1)
	DSN	1.20	MNO-714	2399	ENE	20-30	-	(2)
	DSN	1.21	MNO-584	2085	SW	20-30	+/+	(3)
	DSN	1.23	MNO-529	2430	E	surface	+	(4)
	DSN	1.30	MNO-458	2164	S	30-40	-	(1)
	DSN	1.44	MNO-382	2195	S	30-46	+/+	(5,6)
	DSN	1.50	MNO-458	2164	S	10-20	-	(1)
	DSN	1.73	MNO-11	2250	NE	20-30	+/+	(7)
	DSN	1.80	MNO-458	2164	S	10-20	-	(1)
	DSN	1.91	INY-1386	1341	NE	0-15	-	(8)
	DSN	2.00	MNO-458	2164	S	0-10	-	(1)
	DSN	2.00	MNO-1826	2140	SSE	0-10	+/+	(6)
	DSN	2.10	MNO-458	2164	S	surface	-	(1)
	DSN	2.10	MNO-458	2164	S	10-20	-	(1)
	DSN	2.60	INY-2146	1253	ESE	surface	+	(9)
	DSN	2.90	MNO-458	2164	S	0-10	-	(1)
	DSN	3.10	MNO-458	2164	S	0-10	-	(1)
	CT	1.30	MNO-458	2164	S	10-20	-	(1)
	CT	1.40	MNO-458	2164	S	10-20	-	(1)
	CT	1.58	MNO-529	2430	E	surface	+	(4)
	CT	1.70	INY-30	1143	ESE	13	-	(10)
	CT	1.80/6.10	MNO-458	2164	S	surface	-	(1)
	CT	1.80	MNO-1811	2620	ENE	surface	+	(6)
	CT	2.10	MNO-1878	2244	NW	surface	+	(6)
	CT	2.20	MNO-1827	2287	S	surface	+	(6)
	CT	2.65	MNO-382	2195	S	?	+	(5,6)
	CT	2.71	MNO-382	2195	S	46-61	+/+	(5,6)
	CT	2.80	MNO-1869	2195	ESE	surface	-	(6)
	CT	3.10	MNO-458	2164	S	20-30	-	(1)
	CT	3.42**	MNO-382	2195	S	46-61	+	(5,6)
1250-650	EGES	1.40	MNO-458	2164	S	10-20	-	(1)
	EGES	1.60	MNO-458	2164	S	20-30	-	(1)
	EGES	2.10	MNO-1799	2896	W	surface	+	(6)
	EGES	2.32	MNO-529	2430	E	surface	+	(4)
	EGES	2.40	MNO-458	2164	S	40-50	-	(1)
	EGES	2.60	MNO-1826	2140	SSE	surface	+	(6)
	EGES	3.30	MNO-1799	2896	W	surface	+	(6)
	EGES	3.60	MNO-703	2244	SE	surface	-	(11)
	EGES	3.70	MNO-458	2164	S	20-30	-	(1)
	EGES	4.30	MNO-458	2164	S	surface	-	(1)
	EGSS	3.75	MNO-382	2195	S	30-46	+/+	(5,6)

TABLE 1, CONTINUED

C-14 Age B.P.	PrPt	Hydration	Site	Elev	Provenience		84R	Ref
					Asp	Depth		
	EGSS	3.94	MNO-382	2195	S	15-30	+/+	(5,6)
	EGSS	3.98	MNO-382	2195	S	0-30	+/+	(5,6)
	RSCN	1.80	MNO-1878	2244	NW	surface	+	(6)
	RSCN	2.90	MNO-1644	2288	ESE	10-20	+/+	(7)
	RSCN	3.17	MNO-382	2195	S	15-30	+/+	(5,6)
	RSCN	3.23	MNO-561	2392	E	10-20	+/+	(12)
	RSCN	4.00	INY-2596	1463	E	38	-	(13)
	RSCN	4.20	MNO-561	2392	E	surface	+	(12)
	RSCN	4.30	INY-2146	1253	ESE	surface	+	(9)
3250-1250	EE	2.21**	MNO-11	2250	NE	40-50	+	(7)
	EE	2.89	MNO-561	2392	E	30-40	+/+	(12)
	EE	2.90	MNO-382	2195	S	0-15	+/+	(5,6)
	EE	3.70	MNO-186	2659	SW	surface	+	(6)
	EE	3.75	MNO-561	2392	E	0-10	+/+	(12)
	EE	3.80	MNO-11	2250	NE	60-70	+/+	(7)
	EE	3.80	MNO-1795	2679	NNW	surface	+	(6)
	EE	3.86	MNO-561	2392	E	10-20	+/+	(12)
	EE	3.89	MNO-561	2392	E	40-50	+/+	(12)
	EE	4.00	MNO-1529	2475	E	surface	+	(14)
	EE	4.00	MNO-1799	2896	W	surface	+	(6)
	EE	4.00	4-51-542***	2976	SSE	surface	+	(6)
	EE	4.21	MNO-382	2195	S	76-91	+/+	(5,6)
	EE	4.27	MNO-382	2195	S	0-15	+/+	(5,6)
	EE	4.40	MNO-1809	2634	SSW	surface	+	(6)
	EE	4.43	MNO-561	2392	E	10-20	+/+	(12)
	EE	4.50	MNO-782	2683	SSW	surface	+	(6)
	EE	4.83	MNO-382	2195	S	46-61	+/+	(5,6)
	EE	4.88	MNO-382	2195	S	0-15	+/+	(5,6)
	EE	5.00	INY-382	2195	S	61-76	+/+	(5,6)
	EE	5.14	INY-1386	1341	NE	15-30	-	(8)
	EE	5.50	INY-2146	1253	ESE	surface	+	(15)
	EE	6.97	INY-1386	1341	NE	0-15	-	(8)
	ECN	2.70	MNO-1529	2475	E	surface	+	(14)
	ECN	3.02	MNO-446	2185	NE	10-20	+/+	(16)
	ECN	3.10	MNO-1809	2634	SSW	surface	+	(6)
	ECN	3.17	MNO-561	2392	E	50-60	+/+	(12)
	ECN	3.28	MNO-561	2392	E	30-40	+/+	(12)
	ECN	3.37	MNO-561	2392	E	30-40	+/+	(12)
	ECN	3.40	MNO-1851	2295	SSW	surface	+	(6)
	ECN	3.60	MNO-1529	2475	E	0-10	+/+	(14)
	ECN	3.60	MNO-1869	2195	ESE	surface	+	(6)
	ECN	3.84	MNO-561	2392	E	30-40	+/+	(12)
	ECN	3.86	MNO-11	2250	NE	50-60	+/+	(7)
	ECN	3.93	MNO-561	2392	E	20-30	+/+	(12)

TABLE 1, CONTINUED

C-14 Age B.P.	PrPt	Hydration	Provenience Site	Elev	Asp	Depth	84R	Ref
	ECN	3.96	MNO-561	2392	E	10-20	+/+	(12)
	ECN	4.06	MNO-382	2195	S	30-46	+/+	(5,6)
	ECN	4.18	MNO-11	2250	NE	20-30	+/+	(7)
	ECN	4.38	MNO-382	2195	S	46-61	+/+	(5,6)
	ECN	4.50	INY-1386	1341	NE	15-30	+/+	(8)
	ECN	4.56	MNO-382	2195	S	30-46	+/+	(5,6)
	ECN	4.68	MNO-382	2195	S	76-91	+/+	(5,6)
	ECN	5.00	MNO-1529	2475	E	surface	+	(14)
	ECN	5.04	MNO-382	2195	S	76-91	+/+	(5,6)
	ECN	5.10	MNO-382	2195	S	15-30	+/+	(5,6)
	ECN	5.25	MNO-561	2392	E	30-40	+/+	(12)
	ECN	5.31	MNO-446	2185	NE	70-80	+/+	(16)
	ECN	5.32	MNO-529	2430	E	30-40	+/+	(4)
	ECN	5.53	MNO-382	2195	S	107-122	+/+	(5,6)
	ECN	5.79	MNO-561	2392	E	30-40	+/+	(12)
	ELK	3.54	MNO-561	2392	E	50-60	+/+	(12)
	ELK	3.60	MNO-458	2164	S	surface	-	(1)
	ELK	3.78	MNO-382	2195	S	30-46	+/+	(5,6)
	ELK	3.82	MNO-561	2392	E	20-30	+/+	(12)
	ELK	3.86	MNO-382	2195	S	61-76	+/+	(5,6)
	ELK	3.94	MNO-561	2392	E	0-10	+/+	(12)
	ELK	4.05	MNO-382	2195	S	61-76	+/+	(5,6)
	ELK	4.40	MNO-529	2430	E	surface	+	(4)
	ELK	4.51	MNO-382	2195	S	61-76	+/+	(5,6)
	ELK	4.80	MNO-1529	2475	E	surface	+	(14)
	ELK	4.80	INY-30	1143	ESE	60-70	-	(10)
	ELK	5.40	INY-30	1143	ESE	40-50	-	(10)
	ELK	5.60	MNO-458	2164	S	surface	-	(1)
	ELK	5.60	INY-30	1143	ESE	50-60	-	(10)
	GCS	3.60	MNO-1871	2244	N	surface	+	(6)
	GCS	3.72	MNO-382	2195	S	61-76	+/+	(5,6)
	GCS	3.80	MNO-1529	2475	E	surface	+	(14)
	GCS	3.84	MNO-382	2195	S	46-61	+/+	(5,6)
	GCS	3.96	MNO-561	2392	E	40-50	+/+	(12)
	GCS	4.00	MNO-382	2195	S	61-76	-	(5,6)
	GCS	4.00	MNO-458	2164	S	10-20	-	(1)
	GCS	4.03	MNO-382	2195	S	76-91	+/+	(5,6)
	GCS	4.24	MNO-382	2195	S	46-61	+/+	(5,6)
	GCS	4.38	MNO-446	2185	NE	20-30	+/+	(16)
	GCS	4.41	MNO-382	2195	S	46-61	+/+	(5,6)
	GCS	4.49	MNO-382	2195	S	46-61	+/+	(5,6)
	GCS	4.52	MNO-11	2250	NE	40-50	+/+	(7)
	GCS	4.64	MNO-382	2195	S	46-61	+/+	(5,6)
	GCS	5.00	MNO-382	2195	S	107-122	+/+	(5,6)
	GCS	5.49	MNO-382	2195	S	76-91	+/+	(5,6)
	GCS	5.56	MNO-382	2195	S	76-91	+/+	(5,6)
	GCS	5.80	INY-1386	1341	NE	46-61	-	(8)
	GCS	6.00	INY-1386	1341	NE	surface	-	(8)

TABLE 1, CONTINUED

C-14 Age B.P.	PrPt	Hydration	Site	Elev	Provenience		84R	Ref
					Asp	Depth		
4950-3250	LLSS	3.75	MNO-561	2392	E	30-40	+/+	(12)
	LLSS	4.04	MNO-561	2392	E	80-90	+/+	(12)
	LLSS	4.80	MNO-1826	2140	SSE	surface	+	(6)
	LLSS	4.90	MNO-1789	2713	NW	surface	+	(6)
	LLSS	6.00	4-52-217	2200	ESE	surface	+	(6)
	LLSS	6.50	MNO-1789	2713	NW	surface	+	(4)
	LLSS	6.82	MNO-529	2430	E	surface	+	(4)
	LLSS	6.85	MNO-561	2392	E	50-60	+/+	(12)
	LLSS	7.80	MNO-458	2164	S	surface	-	(1)
Indefinite	RSCS	2.50	MNO-1871	2244	N	surface	-	(6)
	LSN	3.80	MNO-1529	2475	E	surface	-	(14)
	LSN	4.00	MNO-1529	2475	E	surface	-	(14)
	LSN	4.40	MNO-1529	2475	E	surface	-	(14)
	LSN	5.40	MNO-382	2195	S	surface	-	(17)
	LSN	5.40	MNO-458	2164	S	50-60	-	(1)
	LSN	5.50	MNO-382	2195	S	30-46	-	(5,6)
	LSN	5.82	MNO-561	2392	E	70-80	-	(12)
	WSBS	4.10	4-51-557	2963	SW	surface	-	(6)
	WSBS	4.40	MNO-186	2659	SW	surface	-	(6)
	WSBS	4.40	4-52-872	2159	S	surface	-	(11)
	WSBS	4.97	MNO-561	2392	E	20-30	-	(12)
	WSBS	5.78	MNO-561	2392	E	10-20	-	(12)
	WSBS	6.20	MNO-382	2195	S	46-61	-	(5,6)
	WSBS	6.40	MNO-1822	2159	SSE	surface	-	(6)
	WSBS	6.51	MNO-382	2195	S	30-46	-	(5,6)
	WSBS	7.00	MNO-458	2164	S	surface	-	(1)
	WSBS	8.16	MNO-382	2195	S	91-107	-	(5,6)
	WSBS	8.18	MNO-584	2085	SW	50-60	-	(3)
	WSBS	8.80	4-52-874	2221	S	surface	-	(11)
	WSNS	5.00/5.40	4-51-519	2756	NNE	surface	-	(6)
	WSNS	6.01	MNO-446	2185	NE	70-80	-	(16)
	WSNS	6.32	MNO-561	2392	E	50-60	-	(12)
	WSNS	7.24	MNO-561	2392	E	50-60	-	(12)
	WSNS	7.80	4-52-208	2128	E	surface	-	(6)
	WSNS	8.50	MNO-680	2195	ESE	surface	-	(6)
	WSNS	9.00	MNO-680	2195	ESE	surface	-	(6)
	MCNS	1.34	MNO-382	2195	S	?	-	(5,6)
	MCNS	1.65	INY-1386	1324	NE	0-15	-	(8)
	MCNS	1.80	MNO-1878	2244	NW	surface	-	(6)
	MCNS	1.90	4-52-203	2293	WNW	surface	-	(6)
	MCNS	2.60	MNO-1878	2244	NW	surface	-	(6)
	MCNS	2.60	MNO-1809	2634	SSW	surface	-	(6)

TABLE 1, CONTINUED

C-14 Age B.P.	PrPt	Hydration	Site	Elev	Provenience Asp	Depth	84R	Ref
	MCNS	3.14	MNO-382	2195	S	46-61	-	(5,6)
	MCNS	3.36	MNO-382	2195	S	46-61	-	(5,6)
	MCNS	3.50	MNO-1789	2713	NW	surface	-	(6)
	MCNS	3.70	MNO-1872	2146	NE	surface	-	(6)
	MCNS	4.70	4-51-580	2378	SSE	surface	-	(6)
	MCNS	5.90	4-51-587	2930	SW	surface	-	(6)
	MCNS	6.00/8.10	4-15-532	2659	ENE	surface	-	(6)
	MCNS	7.60	4-52-211	2119	E	surface	-	(6)
	MCNS	8.00	MNO-800	2146	E	surface	-	(6)
	HBN	1.20	MNO-714	2399	ENE	10-20	-	(2)
	HBN	3.10	MNO-574	2317	W	surface	-	(18)
	HBN	3.60	INY-30	1143	ESE	67	-	(10)
	HBN	3.80	MNO-458	2164	S	surface	-	(1)
	HBN	3.91	MNO-823	2238	ENE	30-40	-	(7)
	HBN	4.57	INY-1386	1341	NE	30-46	-	(8)
	HBN	4.60	MNO-458	2164	S	surface	-	(1)
	HBN	5.50	INY-2146	1253	ESE	surface	-	(15)
	HBN	5.50	MNO-382	2195	S	15-30	-	(5,6)
	HBN	6.20	INY-30	1143	ESE	40-50	-	(10)
	HCB	2.56	MNO-382	2195	S	122-137	-	(5,6)
	HCB	3.38	MNO-382	2195	S	15-30	-	(5,6)
	HCB	3.50	MNO-458	2164	S	surface	-	(1)
	HCB	3.52	MNO-561	2392	E	40-50	-	(12)
	HCB	3.60	MNO-458	2164	S	surface	-	(1)
	HCB	3.60	MNO-1811	2620	ENE	surface	-	(6)
	HCB	3.67	MNO-561	2392	E	20-30	-	(12)
	HCB	3.69	MNO-561	2392	E	70-80	-	(12)
	HCB	3.70	4-51-576	2290	SSW	surface	-	(6)
	HCB	3.72	MNO-382	2195	S	30-46	-	(5,6)
	HCB	3.72	MNO-382	2195	S	76-91	-	(5,6)
	HCB	3.76	MNO-561	2392	E	10-20	-	(12)
	HCB	3.80	MNO-1529	2475	E	0-10	-	(14)
	HCB	3.80	MNO-1817	2512	SSE	surface	-	(6)
	HCB	3.92	MNO-561	2392	E	10-20	-	(12)
	HCB	4.00	4-52-210	2146	SSE	surface	-	(6)
	HCB	4.04	MNO-584	2085	SW	60-70	-	(3)
	HCB	4.10	4-52-208	2128	E	surface	-	(6)
	HCB	4.17	MNO-561	2392	E	70-80	-	(12)
	HCB	4.28	MNO-561	2392	E	80-90	-	(12)
	HCB	4.39	MNO-561	2392	E	50-60	-	(12)
	HCB	4.40	MNO-1833	2256	SSW	surface	-	(6)
	HCB	4.51	MNO-561	2392	E	30-40	-	(12)
	HCB	4.52	MNO-382	2195	S	91-107	-	(5,6)
	HCB	4.60	MNO-1789	2713	NW	surface	-	(6)
	HCB	4.76	MNO-382	2195	S	46-61	-	(5,6)
	HCB	4.78	MNO-561	2392	E	40-50	-	(12)

TABLE 1, CONTINUED

C-14 Age B.P.	PrPt	Hydration	Site	Elev	Asp	Depth	84R	Ref
			Provenience					
	HCB	5.20	4-52-216	2213	E	surface	-	(6)
	HCB	5.40	MNO-382	2195	S	15-30	-	(5,6)
	HCB	5.50	MNO-1794	2779	NE	surface	-	(6)
	HCB	5.52	MNO-382	2195	S	0-30	-	(5,6)
	HCB	5.74	MNO-561	2392	E	70-80	-	(12)
	HCB	5.87	MNO-561	2392	E	40-50	-	(12)
	HCB	5.90	MNO-186	2659	SW	surface	-	(6)
	HCB	6.03	INY-1386	1341	NE	30-46	-	(8)
	HCB	6.49	INY-1386	1341	NE	0-15	-	(8)
	HCB	7.92	MNO-382	2195	S	15-30	-	(5,6)
	HCB	8.13	INY-1386	1341	NE	30-46	-	(8)
	GBCB	10.00	MNO-1847	2299	SW	surface	-	(6)
	GBCB	10.20	MNO-679	2186	ENE	surface	-	(6)

KEY:	C-14 Age	Radiocarbon chronology as largely defined by Thomas (1981) for certain projectile point forms in the central and western Great Basin (cf. Bettinger and Taylor 1974; Heizer and Hester 1978; Holmer 1986); evidence indicates that in east-central California large, contracting-stem points (GCS) are more characteristic of the period ca. 3250-1250 B.P. than ca. 4950-3250 (as in central Nevada); B.P. = radiocarbon years before A.D. 1950.
	PrPt	Point type: DSN, Desert Side-notched; CT, Cottonwood Triangular; EGES, Eastgate Expanding-stem; EGSS, Eastgate Split-stem; RSCN, Rose Spring Corner-notched; EE, Elko Eared; ECN, Elko Corner-notched; ELK, Elko series (indistinguishable EE and ECN fragments); GCS, Gypsum Contracting-stem; LLSS, Little Lake Split-stem; RSCS, possible Rose Spring Contracting-stem; LSN, large side-notched; WSBS, large wide-stemmed, shoulders broad, pronounced; WSNS, large wide-stemmed, shoulders narrow, rounded; MCNS, miscellaneous, untypable corner-notched or shouldered forms (usually large); HBN, Humboldt Basal-notched; HCB, Humboldt Concave-base; GBCG, Great Basin Concave-base series.
	Hydration	Measurement in microns
	Site	(MNO-, Mono County; INY-, Inyo County)
	Elev	Approximate elevation (m) above mean sea level
	Asp	Aspect
	Depth	Depth (cm) below ground surface
	84R	+, considered but not used in computation of Hall (1984) Casa Diablo hydration rate; +/+, used in 1984 rate derivation; -, data not available in 1984.
	Ref	Reference: 1, Burton 1985a; 2, R. Jackson 1986; 3, Garfinkel and Cook 1979; 4, Basgall 1983; 5, Michels 1965; 6, R. Jackson 1985; 7, Bouscaren, Hall and Swenson 1982, and Bouscaren and Wilke 1987; 8, Bouscaren 1985; 9, Bettinger, Delacorte and McGuire 1984; 10, Basgall and McGuire 1987; 11, Burton 1986a; 12, Hall 1983; 13, Burton 1986b; 14, Basgall 1984; 15, Garfinkel 1980; 16, Bettinger 1981; 17, Burton 1985b; 18, Mone 1986.
	*	also recorded as MNO-630
	**	statistically extreme outlier value in Hall (1984) hydration rate derivation experiment
	***	Inyo National Forest isolate designation, Mono County (4-51-, Mono Lake Ranger District; 4-52-, Mammoth Ranger District)

TABLE 2
HYDRATION SUMMARY STATISTICS FOR CASA DIABLO OBSIDIAN PROJECTILE POINTS FROM MONO COUNTY, CALIFORNIA (35 SITES, 15 ISOLATES, 2000-3000 M)

SUBSURFACE

Proj Pt	N	Range	Medn	Mean	SD
DSN+CT	18	1.20-3.42	1.77	1.97	0.75
DSN	13	1.20-3.10	1.73	1.81	0.62
CT	5	1.30-3.42	2.71	2.39	0.98
EG+RSCN	10	1.40-3.98	3.20	3.01	0.93
EG	7	1.40-3.98	3.70	2.97	1.14
RSCN	3	2.90-3.23	3.17	3.10	0.18
ELK+GCS	56	2.21-5.79	4.06	4.21	0.74
ELK***	41	2.21-5.79	4.05	4.14	0.79
EE	13	2.21-5.00	3.89	3.92	0.84
ECN	21	3.02-5.79	4.18	4.34	0.84
GCS	15	3.72-5.56	4.38	4.42	0.56
LLSS	3	3.75-6.85	4.04	4.88	1.71

SURFACE

Proj Pt	N	Range	Medn	Mean	SD
DSN+CT	8	1.23-2.80	1.95	1.95	0.47
DSN	2	1.23-2.10	1.67	1.67	0.62
CT	6*	1.58-2.80	1.95	2.05	0.43
EG+RSCN	8	1.80-4.30	2.95	3.03	0.96
EG	6	2.10-4.30	2.95	3.04	0.84
RSCN	2	1.80-4.20	3.00	3.00	1.70
ELK+GCS	18	2.70-5.60	3.90	4.00	0.70
ELK***	16	2.70-5.60	4.00	4.04	0.73
EE	7	3.70-4.50	4.00	4.06	0.29
ECN	5	2.70-5.00	3.40	3.56	0.87
GCS	2	3.60-3.80	3.70	3.70	0.14
LLSS	6	4.80-7.80	6.25	6.14	1.16

TOTAL

Proj Pt	N	Range	Medn	Mean	SD
DSN+CT	27	1.20-3.42	1.80	1.99	0.67
DSN	15	1.20-3.10	1.73	1.79	0.60
CT	12**	1.30-3.42	2.15	2.24	0.69
EG+RSCN	18	1.40-4.30	3.20	3.02	0.92
EG	13	1.40-4.30	3.30	3.00	0.97
RSCN	5	1.80-4.20	3.17	3.06	0.86
ELK+GCS	74	2.21-5.79	4.00	4.16	0.73
ELK***	57	2.21-5.79	4.00	4.11	0.77
EE	20	2.21-5.00	4.00	3.97	0.69
ECN	26	2.70-5.79	4.01	4.19	0.89
GCS	17	3.60-5.56	4.24	4.33	0.58
LLSS	9	3.75-7.80	6.00	5.72	1.40

*a second value of 6.10 microns for one CT (Table 1) dismissed as aberrant (remnant surface)

**total includes hydration measurement on one specimen of unknown stratigraphic provenience

***ELK encompasses measurements on EE and ECN points, and identifiable, but indistinguishable fragments of each form

TABLE 2, CONTINUED

SUBSURFACE

Proj Pt	N	Range	Medn	Mean	SD
RSCS	-	-	-	-	- -
LSN	3	5.40-5.82	5.50	5.57	0.22
WSBS	6	4.97-8.18	6.36	6.63	1.30
WSNS	3	6.01-7.24	6.32	6.52	0.64
MCNS	2	3.14-3.36	3.25	3.25	0.16
HBN	3	1.20-5.50	3.91	3.54	2.17
HCB	23	2.56-7.92	4.17	4.42	1.11
GBCB	-	-	-	-	-

SURFACE

Proj Pt	N	Range	Medn	Mean	SD
RSCS	2	2.50-3.80	3.15	3.15	0.92
LSN	3	4.00-5.40	4.40	4.60	0.72
WSBS	6	4.10-8.80	5.40	5.85	1.88
WSNS	4*	5.20-9.00	8.15	7.63	1.69
MCNS	12**	1.80-8.00	4.20	4.70	2.36
HBN	3	3.10-4.60	3.80	3.83	0.75
HCB	12	3.50-5.90	4.05	4.33	0.81
GBCB	2	10.00-10.20	10.10	10.10	0.14

TOTAL

Proj Pt	N	Range	Medn	Mean	SD
RSCS	2	2.50-3.80	3.15	3.15	0.92
LSN	6	4.00-5.82	5.40	5.09	0.72
WSBS	12	4.10-8.80	6.30	6.24	1.59
WSNS	7	5.20-9.00	7.24	7.15	1.38
MCNS	15***	1.34-8.10	3.50	4.28	2.31
HBN	6	1.20-5.50	3.86	3.69	1.46
HCB	35	2.56-7.92	4.10	4.39	1.01
GBCB	2	10.00-10.20	10.10	10.10	0.14

*values of 5.00 and 5.40 microns reported for one specimen (Table 1) averaged here as 5.20 microns
**both values (6.00, 8.10) reported for one specimen (Table 1) treated independently here
***total includes hydration measurement on one specimen of unknown stratigraphic provenience

Key: DSN, Desert Side-notched; CT, Cottonwood Triangular; EG, Eastgate series (10 Expanding-stem, 3 Split-stem); RSCN, Rose Spring Corner-notched; ELK, Elko series; EE, Elko Eared; ECN, Elko Corner-notched; GCS, Gypsum Contracting-stem; LLSS, Little Lake Split-stem; RSCS, possible Rose Spring Contracting-stem; LSN, large side-notched; WSBS, large wide-stemmed, shoulders broad, pronounced; WSNS, large wide-stemmed, shoulders narrow, rounded; MCNS, miscellaneous, untypable corner-notched or shouldered forms (usually large); HBN, Humboldt Basal-notched, HCB, Humboldt Concave-base; GBCB, Great Basin Concave-base series.

TABLE 3
REVISED HYDRATION SUMMARY STATISTICS FOR CASA DIABLO OBSIDIAN PROJECTILE POINTS FROM MONO COUNTY, CALIFORNIA (EXTREME OUTLIERS ELIMINATED)

SUBSURFACE

Proj Pt	N	Range	Medn	Mean	SD
DSN+CT	17	1.20-3.10	2.00	1.88	0.68
DSN	12	1.20-2.90	1.62	1.70	0.50
CT	5	1.30-3.42	2.71	2.39	0.98
EG+RSCN	9	1.60-3.98	3.94	3.19	0.79
EG	7	1.40-3.98	3.70	2.97	1.14
RSCN	3	2.90-3.23	3.17	3.10	0.18
ELK+GCS	55	2.89-5.79	4.06	4.25	0.70
ELK***	40	2.89-5.79	4.01	4.19	0.74
EE	12	2.89-5.00	4.05	4.06	0.69
ECN	21	3.02-5.79	4.18	4.34	0.84
GCS	13	3.72-5.00	4.24	4.25	0.36
LLSS	3	3.75-6.85	4.04	4.88	1.71

SURFACE

Proj Pt	N	Range	Medn	Mean	SD
DSN+CT	7	1.23-2.20	1.80	1.83	0.34
DSN	2	1.23-2.10	1.67	1.67	0.62
CT	5*	1.58-2.20	1.80	1.90	0.25
EG+RSCN	8	1.80-4.30	2.95	3.03	0.96
EG	5	2.10-3.60	2.60	2.78	0.64
RSCN	2	1.80-4.20	3.00	3.00	1.70
ELK+GCS	17	2.70-5.00	3.80	3.91	0.59
ELK***	15	2.70-5.00	4.00	3.93	0.62
EE	6	3.70-4.40	4.00	3.98	0.24
ECN	4	2.70-3.60	3.25	3.20	0.39
GCS	2	3.60-3.80	3.70	3.70	0.14
LLSS	5	4.80-6.82	6.00	5.80	0.92

TOTAL

Proj Pt	N	Range	Medn	Mean	SD
DSN+CT	26	1.20-3.10	2.50	1.93	0.62
DSN	13	1.20-2.10	1.50	1.60	0.37
CT	12**	1.30-3.42	2.15	2.24	0.69
EG+RSCN	18	1.40-4.30	3.20	3.02	0.92
EG	13	1.40-4.30	3.30	3.00	0.97
RSCN	3	2.90-3.23	3.17	3.10	0.18
ELK+GCS	73	2.70-5.79	4.00	4.19	0.70
ELK***	56	2.70-5.79	4.00	4.14	0.73
EE	19	2.89-5.00	4.00	4.06	0.57
ECN	26	2.70-5.79	4.01	4.19	0.89
GCS	15	3.60-5.00	4.03	4.18	0.39
LLSS	9	3.75-7.80	6.00	5.72	1.40

*a second value of 6.10 microns for one CT (Table 1) dismissed as aberrant (remnant surface)
**total included hydration measurement on one specimen of unknown stratigraphic provenience
***ELK encompasses measurements on EE and ECN points, and identifiable, but indistinguishable fragments of each form

TABLE 3, CONTINUED

SUBSURFACE

Proj Pt	N	Range	Medn	Mean	SD
RSCS	-		-	-	-
LSN	3	5.40-5.82	5.50	5.57	0.22
WSBS	6	4.97-8.18	6.36	6.63	1.30
WSNS	3	6.01-7.24	6.32	6.52	0.64
MCNS	2	3.14-3.36	3.25	3.25	0.16
HBN	3	1.20-5.50	3.91	3.54	2.17
HCB	22	2.56-5.87	4.11	4.26	0.83
GBCB	-	-	-	-	-

SURFACE

Proj Pt	N	Range	Medn	Mean	SD
RSCS	2	2.50-3.80	3.15	3.15	0.92
LSN	3	4.00-5.40	4.40	4.60	0.72
WSBS	5	4.10-7.00	4.40	5.26	1.34
WSNS	3*	7.80-9.00	8.50	8.43	0.60
MCNS	12**	1.80-8.00	4.20	4.70	2.36
HBN	3	3.10-4.60	3.80	3.83	0.75
HCB	11	3.50-5.50	4.00	4.18	0.68
GBCB	2	10.00-10.20	10.10	10.10	0.14

TOTAL

Proj Pt	N	Range	Medn	Mean	SD
RSCS	2	2.50-3.80	3.16	3.15	0.92
LSN	5	4.40-5.82	5.40	5.30	0.53
WSBS	12	4.10-8.80	6.30	6.24	1.59
WSNS	7	5.20-9.00	7.24	7.15	1.38
MCNS	15***	1.34-8.10	3.50	4.28	2.31
HBN	5	3.10-5.50	3.91	4.18	0.91
HCB	34	2.56-5.90	4.07	4.28	0.81
GBCB	2	10.00-10.20	10.10	10.10	0.14

*values of 5.00 and 5.40 microns reported for one specimen (Table 1) averaged here as 5.20 microns

**both values (6.00, 8.10) reported for one specimen (Table 1) treated independently here

***total includes hydration measurement on one specimen of unknown stratigraphic provenience

Key: DSN, Desert Side-notched; CT, Cottonwood Triangular; EG, Eastgate series (10 Expanding-stem, 3 Split-stem); RSCN, Rose Spring Corner-notched; ELK, Elko series; EE, Elko Eared; ECN, Elko Corner-notched; GCS, Gypsum Contracting-stem; LLSS, Little Lake Split-stem; RSCS, possible Rose Spring Contracting-stem; LSN, large side-notched; WSBS, large wide-stemmed, shoulders broad, pronounced; WSNS, large wide-stemmed, shoulders narrow, rounded; MCNS, miscellaneous, untypable corner-notched or shouldered forms (usually large); HBN, Humboldt Basal-notched, HCB, Humboldt Concave-base; GBCB, Great Basin Concave-base series.

direct exposure to solar radiation of surface materials, factors which presumably increase effective hydration temperature and thereby enhance the hydration process. Comparison of hydration summary statistics for Casa Diablo obsidian projectile points from the source area in Mono County, California (Tables 2-3), reveals relatively minimal divergence between hydration values obtained on surface and subsurface specimens. By individual point form, with few exceptions, hydration means are consistently larger for subsurface than for surface specimens — ceteris paribus, an expectable stratigraphic relationship. Across the major point groups represented (Desert Side-notched/Cottonwood Triangular, Eastgate/Rose Spring, Elko/Gypsum, Little Lake, and Humboldt Concave-base series), and including statistically outlying point values, the average difference (Table 2) between surface and subsurface means is a negligible 0.32 microns (0.09 microns when the small number of Little Lake forms are excluded). Perhaps the most interesting disjunctions in surface/subsurface artifact hydration patterns, though magnitudes are only vaguely discernable given the few available analyzed examples, hold for point forms that tend to yield values of 7.0 microns or more (Tables 1-3, Fig. 1). These indications suggest that stratigraphic position may become a more significant hydration variable insofar as Casa Diablo glass in early Holocene cultural assemblages.

What is apparent generally, rather, are potentially meaningful differences in hydration measurements for specific point types (of Casa Diablo obsidian) from Owens Valley (Inyo County, 1100-1500 m) and the higher (2000-3000 m) Mono County localities to the north. Albeit the Owens Valley sample sizes are limited (Table 1), there is marked tendency for points of a particular morpho-chronological category to display thicker hydration bands than in the Casa Diablo source area (Fig. 1). This probably can be attributed to higher effective hydration temperatures in the Owens Valley region. It can also be noted that the absence of appreciable differences in hydration values for similar point forms from 2000-2500 and 2500-3000 m elevations in Mono County could reflect, conceivably, the predominantly surface provenience of specimens recovered in the latter contexts (i.e., solar-enhanced hydration of surface materials might mask the otherwise retarded hydration of samples due to lower effective temperatures above 2500 m). In sum, then, while inter-sample variation in effective hydration temperature is certainly an important consideration, for four reasons (cf. Hall 1984; R. Jackson 1984a) excessive concern with surface/subsurface provenience on a local level may be inappropriate.

First, the thermal history of an obsidian artifact after it entered the archaeological record (tool curation and post-deposit material scavenging factors notwithstanding) is virtually impossible to ascertain in most instances. Second, it thus cannot be assumed a priori that the respective stratigraphic positions of surface and subsurface debris have remained unchanged through time. Third, actual effects of varying effective temperatures are difficult to document and probably more relevant on an areal (elevational) basis. Fourth, there is, after all, a broader, principal interest in large-scale, multi-site trends in source-specific hydration data, patterns not likely to be measurably affected by microenvironmental temperature differentials.

Lastly, in our opinion, the Casa Diablo obsidian hydration data presented in Tables 1-3 provide a fairly convincing endorsement of the reliability of certain projectile point forms as at least relative, if not absolute (in many cases), time-markers in eastern California and the western Great Basin. Hydration measurements on arrowpoints, dartpoints, and possible spearpoints of Casa Diablo glass do seem to sort out well in a manner accordant with arguable, but stratigraphically established morpho-chronological schemes (Bettinger and Taylor 1974; Clewlow 1967; Heizer and Hester 1978; Holmer 1986; Lanning 1963; Thomas 1981, 1983). Crucial to this assessment is an explicit understanding that these points achieve chronological value primarily when considered as populations of specific kinds of artifacts. As with a single hydration measurement, which alone cannot be viewed as necessarily temporally significant due to such factors as tool curation and material scavenging, because of its unique techno-morphological trajectory (resharpening, rejuvenation, etc.) a single projectile point also cannot be taken as an unequivocal chronological indicator (cf. Flenniken and Raymond 1986; Flenniken and Wilke 1986). Duly incorporating the reality of temporal gradations afforded by hydration data, therefore, and excluding type-specific outlying values (never more than one or two per morphological category [compare Tables 2 and 3], and as determined by Chauvenet's criterion [Long and Rippeteau 1974] where p[x] < 1/2n [i.e., the probability (p) of obtaining a given value (x) is less than the inverse of twice the subject sample size (n)]), micron ranges (cf. Tables 1, 3) can be estimated for hydration on the following point forms of Casa Diablo obsidian in Mono County:

1.3-2.6	Desert Side-notched/Cottonwood Triangular;
2.1-3.9	Eastgate series/Rose Spring Corner-notched;

3.3-5.3	Elko series/Gypsum Contracting-stem/Humboldt series;
4.5-7.5	Little Lake Split-stem/"Pinto-like" large wide-stemmed forms with broad, pronounced shoulders;
6.0-9.0	large wide-stemmed forms with narrow, rounded shoulders — comparable to Lake Mohave/Silver Lake/Parman/Great Basin Stemmed series (cf. Amsden 1937; R. Jackson and Bettinger 1985; Layton 1979; Pendleton 1979; Tuohy 1974; Tuohy and Layton 1979); and
9.0-10.0	large, relatively thin,basally- and edge-ground concave-base forms (Great Basin Concave-base series) of apparent early Holocene age (cf. Basgall [this volume], n.d., 1987; Clewlow 1968; Pendleton 1979; Tuohy 1974).

Hence, while there is undoubtedly a need to exercise caution in using artifact cross-dating on a site-specific basis, especially when strictly surface assemblages are involved (Basgall, Hall, and Hildebrandt 1988; Flenniken and Raymond 1986; Thomas 1986), the Casa Diablo obsidian hydration projectile point profiles confirm an overall time-diagnostic utility to these artifacts that cannot be empirically discounted.

RATE CONSTRUCTION

Prior to 1984, the most archaeologically useful hydration rates proposed for Casa Diablo obsidian consisted of linear functions calibrated against hydration values for temporally-sensitive projectile point forms (Basgall 1983:130-134; Garfinkel 1980:25-26; Hall 1983:193-196). Of these, only the Hall (1983) formulation controlled for specimen geologic origin and the resultant rate also appeared to yield the widest range of apparently acceptable absolute age estimates (Bouey and Basgall 1984: 136-137). There were, however, two critical problems with the derivation and use of this rate. First, the least- squares regression performed to obtain the rate was based primarily on hydration measurements for points from a single site, CA-MNO-561 (Hall 1983), located on Mammoth Creek in southwestern Long Valley. Consequently, it was necessary to assume that the range in values for a given point series at the site encompassed the region-wide hydration span for the same point series (R. Jackson 1984b:178). Since such an assumption may be invalid, the calculated hydration rate could contain a significant temporal bias. Second, the Hall (1983) linear rate tends to produce age estimates unacceptably too recent when used to convert hydration values of less than ca. 1.2 microns or more than ca. 7.0 microns (cf. R. Jackson 1984b:181). The linear rate does appear to provide reasonable age estimates for intermediate values between ca. 2.0 and 7.0 microns — a characteristic of many proposed source-specific rates in California (cf. Bouey and Basgall 1984:Table 2; Ericson 1978:Tables 1-2; R. Jackson 1984b:Table 2; Meighan 1983:603, 1984:229-230).

In developing the Hall (1984) Casa Diablo hydration rate, each of the subject 108 projectile points (Table 1) was assigned to one of four temporal periods depending upon its morphological classification. Period definition was based on the radiocarbon chronology outlined by Thomas (1981) for certain point forms in the central and western Great Basin. Though similar in most respects, the point chronology offered by Bettinger and Taylor (1974) for interior southern California was not employed because it was established using "corrected" radiocarbon dates. A reluctance to adopt a "corrected" chronology stems from the uncertainties involved in calibrating secular variations in radiocarbon production over time, and in the methods of applying a given calibration scheme (R. E. Taylor, personal communication 1983). The four temporal periods and diagnostic point forms consist of: 4950-3250 B.P., Little Lake Split- stem; 3250-1250 B.P., Elko series (Corner-notched, Eared, indistinguishable fragments thereof) and Gypsum Contracting-stem; 1250-650 B.P., Rose Spring Corner-notched and Eastgate series (Split-stem, Expanding-stem); and 650-100 B.P., Desert Side-notched and Cottonwood Triangular. Gypsum Contracting-stem points, sometimes also referred to as Elko or Gatecliff contracting-stem (Clewlow 1967; Thomas 1981, 1983), were grouped together with Elko series forms since hydration values on Casa Diablo obsidian specimens in east-central California (Tables 2-3) both span and are encompassed by the range in values for Elko series points made from this glass in the region.

It can also be observed that the Casa Diablo hydration profiles for Humboldt series points (in particular, the concave-base form [Fig. 1]) substantially parallel the Elko pattern (Tables 2-3). Questions regarding their chronological placement (cf. Thomas 1981:17-18), however, precluded inclusion of Humboldt points as contemporaneous artifacts in deriving the Hall (1984) rate. For the same reason (poorly established temporal position), along with as yet unclear morphological definition, various, putatively

FIGURE 1

Figure 1. Depositional context and hydration histograms of Casa Diablo obsidian projectile points from east-central California.

```
                                                                          Microns

Proj Pt   County   Context      0.........1.........2.........3.........4.........5.........6.........7.........8.........9

DSN+CT                                            s  s
           Mono    surface                  s   s s  ss     o
                                            x
                                            xxx     x          x
           Mono    subsurf                  xxxx xx xx     x x x  o
           Inyo    surface                                s
           Inyo    subsurf                           x x

                                0.........1.........2.........3.........4.........5.........6.........7.........8.........9

EG+RSCN    Mono    surface                        s  s s  s      s  s     ss
                                                                x
           Mono    subsurf                    o x       x    x  x    xxxx
           Inyo    surface                                                 s
           Inyo    subsurf                                              x

                                0.........1.........2.........3.........4.........5.........6.........7.........8.........9

ELK+GCS                                                             s   s
                                                                    s s s   s
           Mono    surface                                 s   s  s sss s   ss  s s     o
                                                                      xx
                                                                      xxx
                                                                      xxx   x
                                                                      xxx x xx    x  x
                                                             x        xxxxx xxx   x  x x
           Mono    subsurf                        o      xx xxxxxxxxxxxxxxxxxxxx x xx x
           Inyo    surface                                                         s    s
           Inyo    subsurf                                               x  x  x  x x x           o

                                0.........1.........2.........3.........4.........5.........6.........7.........8.........9
```

FIGURE 1, CONTINUED

```
                                                   Figure 1 (Continued)

                                                                         Microns
Proj Pt   County   Context     0.........1.........2.........3.........4.........5.........6.........7.........8.........9

LLSS      Mono     surface                                                     ss          s    s  s         o
          Mono     subsurf                                           x x                            x

HBN       Mono     surface                                    s      s       s
          Mono     subsurf                 x                          x               x
          Inyo     surface                                                            s
          Inyo     subsurf                                         x         x               x

HCB                                                                s
          Mono     surface                                        ssss ss  s s     s  s   o
                                                                    x
                                                                    x
                                                                    xx      x  x
          Mono     subsurf                                 x       xx xxxx xxxx  x     xx x x                   o
          Inyo     subsurf                                                                 x    x               x

                               0.........1.........2.........3.........4.........5.........6.........7.........8.........9

WSBS                                                                           s
          Mono     surface                                                  s  s                   s     s                 o
                                                                                                                 x
          Mono     subsurf                                                           x       x   x  x                x

WSNS      Mono     surface                                                                 o                         s      s    s
.         Mono     subsurf                                                                     x  x        x

                               0.........1.........2.........3.........4.........5.........6.........7.........8.........9
```

KEY: Four Inyo (1100-1500 m) and 41 Mono (2000-3000 m) county locations; s, surface; x, subsurface; o, statistical outlier; DSN, Desert Side-notched; CT, Cottonwood Triangular; EG, Eastgate series (Expanding-stem, Split-stem); RSCN, Rose Spring Corner-notched; ELK, Elko series (Eared, Corner-notched, indistinguishable fragments thereof); GCS, Gypsum Contracting-stem; LLSS, Little Lake Split-stem; HBN, Humboldt Basal-notched; HCB, Humboldt Concave-base; WSBS, large wide-stemmed, shoulders broad, pronounced; WSNS, large wide-stemmed, shoulders narrow, rounded (values of 5.00 and 5.40 microns for one of latter specimens [Table 1] averaged here as 5.20 microns [outlier]).

early Holocene wide-stemmed (cf. Great Basin Stemmed) and concave-base (cf. Great Basin Concave-base) point forms were excluded in rate formulation. It should as well be noted that although artifact typology is a major consideration here, the categorical consistency supplied by the Thomas (1981) morphological key, the large numbers of specimens involved, and the continuity in multi-laboratory, multi-analyst hydration results, far outweigh the consequences of possible, but incidental point form misclassifications.

To generate variate pairs for calculating experimental, "potential" Casa Diablo rates, period-specific point hydration measurements (from Mono County) were manipulated in three steps (Hall 1984). All numerical operations were performed with a handheld Texas Instruments Programmable 58C calculator. First, correlations were made between the mean and then median values for a given period and the temporal midpoint of that period, or between a value representing, in hydration terms, the maximum proportional separation of two periods and the transition date between the two periods. In the latter instance, the procedure requires determining a hydration measurement above or below of which appropriately fall the greatest proportions of measurements for points assigned to two sequential periods. Second, to derive values for mean, median, and maximum separation variate pairs, period-specific hydration measurements were categorized in four ways: (1) as are, without regard for surface or subsurface provenience; (2) as are, without regard to surface/subsurface provenience, but with extreme "outliers" excluded by applying Chauvenet's criterion; (3) values for specimens found only in a buried context; and (4) values for specimens found only in buried context, but with extreme outliers excluded. The latter two categories of hydration values were included in the analysis, despite the foregoing discussion, out of due consideration to the surface/subsurface provenience vz. effective hydration temperature issue. Third, each of the 12 sets of variate pairs developed during the first two steps was used to calculate a total of 48 "potential" rates based on four functions (where y = years B.P., x = microns, b = y-intercept, and m = slope of fitted line):

linear	$y = b + mx$
exponential	$y = be^{mx}$
power	$y = bx^{m}$
logarithmic	$y = b + m \ln x$

RATE EVALUATION

Correlation coefficients (r) for the 48 experimental Casa Diablo hydration rates thus derived range from 0.86 to 1.00, with most (75%) greater than 0.95. The small number of actual variate pairs, per rate, no doubt underlies the uniformly high co-efficients (cf. Meighan 1983: 601-603). Of interest, nonetheless, is that coefficients above 0.95 were obtained for all exponential and power rates (24), whereas four linear and four logarithmic functions yielded r values of 0.90-0.95, and four of the latter form a value under 0.90. These admittedly minor differences could be construed as supportive of the classical diffusion model of Friedman and Smith (1960), and may reflect the ultimate, general ineffectiveness of logarithmic and, perhaps to a lesser degree, linear hydration rate configurations. To evaluate the accuracy of the 48 potential rates relative to each other, a multi-step strategy was used (cf. Hall 1984) that involved the following statistical manipulations:

(1) per rate, determine proportion of rate-construction, period-point hydration values correctly assigned (by age-conversion and stipulated temporal framework) to said period;
(2) per rate, determine proportion of all period specific values correctly assigned to said period;
(3) per rate, determine cross-period averages of proportions calculated in steps (1) and (2);
(4) per period, rank proportions obtained in steps (1) and (2); ordinal control introduced to the evaluation system in order to dampen proportional distortions due to period-specific, sample-size inequalities;
(5) per rate, determine cross-period averages of ranks formulated in step (4);
(6) repeat steps (1) through (5), but exclude Little Lake Split-stem values given small sample sizes (Tables 1-3);
(7) use cross-period proportion and rank averages to organize rates from most to least effective (eight separate orders); and
(8) determine mean of ordinal ("best-fit/worst-fit") positions (eight) established for each rate in step (7).

Overall, power functions fared well in the evaluation process (seven of 10 best-fit rates), while linear approximations performed poorly (seven of 10 worst-fit rates). Without going into unnecessary quantitative detail, two other observations can be made with respect to the 48 experimental rates. First, the best-fit rates are

TABLE 4
COMPARISON OF AGE ESTIMATES BY PROPOSED HYDRATION RATES FOR CASA DIABLO OBSIDIAN

x	A	B	C	D	E	F	G	H
0	0	+637	0	+934	+745	0	0	0
1	130	32	229	+234	+80	200	220	128
2	460	700	637	466	586	800	440	321
3	964	1369	1158	1166	1251	1800	660	551
4	1630	2037	1770	1866	1917	3200	880	808
5	2450	2706	2459	2566	2582	5000	1100	1087
6	3417	3374	3218	3266	3247	7200	1320	1385
7	4528	4043	4040	3966	3913	9800	1540	1700
8	5779	4711	4919	4666	4578	12800	1760	2031
9	7165	5380	5853	5366	5244	16200	1980	2375
10	8685	6048	6837	6066	5909	20000	2200	2732
11	10337	6717	7869	6766	6575	24200	2420	3102
12	12117	8022	8946	7466	7240	28800	2640	3482

Rates (y = years B.P.; x = microns)

A	$y = 129.656x^{1.826}$	(Hall 1984)
B	$y = 668.54x - 637.000$	(Hall 1983)
C	$y = 229.002x^{1.475}$	(R. Jackson 1984b)
D	$y = 700.0x - 933.6$	(Basgall 1983)
E	$y = 665.41x - 745.00$	(Garfinkel 1980)
F	$y = 1000x^2/5$	(Friedman and Smith 1960)
G	$y = 200x$	(Meighan 1978)
H	$y = 127.806x^{1.33}$	(Ericson 1977a; Clark [1964] model)

TABLE 4, (CONTINUED)

x	I	J	K	L	M	N	O
0	0	0	0	0	0	0	0
1	487	111	285	40	1000	0	6
2	689	222	1140	158	2000	94	51
3	844	333	2564	356	3000	283	174
4	975	444	4558	633	4000	566	412
5	1090	555	7123	988	5000	943	804
6	1194	666	10256	1423	6000	1414	1389
7	1289	777	13960	1937	7000	1979	2206
8	1378	888	18234	2530	8000	2639	3293
9	1462	999	23077	3202	9000	3393	4689
10	1541	1110	28490	3953	10000	4241	6432
11	1616	1221	34473	4783	11000	5184	8561
12	1688	1332	41026	5693	12000	6221	11114

Rates (y = years B.P.; x = microns):

I	$y = 487.28x^{0.50}$	(Ericson 1977a)
J	$y = 111x$	(Ericson 1977a; Meighan, Foote and Aiello [1968] model)
K	$y = 1000x^2/3.51$	(Michels 1982)
L	$y = 39.532x^2$	(Ericson 1977a; Friedman and Smith [1960] model)
M	$y = 1000x$	(Michels 1965; Ericson 1982)
N	$y = 47.126(x^2 - x)$	(Ericson 1977a; Findlow et al. [1975] model)
O	$y = 6.432x^3$	(Ericson 1977a; Kimberlin [1976] model)

three to four times more accurate than the worst-fit rates in placing period-specific point hydration values in their expected chronological position. Second, differences in the accuracy of the top four rates (all power functions) are quite negligible (2-4%). The most effective rate identifed with these procedures is:

$$y = 129.656x^{1.826}$$

In terms of its derivation the top-ranked rate was based on a correlation of period-specific hydration medians with period midpoints and, interestingly, on hydration values for projectile points recovered from subsurface contexts with extreme outlier measurements excluded. Although this in no way documents a significant difference in the rate of hydration between buried obsidian specimens and those found on the surface, as regards Casa Diablo glass in the east-central Sierra Nevada it should satisfy those archaeologists who might argue abjectly that hydration values obtained for surface materials cannot be used in calculating an empirical hydration rate.

Including the Hall (1984) formulation, then, 15 hydration rates have been proposed for or considered generally applicable to Casa Diablo obsidian (Tables 4-5). Ideally it would be possible to evaluate the accuracy of these rates against a broad range of alternative, direct radiometric data. The latter are unfortunately both limited (a reflection of poor organic preservation at most Casa Diablo obsidian-bearing sites) and of commonly questionable applicability (the radiocarbon/hydration sample association problem alluded to above). What is left are indirect methods of rate evaluation, of which two are considered here.

On the premise of fairly well-established maximum (ca. 12,000- 10,000 B.P.) hydration values of 12-10 microns on Casa Diablo obsidian artifacts in the source area (cf. Basgall n.d., 1987; Hall n.d., 1984, 1986; R. Jackson 1984b, 1985), an initial assessment can be made by simple comparison of rate-specific age-conversions. Of the 15 rates depicted in Table 4, two (F, K) might be dismissed as "too slow" (yielding estimates of 41,026-20,000 years for 12-10 microns of hydration [see Endnote 1]). Three others, all linear functions (B, D, E), translate small hydration measurements (less than ca. 1.2 microns) either to the future or the immediate (by decades) past. Six of the rates (G, H, I, J, L, N) are apparently "too fast" (12-10 microns convert to a maximum of 6221 and a minimum of 1110 years). One of the four remaining rates (O, a cubic model) appears to be simultaneously too fast at the recent end of the cultural hydration range and too slow at the early end. The last three, perhaps most reasonable rates from this generalistic evaluation perspective, consist of the Hall (1984) proposal (A), a second power function (C) submitted by R. Jackson (1984b), and a simple, one micron = one thousand years formula (M) used by Michels (1965) and Ericson (1982). Among these, the Hall (1984) rate seems superior; the R. Jackson (1984b) power function provides age estimates possibly too young for roughly eight or more microns of hydration (this may be a consequence of the inappropriate use of 0,0 [no time, no hydration] as a [false] variate pair in actual rate calculation). Relative to all of the proposed rates, the y = 1000x linear approximation appears much too slow for values under 3-5 microns (Table 4).

A second, more particular, yet still indirect way of evaluating the accuracy of proposed Casa Diablo rates focuses on hydration measurements for time-diagnostic projectile point forms of this glass. As might be anticipated logically, the five rates (Basgall 1983 [D]; Garfinkel 1980 [E]; Hall 1983 [B], 1984 [A]; R. Jackson 1984b [C]) constructed with such data place proportionally more points in their "correct" temporal order (as determined by cross-period means, and with the Hall [1984] formulation thus adjudged most effective) than the other 10 subject rates (Tables 4-5). However, it is imperative to understand that these specimen-specific hydration values represent chronological reality (absolute or relative) and are of distinct archaeological relevance. Further, the proportions given in Table 5 were calculated on the basis of extant (Mono County) Casa Diablo point hydration values (Table 1), and not only on those employed directly in developing the five artifact- derived rates. Hence, the fact that, on average, the Hall (1984) rate (A) is nearly three times (58% vs. 20%) more accurate in projectile point temporal assignment than the experimentally induced (Michels 1982) rate (K) cannot be attributed casually to statistical bias (see Endnote 2). To interpret otherwise would require disputing point morphochronological sequences in east-central California, sample-specific hydration measurements, or both — alternative arguments of which none seems very likely practicable.

TABLE 5
PROPORTIONS OF HYDRATION VALUES FOR TIME-DIAGNOSTIC PROJECTILE POINT FORMS OF CASA DIABLO OBSIDIAN CONVERTED TO CORRECT CHRONOLOGICAL PERIOD BY PROPOSED SOURCE-SPECIFIC HYDRATION RATES (SPECIMENS FROM SOURCE AREA [MONO COUNTY] LOCATIONS)

Rate	Period IV	Period III	Period II	Period I	Average
A	0.741	0.278	0.865	0.444	0.582
B	0.519	0.222	0.973	0.556	0.568
C	0.593	0.278	0.919	0.444	0.559
D	0.444	0.222	0.919	0.556	0.535
E	0.444	0.278	0.946	0.444	0.528
F	0.519	0.167	0.514	0.333	0.383
G	0.889	0.556	0.014	-	0.365
H	0.963	0.389	0.041	-	0.348
I	0.407	0.889	-	-	0.324
J	1.000	-	-	-	0.250
K	0.333	0.111	0.122	0.222	0.197
L	0.630	0.111	0.014	-	0.189
M	-	-	0.095	0.444	0.135
N	0.407	0.056	0.014	-	0.119
O	0.259	-	-	-	0.065
Average	0.543	0.237	0.362	0.230	0.343

Key:

Period	IV,	650-100 B.P. (Desert Side-notched and Cottonwood Triangular points [27 specimens]);
Period	III,	1250-650 B.P. (Rose Spring Corner-notched and Eastgate series points [18 specimens]);
Period	II,	3250-1250 B.P. (Elko series and Gypsum Contracting-stem points [74 specimens]);
Period	I,	4950-3250 B.P. (Little Lake Split-stem points [nine specimens]); see Table 4 legend for rate and origin.

CONCLUSIONS

It is perhaps unfortunate that yet another Casa Diablo obsidian hydration rate has been formulated and proposed, and that the probability of settling upon an acceptable, permanent rate remains small. Nevertheless, the rate advocated here (Hall 1984), as well as appearing to be archaeologically more accurate, has distinct advantages over the apparently usable "rough and ready" Casa Diablo linear rates in that it does not erroneously date small hydration values to this century or in the future, and that it does recognize a substantial, but reasonable, absolute age difference between specimens with values in the 5.0-6.0 micron range and those measuring over seven microns. According to the Hall (1984) rate, of over a thousand hydration values on Casa Diablo obsidian artifacts in the eastern Sierra Nevada, the smallest converts to ca. 130 B.P. (see Endnote 3) and the largest to ca. 12,000 B.P. Moreover, when simple percentage adjustments (cf. Trembour and Friedman 1984) are made for (areal/elevational) differences in effective hydration temperatures, this rate yields age estimates that correspond well with radiocarbon-dated sample contexts in southern Owens Valley (Basgall and McGuire 1987; M. Basgall, personal communication 1988) and the western Sierra Nevada (T. Jackson, personal communication 1985).

The obsidian hydration rate derivation procedure described above, tailored as it is to a particular archaeological/ geological situation, is only one of several, potentially effective approaches. Continued, problem-oriented research will no doubt improve the efficacy of hydration dating, but it is evident that real returns on judicious, careful use of the technique have already been realized. Until "perfect" laboratory-derived rates are available, however, to be successful hydration dating will be necessarily dependent upon a clear appreciation of local and regional archaeological records (cf. Meighan 1983:607). For source-specific hydration rates, in particular, the criterion of archaeological relevance is paramount and must be satisfied before interpretive application can proceed.

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ENDNOTES

1. In this discussion, it is assumed (reasonably) that humans did not occupy the Casa Diablo obsidian source area any earlier than ca. 12,000-10,000 B.P. (cf. Basgall n.d., 1987; Bettinger 1982b; Hall n.d., 1984; Haynes 1967; Payen 1982).

2. The generally low proportions (Table 5) of correctly temporally placed projectile point hydration values, across all rates, for two of the four time periods (I, III) is most probably a function of limited sample sizes (cf. Table 2).

3. T. Jackson (1984:122-124) recently considered the virtual lack of hydration values under one micron in the western Sierra Nevada (cf. Origer [this volume]). He reasoned that since there was no specific technical explanation for why such small bands could not be detected, the lack of values less than one micron constituted "some culturally-related phenomenon and not some product of the chemical or physical aspects of the hydration process" (1984:124). Hence, it was suggested that one micron of hydration could be roughly equated with about 250 years B.P. and that the absence of smaller values reflected the massive, disease-induced depopulation (and consequent cessation of obsidian tool-use) of indigenous California following establishment of Spanish missions in southern California in the late 18th century. Several comments are appropriate. First, the infrequency of hydration values of a micron or less is common wherever hydration studies have been pursued and, therefore, may have nothing at all to do with whether or not obsidian-using populations were ravaged by epidemics. Second, there may well be physical and technical factors that tend to prevent measurement of such small hydration bands. For example, mechanical strain between the hydrated rind and unaltered interior of an obsidian specimen may not be sufficient at depths of less than ca. 1.0 microns to produce the strain birefringence that optically demarcates the diffusion front. Also, commonly employed magnifications (500 to 1200X) may be inadequate to separate a diffusion front at depths of under a micron from the surface undergoing hydration, and there is no assurance that higher magnifications would make consistent, reliable separation possible. Finally, and this assumes that hydration bands smaller than a micron could be measured if present, Cook (1978:93) concluded that significant depopulation as a result of Euroamerican colonization did not occur in regions of the Sierra Nevada until the mid-19th century gold rush. In this regard, using the power function Casa Diablo hydration rate discussed in the present paper, one micron converts

to a data of ca. 130 B.P. If radiocarbon and sidereal temporal scales are more-or-less compatible for such modem age estimates, the lack of hydration values under a micron would represent a period of time after ca. A.D. 1820, which correlates well with the Euroamerican impact on Sierra populations as dated by Cook (1978).

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ESTABLISHING AN HYDRATION RATE FOR FISH SPRINGS OBSIDIAN

Robert L. Bettinger

DESPITE GROWING RELIANCE UPON OBSIDIAN hydration as a means for establishing archaeological chronologies, particularly in California and the Great Basin, many aspects of the method that directly bear on its utility as a tool for dating remain problematic. Two of these are crucial. Firstly, however unambiguous they may seem in theory, many elements of the hydration process are unresolved in practice. The basic shape of the hydration curve itself is one such example (e.g., Meighan 1983). These are exceedingly technical matters. Apart from working solutions that must from time to time be developed in desperation by archaeologists, they are on the whole best left to specialists: experimentalists and theorists familiar with the physical mechanics and theory of the diffusion process. The other nagging problem in contemporary obsidian hydrations studies is that of establishing hydration rates for individual glass sources or localities within certain areally extensive and chemically heterogeneous sources. This problem is substantially less technical than the first and more readily dealt with by archaeologists. Indeed, a case can be made that hydration rates are more readily determined by the archaeologist than by the physicist/chemist (cf. Meighan 1983).

The matter of hydration rates was less a problem in early applications of obsidian hydration dating because reliable means for chemical sourcing were generally unavailable. Lacking this information, it sufficed to establish a few rates for large regions (e.g., Friedman and Smith 1960; Clark 1964), primarily to control for temperature, which, along with time, was seen as a major variable contributing to hydration rind thickness. As early as the 1970's, however, improving means of, and access to, chemical sourcing applicable to natural glass (e.g., Jack 1976) showed that hydration rate varied between geological sources, presumably as an effect of chemical constitutents that speeded or slowed the diffusion process (Michels and Bebrich 1971). It was clear thereafter that source variability would have to be addressed if obsidian hydration were to be used as a means of archaeological dating. Of course, the sourcing methods that raised chemical composition as a problem in the first place were the obvious means for its solution.

Knowing that hydration rates vary by source and having the capability to assign glass to chemically distinguishable sources makes the method by which rates are obtained all the more important. Two fundamentally distinct approaches are available, one geochemical, the other contextual/archaeological. The first seeks to isolate the effect on hydration rate of certain glass constituents, for example, silica (e.g. Michels 1981). Prospects for this approach seem good. To date, however, in the instances where it has been attempted the results have been problematic, proving more than anything else that the approach is still in its infancy and not to be relied upon generally.

As an alternative to chemical analysis, hydration rates may be obtained empirically with reference to a suite of rind measurements from contexts independently dated by either physical, e.g., radiocarbon, or cultural means, e.g., time-marker artifacts. Other things being equal, dating by physical techniques is clearly the more preferable. This is not generally possible, however. Indeed, interest in obsidian hydration as a dating method arose directly in response to the limited applicability of most other physical methods, including radiocarbon, in many archaeological contexts — particularly in California and the Great Basin. The archaeologist must operate as best he can with what is left, calibrating hydration rates by means of cultural chronologies, aided here and there by dates obtained through other means.

BACKGROUND

Described below are the methodology and results of an attempt to develop an hydration rate for Fish Springs obsidian, the source of which lies a few miles south of the modern town of Big Pine in eastern California. The hydration rate for this glass is locally important in central Owens Valley where material from this source constitutes approximately 50% - 100% of all chipping waste (Bettinger 1982). It is, further, of more general regional importance in eastern California than its limited regional distribution might suggest because Fish Springs obsidian can be readily and reliably identified by visual means (Bettinger, Delacorte, and Jackson 1984). This makes it possible to eliminate the costly step of chemical sourcing when dating assemblages by hydration rind measurements (cf. Meighan 1983: 608).

Work with the hydration rate for Casa Diablo obsidian (Garfinkel 1980, Basgall 1983, Hall 1983, Hall and Jackson [this volume]), a source located 90 km. north of Fish Springs in Long Valley, Mono County, demonstrates the efficacy of calibrating the hydration rate for that material by cross-dating obsidian hydration rind measurements obtained from well-known projectile point forms against the well-established dates for those forms. In these studies projectile points of different types made of Casa Diablo obsidian were submitted for hydration analysis. Simple correlation between the mean date of the time-span for each type and the mean hydration rind thickness for points representing those types yielded an estimate of hydration rate for Casa Diablo obsidian.

A modified, and less direct, form of this procedure was used by Bettinger (1980) to propose a provisional hydration rate for Fish Springs obsidian. In this study obsidian hydration rind measurements were obtained from samples of debitage recovered from the surfaces of six Owens valley sites belonging to three separate settlement categories (cf. Bettinger 1977). The dating independently inferred for these categories on the basis of time- sensitive projectile points was then used to calculate an hydration rate. This was done by correlating dates that marked the inception or termination of use of the three categories and the largest (i.e., oldest) or smallest (i.e., youngest) hydration rind measurement for those categories (for details see Bettinger 1980). Following the generally accepted model of diffusion, to which in theory the hydration of obsidian conforms, the initial calculation presumed that rate of hydration rind growth decreases directly in proportion to the square root of the amount of time that has lapsed since the surface being measured for rind thickness was first exposed to the atmosphere. This gave:

$$Y = 189.7\,X^2 - 12.11, \quad (1)$$

where X is the observed hydration rind in microns and Y is the age of the rind in years before present. Although faithful to theory, this rate produced unacceptably large estimates of age for the obsidian specimen yielding the largest rind measurement observed in the study (10.9 microns = 22,526 years). The most parsimonious alternative assumed the rate of hydration to be linear. This gave:

$$Y = 985.4\,X - 963.1, \quad (2)$$

where X and Y are defined as in Equation 1, i.e., the hydration rind measurement and age in years B.P., respectively.

The working hydration rate for Fish Springs provided by Equation 2 was most useful despite its obvious shortcomings, most notably that: 1) the correlation derived from only three data points (1200 B.C. and 4.1 microns, A.D. 600 and 2.5 microns, and A.D. 1850 and 1.0 microns); and 2) the inferred temporal linkage between rind measurement and age was indirect and hence problematic for all three (i.e., in this study projectile points provided the dates for the settlement categories, which in turn provided the dates that were correlated with rind measurements to obtain the rate). Continuing archaeological research in Owens Valley and eastern California favored development of a new hydration rate more precise and more accurate than the first.

METHODOLOGY

Because there are still no well-stratified and reliably radiometrically dated sites or series of sites from which samples of Fish Springs obsidian can be

TABLE 1

OBSIDIAN HYDRATION MEASUREMENTS FOR TYPABLE PROJECTILE POINTS

Specimen Number	UCD Laboratory Number	Type/ Series	Hydration Reading
OX-10	543	Desert Side-notched	NVH*
O-1301	3578	Desert Side-notched	NVH*
O-1291	3576	Desert Side-notched	1.6
O-1651	3583	Desert Side-notched	1.7
O-8	3559	Desert Side-notched	1.8
O-1315	3579	Desert Side-notched	1.9
O-484A	3564	Desert Side-notched	2.2
O- 930	3573	Desert Side-notched	2.7
OX- 13	545	Cottonwood Triangular	NVH*
O- 127	3560	Cottonwood Triangular	NVH*
O- 315	3562	Cottonwood Triangular	NVH*
O- 792	3567	Cottonwood Triangular	NVH*
O-1717	3584	Cottonwood Triangular	NVH*
OX- 45	552	Cottonwood Triangular	1.0
O- 749	3565	Cottonwood Triangular	1.1
OX- 53	554	Cottonwood Triangular	1.6
O- 410	3563	Cottonwood Triangular	1.9
O- 764	3566	Cottonwood Triangular	2.2
O-1745	3585	Cottonwood Triangular	2.6
O- 803	3568	Cottonwood Triangular	2.8
O- 670/2	3586	Cottonwood Triangular	3.3
O-1004	3574	Cottonwood Triangular	3.3
OX- 39	548	Rose Spring series	1.2
OX- 7	541	Rose Spring series	1.6
X- 11	529	Rose Spring series	2.0, 2.7**
OX- 38	547	Rose Spring series	2.0
O-1292	3577	Rose Spring series	2.2
X- 12	530	Rose Spring series	2.2
O-1613	3582	Rose Spring series	2.5
O-1457	3580	Rose Spring series	2.6
O- 808	3569	Rose Spring series	2.7
O- 832	3571	Rose Spring series	3.3
O- 835	3572	Rose Spring series	3.7
O- 238	3561	Elko series	1.9
OX- 70	556	Elko series	3.1
O-1290	3575	Elko series	3.5
X- 49	535	Elko series	4.0
X- 5	528	Elko series	5.4
X- 50	536	Elko series	7.7
OV-872	557	Little Lake series	4.9
X- 36	532	Humboldt Concave Base "A"	6.5

* NVH = no visible hydration

** two distinct hydration bands; the larger, 2.7 microns, is assumed to correspond to the date of manufacture.

TABLE 2

Type/Series	Mean	S	Max	Min	NVH	n
Desert Side-notched	1.98	0.41	2.7	1.6	2	8
Cottonwood Triangular	2.20	0.87	3.3	1.0	5	14
Desert Side-notched and Cottonwood Triangular	2.11	0.71	3.3	1.0	7	22
Rose Spring series	2.43	0.71	3.7	1.2	0	11
Elko series	4.27	2.03	7.7	1.9	0	6
Little Lake series/ Humboldt Concave Base "A"	5.70	1.13	6.5	4.9	0	2

obtained for hydration rind measurement, as in previous work with eastern California obsidians, it was necessary to use well-known and well-dated projectile points types to develop the rate proposed here. Little about this was remarkable. Collections of obsidian projectile points recovered from sites in central Owens Valley during surface survey (e.g., Bettinger 1977) or excavation (e.g., Bettinger 1989) were examined visually (cf. Bettinger, Delacorte, and Jackson 1984) to segregate for further analysis ones that could be identified with certainty as having been made of Fish Springs obsidian. Out of these, 41 pieces that could be confidently assigned to time-sensitive projectile point types (cf. Bettinger and Taylor 1974; Thomas 1981) were submitted to R. Jackson for hydration rind measurement.

Represented in the sample were the following types and series: Desert Side-notched (n = 8), Cottonwood Triangular (n = 14), Rose Spring series (n = 11), Elko series (n = 6), Little Lake series (n = 1), and Humboldt Concave Base "A" (n = 1). It is generally accepted (Bettinger and Taylor 1974; Bettinger 1977, 1989) that in eastern California Desert Side-notched and Cottonwood Triangular points date between A.D. 1300 and historic times (1850; but see Rector, Swenson, and Wilke 1981), Rose Spring series points between A.D. 600 and A.D. 1300, and Elko series points between 1200 B.C. and A.D. 600. These dates are followed here. Themselves poorly dated, Humboldt Concave Base "A" points (cf. Heizer and Clewlow 1968) have often been assumed to be coeval with those of the Little Lake series, which are held to date between 3500 B.C. and 1200 B.C. Data summarized by Thomas (1981) put this temporal equivalence in doubt but so few Little Lake series points made of Fish Springs obsidian were available for study that we were forced provisionally to accept it. Both forms were assigned to the period from 2500 B.C. - 1200 B.C. This estimate is conservative but the one most consistent with the range of dates currently pertaining to the Little Lake series in the western Great Basin (cf. Thomas 1981). The hydration rind for the one Humboldt point examined is consistent with the traditional type of dating, the one proposed here, and the one proposed by Thomas.

Seven of the 41 points cut and microscopically examined lacked visible hydration bands. The remaining 34 exhibited bands ranging from 7.7 microns to 1.0 microns. A single specimen (X-11) showed two distinct hydration bands suggesting the possibility of reuse. The younger (smaller) of these two was ignored, since it is the earlier (larger) that presumably corresponds to the date of manufacture of the point. Individual measurements for each specimen are provided in Table 1 and summarized by relevant type or series in Table 2.

Given the well-established dating for selected Great Basin projectile points and a reasonable sample of archaeological pieces made from Fish Springs obsidian, the problem is to match the one to the other and derive an hydration rate therefrom. As noted earlier, this has often been done by correlation of the mean hydration rind thickness for a given point form with the mean date (i.e., the midpoint of the temporal span) for that form. In the case of the Elko series, for example, the mean of the hydration rind measurements for each piece representing the series would be matched against the date 2270 B.P., the midpoint of temporal span for that series (3170 B.P. to 1370 B.P.) in years before present, taken here to be 1970. This reduces our correlation problem to just four independent data points: 2.11 microns and 670 B.P. for the Desert Side-notched and Cottonwood types combined, 2.43 microns and 1020 B.P. for the Rose Spring series, 4.27 microns and 2270 B.P. for the Elko series, and 5.70 microns and 3820 B.P. for the Little Lake series and Humboldt Concave Base "A" type combined.

It seems a waste of useful temporal data to assume, as in effect the procedure outlined above does, that hydration rind measurements are indicative only of the midpoint of the temporal span of the type or series to which they belong. It is no less reasonable to assume that the range of hydration measurements for each form in some way corresponds to its temporal floruit, the larger readings denoting older pieces, smaller readings younger pieces. One might, therefore, add to the number of points in the hydration measurement-temporal date correlation by assigning to the largest hydration measurement for each type or series the oldest date for that type or series, and to smallest reading the youngest date. There are good reasons for not doing this. Myriad circumstances — sampling error and artifact reuse to name two — make any single hydration measurement simply too unreliable.

It is more reasonable to work with dates that define temporal boundaries between sequent types or series (e.g., the date of A.D. 1300 which divides the Rose Spring series from the Desert Side-notched and Cottonwood Triangular types) and seek an appropriate hydration value to match with this. This hydration value should be the one that marks the point of maximal divergence between the cumulative frequency distributions of hydration readings for the two point forms in question. This point is the same as the statistic D in the Kolmogorov-Smirnov two sample test (Siegel 1956):

$$D = \text{maximum } [Sn_1(X) - Sn_2(X)],$$

and $$Sn_1(X) = K_1/n_1,$$

$$Sn_2(X) = K_2/n_2,$$

where K_1 is the number of cases greater than or equal to X in the first sample (n_1), and K_2 is the number of cases greater than or equal to X in the second sample (n_2).

TABLE 3

Hydration Reading (microns)	Date	Explanation
1.00	200 B.P.	Minimal limit of visible hydration.
1.95	670 B.P.	Maximal segregation of hydration measurements and temporal boundary between Desert Side-notched and Cottonwood type points and Rose Spring series points.
2.43	1020 B.P.	Hydration mean and time span midpoint for Rose Spring series points.
2.90	1370 B.P.	Maximal segregation of hydration measurements and temporal boundary between Rose Spring series and Elko series points.
4.27	2270 B.P.	Hydration mean and time span midpoint for Elko series points.
4.45	3170 B.P.	Maximal segregation of hydration measurements and temporal boundary for Elko series and Little Lake series and Humboldt Concave Base "A" type points.
5.70	3820 B.P.	Hydration mean and time span midpoint for Little Lake series and Humboldt Concave Base "A" points.

TABLE 4
CORRESPONDENCE BETWEEN FISH SPRINGS AND CASA DIABLO OBSIDIAN HYDRATION READINGS AS EXTRAPOLATED FROM CUMULATIVE FREQUENCY OF READING OBTAINED AT INY-2146

Fish Springs	Casa Diablo	Years B.P.*	Fish Springs	Casa Diablo	Years B.P.*
6.1	7.1	4109.1	4.0	4.6	2437.8
5.8	6.4	3641.1	3.9	4.3	2237.3
5.6	6.1	3440.6	3.8	4.3	2237.3
5.5	5.9	3306.9	3.7	4.2	2170.4
5.4	5.6	3106.3	3.6	4.1	2103.6
5.2	5.6	3106.3	3.5	4.0	2036.7
5.0	5.4	2972.6	3.4	3.9	1968.9
4.9	5.4	2972.6	3.3	3.8	1903.0
4.8	5.3	2905.8	3.2	3.7	1836.2
4.7	5.3	2905.8	3.0	3.7	1836.2
4.6	5.2	2838.9	2.9	3.6	1769.3
4.5	5.1	2772.1	2.6	3.5	1702.5
4.4	4.8	2571.5	2.5	3.4	1635.6
4.3	4.7	2504.7	2.3	2.9	1301.4
4.2	4.7	2504.7	2.2	2.6	1100.8
4.1	4.7	2504.7			

*estimated from hydration rate formula for Casa Diablo (Hall 1983):
$Y = 668.5X - 637.3$,

where X is the thickness of the hydration rind in microns and Y is the age of the rind in years before present.

Along with the four obtained by matching hydration means against time span midpoints, the three pairings of temporal boundaries and maximal hydration measurement segregation for sequent point forms given by the maximum value of D provide a total of seven data points that might be used to obtain a hydration rate for Fish Springs obsidian. Unfortunately, out of these seven, one is clearly inconsistent with the others. Specifically, the point that in theory ought to be the most recent, the one that matches mean hydration measurement with the time span midpoint for Desert Side-notched and Cottonwood Triangular points, has a hydration value (2.11 microns) which is substantially larger than the one associated with the temporal boundary between these types and the Rose Spring series (1.95 microns). Inspection of Table 1 shows this reversal is due to a few excessively large hydration values for Cottonwood points that skew the mean value for Cottonwood and Desert Side-notched points. Note that this has virtually no effect on the point of maximal segration between hydration measurements for these types and those of the Rose Spring series because this statistic is ordinal, as opposed to interval, in scale.

Rather than try to decide which of the anomalously large hydration values for Cottonwood points ought to be excluded, this data point (i.e., mean hydration and time span midpoint for Desert Side-notched and Cottonwood points) was itself excluded from further consideration. This reduces substantially information we can bring to bear on the rate of hydration in Fish Springs obsidian during the most recent time periods, those represented by samples in the early stages of hydration. This is a critical deficiency because in central eastern California much of the material in need of dating is from this period (cf. Bettinger 1977).

To compensate for the one deleted, an additional data point was added that estimated minimum time needed to form a visible hydration rim. The hydration value for this minimum temporal threshold is logically taken to be 1.0 microns — the smallest observed among the 34 measurable hydration rinds. In determining a date for this threshold, it was noted that many Cottonwood and Desert Side-notched points (32%) were without visible hydration bands and that no specimens of older types or series lacked them. This suggested that it must be the recency of the Cottonwood and Desert Side-notched types and not some other circumstance (e.g., fire, abrasion, or alkalinity of soil) that accounts for the absence of visible hydration on these pieces. Assuming this, assume also that the youngest points assayed in our sample (i.e., with no visible hydration) were made no later than historic contact, which is set here at 1850. It follows, then, that a span 120 years is too short to form a visible hydration layer; stated another way, it takes more than 120 years to form a hydration band 1.0 micron thick (but see Origer [this volume]). There are no concrete data to indicate exactly how much longer might be needed but 200 years seems a reasonable estimate. In sum, our last data point pairs the smallest hydration measurement in the study, 1.0 micron, with an estimated date of 200 years before present.

The seven points derived as outlined above (cf. Table 3) were used to calculate the hydration rate for Fish Springs obsidian by simple linear correlation. This was used in preference to a model in which hydration rate decreases exponentially, that model previously having been found lacking empirically in the Fish Springs case. This gives:

$$Y = 806.7X - 827.4, \quad (3)$$

with an associated (Pearson's) correlation coefficient of $r = 0.98$, where, as before, X is the hydration reading of

FIGURE 1
CUMULATIVE FREQUENCY DISTRIBUTIONS OF
CASA DIABLO AND FISH SPRINGS OBSIDIAN

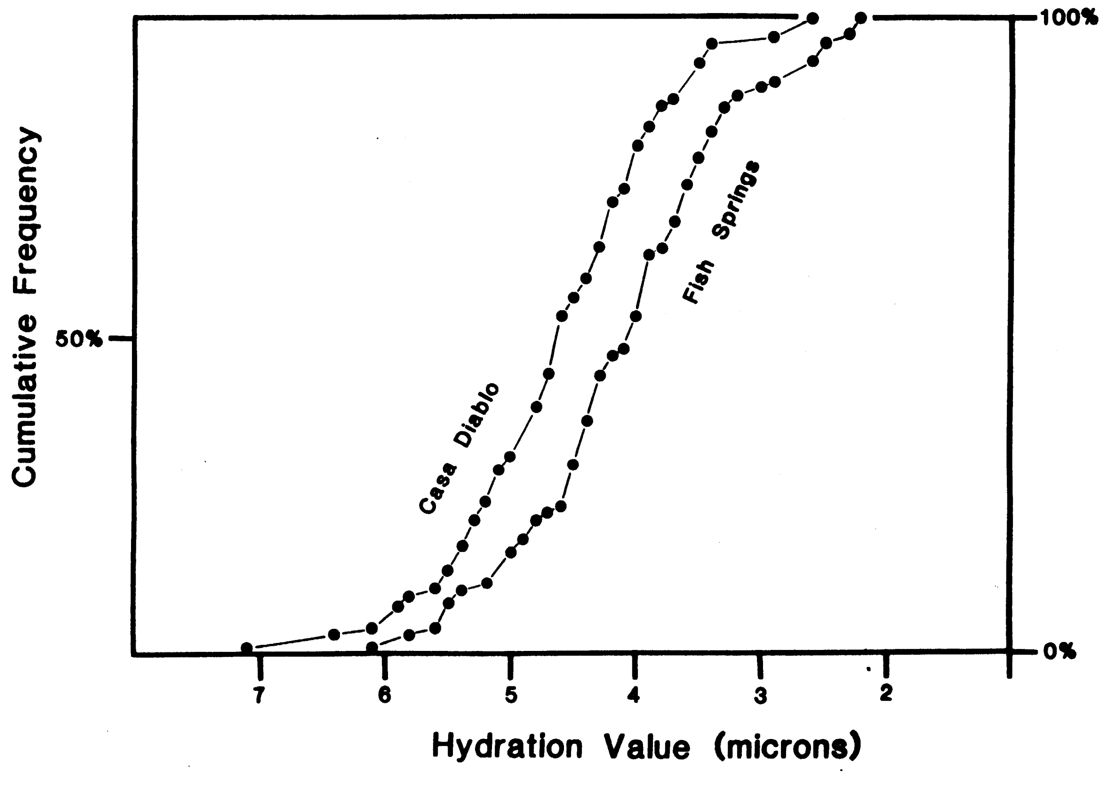
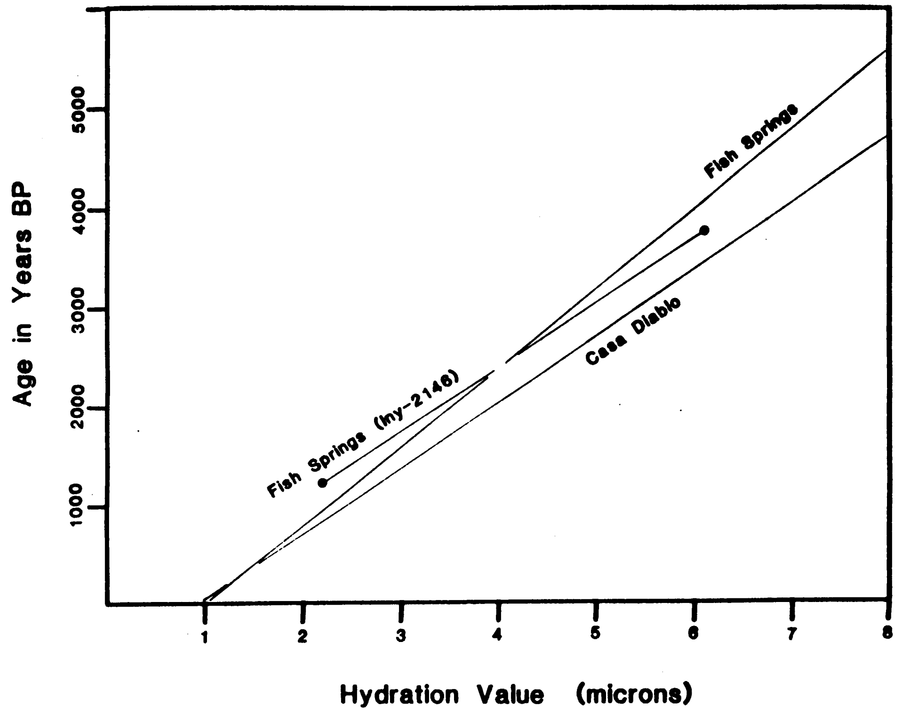


FIGURE 2
HYDRATION RATES FOR FISH SPRINGS AND CASA DIABLO OBSIDIAN



the specimen in microns and Y is the estimated antiquity of the exposed surface in years before 1970. For those wishing to conform to standard radiocarbon format, where B.P. is fixed in terms of years before A.D. 1950, Equation 3 may be corrected by subtracting 20 years (i.e., $Y = 806.7X - 847.4$)[1].

EVALUATION OF RESULTS

Given the assumptions made above (e.g., regarding mean time- span, etc), it can be proved mathematically that Equation 3 is the best estimate of the amount of time needed to form an hydration band of given size on exposed surfaces of Fish Springs obsidian provided we consider only the sample of points from which the rate itself was calculated. The extent to which it is the best estimate for any other sample is unclear. This is so by definition. The problem here, common to all inductive generalizations, is that there are never any independent data against which such a formula can be checked because in developing it all such data are exhausted to assure it provides the "best estimate" given what is known. One can only apply the rate to novel data, hope that it works, and modify it as additional data become available. Ultimately, it is the pattern of modifications that must be made to make the rate fit new data that indicates its fundamental soundness or lack thereof. Successively diminishing modifications suggest improvement in predictive capacity until, ideally, there are no obvious discrepancies between the dates predicted by the rate and dates independently obtained by other means.

The only relevant set of independent data that has become available since the initial calculation of the Fish Springs rate given by Equation 3 is a large suite of hydration rind measurements for artifacts made of Fish Springs (73 readings from 66 specimens) and Casa Diablo (70 readings from 67 specimens) obsidian recovered at Iny-2146, the Partridge Ranch site, located between the modern towns of Big Pine and Bishop in central Owens Valley (Bettinger, Delacorte, and McGuire 1984). The manner in which the sample representing each source was drawn makes it reasonable to assume, at least for the sake of argument, that both faithfully represent the temporal distribution of the total population of material from that source at Iny-2146. That the cumulative frequency distributions for the two sources are so similar in shape (Fig. 1) suggests that this assumption is probably correct and further suggests that both sources were used almost interchangably, i.e., without bias or preference, by the inhabitants of the site. If this is assumed, the curves can be used to calculate an hydration rate for Fish Springs obsidian that can be checked against the one described above. That is, Figure 1 makes it possible to determine for an hydration reading of given size for Fish Springs obsidian its temporal equivalent for Casa Diablo obsidian, the hydration rate for which is comparatively well established (cf. Hall 1983; Hall and Jackson [this volume]). It remains only to perform a regression of specific Fish Springs hydration measurements on dates calculated for the equivalent hydration measurement for Casa Diablo obsidian. Table 4 summarizes the data relevant to these calculations: specific hydration rind measurements for Fish Springs obsidian and equivalent hydration measurement and estimated amount of time needed to form that hydration rim for Casa Diablo obsidian. This gave:

$$Y = 646.2 X - 181.5 \quad (4)$$

where X and Y are defined as throughout the text (r= 0.99).

Figure 2 plots three hydration rates: 1) for Fish Springs as given by Equation 3; 2) for Casa Diablo as calculated in Table 4 following Hall (1983); and 3) for Fish Springs as given by Equation 4 (i.e., calculated from data obtained at Iny-2146). With respect to these rates, note that the Casa Diablo hydration rate of Hall (1983) is faster (i.e., the slope is lower) than the hydration rate proposed here for Fish Springs (Equation 3). This is consistent with the hydration data from Iny-2146 plotted in Figure 1, which, likewise, suggest that hydration rinds on Casa Diablo obsidian are larger than hydration rinds on temporally equivalent specimens of Fish Springs obsidian. Note also that the Fish Springs hydration rate as calculated from obsidian hydration data obtained from Iny-2146 (Equation 4) has about the same slope as the one calculated by Hall for Casa Diablo (roughly 650 years/micron) and differs from it primarily in terms of the Y - intercept. Specifically, according to these rates it takes approximately 450 years longer to form an hydration rind of given thickness on exposed surfaces of Fish Springs obsidian than it does to form a rind of equivalent thickness on Casa Diablo obisidian. This is consistent with the idea that Casa Diablo hydrates faster than Fish Springs obsidian.

Finally, observe in Figure 2 the relationship of all three rates within the interval between 2.2 and 6.1 microns, which is the one over which hydration data are available for Fish Springs obsidian from Iny-2146 and hence the one to which the application of the rate calculated in Equation 4 must be restricted. Within this interval, the rate specified by Equation 4 closely matches the rate specified by Equation 3. Indeed, the two rates intersect at 4.0 microns (i.e., they give the same date for an hydration measurement of that size), which is very near the midpoint of the interval over which the Fish Springs rate calculated from Iny-2146 is viable (4.2 microns). Put another way, while the slope of the hydration rate for Fish Springs obsidian given by Equation 4 differs from that given by Equation 3, the two produce very similar dates for hydration measurements greater than 2.1 microns and less than 6.2 microns. Equation 4 gives older dates than Equation 3 before 4.0 microns and younger dates thereafter. In any case, within this interval the two Fish Springs rates are more similar to each other than either is to the Casa Diablo rate proposed by Hall.

To summarize, then, data presently in hand suggest that Fish Springs obsidian hydrates at a rate sufficiently slower than Casa Diablo obsidian that hydration dates for it must be calculated separately by a different rate. The rate given by Equation 4 is unsuitable for this purpose owing to its limited metric range and its incorporation of all the uncertainties that surround attempts to determine the hydration rate for Casa Diablo obsidian. At the same time, Equation 4 offers strong evidence that the rate given by Equation 3 is for the moment the most reasonable approximation of the relationship between artifact hydration rind thickness and hydration rind antiquity on specimens of Fish Springs obsidian.

NOTE

1. This hydration rate differs negligibly from the one currently in use in Owens Valley (e.g. Bettinger 1989), which was previously calculated from the same data used here: $Y = 800.3 X - 811.2$. The slight difference owes to the hydration measurement for a single point that was first classified as representing the Rose Spring series and then reclassified as Desert Side-notched type subsequent to calculation of the rate given in the equation above. The rates differ in slope by less than one percent and in Y-intercept by scarcely two percent. They intersect at 2.53 microns or 1214 B.P.

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HYDRATION ANALYSIS OF OBSIDIAN FLAKES PRODUCED BY ISHI DURING THE HISTORIC PERIOD

Thomas M. Origer

ALTHOUGH OBSIDIAN HYDRATION HAS BEEN employed as a dating method in archaeology for nearly 30 years, there remain fundamental questions regarding the glass hydration process. Researchers do not agree on how hydration proceeds, whether by a diffusion or a reaction process, and many models have been proposed to describe the rate of hydration over time. Researchers have employed diffusion (e.g., Ericson 1977; Michels 1982), linear (e.g., Meighan 1981; Garfinkel 1980; Basgall 1983) or power function (e.g., Hall 1983) rate constant formulas in an effort to interpret hydration band thickness as elapsed time since the initiation of hydration. Given the differences in these approaches, a single obsidian hydration band of a certain thickness may be assigned a calendar date within a span of some 12,000 years, depending on the conversion formula used (Bouey and Basgall 1984: 157).

Many of the hydration rate formulas which have been proposed are clearly inadequate in some or all respects. For example, Bouey and Basgall (1984: Tables 1 and 2) have shown that some linear rates proposed for Casa Diablo obsidian yield dates for certain hydration band measurements which are in the future. These findings are supported by additional research carried out by Robert Jackson (1984: 180). Problems associated with obtaining a proper "fit" between hydration band thickness and calendar dates stem, in part, from inadequate numbers of hydration samples associated with materials with assigned, reliable, absolute chronometric dates (see Hall and Jackson, this volume). While this data base is gradually improving, it is clear that there is an exceptional paucity of absolute/hydration date correlations for very old and for very young samples. Many proposed hydration rate formulations are inaccurate, in part, because they lack data reference points at the recent end of the temporal scale.

Why is there a paucity of obsidian samples with thin hydration bands? Thomas Jackson commented on the scarcity of archaeological specimens from the southern Sierra Nevada with hydration bands measuring less than one micron. He concluded:

> "either there is a real uniformity in the rate at which the initial micron of hydration is created on the 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 period prehistoric or early historic period sites"
> (T. Jackson 1984: 121).

The clear implication of Jackson's remark is that the archaeological data base lacks samples from sites of

TABLE 1
VISUAL ATTRIBUTES OF OBSIDIAN SOURCE GROUPS IDENTIFIED IN THE ISHI COLLECTION.

Color[1]	Transparency/ color[2]	Inclusions[3]	Texture[4]	Source Assignment
Black	Opaque/gray	None	Glassy	Napa Valley (Group 1)
Black	Opaque/red black	None	Glassy	Napa Valley (Group 2)
Black	Opaque/gray	Phenocrysts	Glassy	Mt. Konocti (Group 1)
Gray	Semi-translucent/gray-brown	Bands	Glassy	Mt. Konocti (Group 2)
Gray	Semi-translucent/gray	Bands	Glassy	GF/LIW/RS[5]
Gray/black	Translucent/gray	None	Glassy	Borax Lake
Gray/black	Semi-translucent/gray	None	Grainy	Tuscan

Legend: [1] This indicates the color of reflected light; [2] indicates the color of light observed when specimens are held against a light source; [3] indicates the presence of attributes that detract from the specimen having a homogenous appearance; [4] this describes specimens having smooth, shiny surfaces (glassy) or specimens with coarse, dull surfaces (grainy); [5] Grasshopper Flat/Lost Iron Well/Red Switchback Chemical Group (see Hughes 1986: Appendix 1).

recent age.

The observation that samples with hydration measurements smaller than one micron are truly uncommon in the archaeological record is supported by examination of the data files of the Obsidian Hydration Laboratory at Sonoma State University. Since its founding in 1978, the laboratory has processed more than 10,000 obsidian artifacts from archaeological contexts in the United States and abroad, yet only a handful of specimens (a few dozen) have hydration bands measuring less than one micron.

These observations prompted several questions. Why are thin (less than one micron) hydration bands so rarely encountered among the archaeological samples? Are hydration bands that measure less than one micron not detected because of limitations associated with standard analytic procedures? How long does it take a measurable hydration band to form under normal conditions?

This paper addresses these questions, along with others relating to processes of hydration band formation and destruction, rate of hydration, and the effects of chemical composition and environmental temperature. In addition, this study generates data on the length of time necessary to develop a discernible and measurable hydration band, relationships among coeval source-specific hydration band measurements, and the effect of temperature on hydration development.

Donovan Clark (1961: 11) suggested that hydration bands measuring at least one micron should form on obsidian specimens after ca. 100 years of uninterrupted hydration. Clark's hypothesis effecively defines "recent" (less than 100 years) for purposes of this study and the logical source of such "recent" specimens should be archaeological sites. However, this assumption is complicated by the fact that the disruption of most California Indian cultures occurred more than 150 years ago. After Euro-American colonization most native peoples quickly abandoned the manufacture of flaked stone tools in favor of metal items, long-distance exchange of obsidian was foreclosed, and archaeological investigations of early contact sites are very rare.

HISTORIC PERIOD HYDRATION SAMPLES: THE ISHI COLLECTION

In 1980 Paul Amaroli and the author conceived a project to analyze obsidian samples from very recent historic period contexts and decided to examine obsidian artifacts made by Ishi, the Yahi Indian made famous by the writings of Theodora Kroeber (1961). Ishi was brought to the University of California by Alfred Kroeber, and lived in San Francisco and Berkeley from August 1911 until his death in March 1916 (Pope 1918; Waterman 1918). During this period Ishi knapped a variety of tools from obsidian and synthetic glass which are now housed at the Lowie Museum of Anthropology, University of California at Berkeley. Despite their appropriateness to obsidian hydration study, the prospect of damaging artifacts made by Ishi was unacceptable.

However, in 1984 Dr. David Fredrickson learned from Dr. Frank Norick of the Lowie Museum that some far-sighted individual, some seven decades ago, had collected and saved a sample of Ishi's chipping debris. This material, accessioned in 1915, is now curated with other Ishi artifacts at the Lowie Museum. Although it is not known for certain whether the Ishi chipping debris was made in 1915, this date will be used in this analysis. Forty-two samples drawn from Ishi's chipping debitage were selected for hydration band measurement.

TIME, TEMPERATURE, AND SOURCE

One critical factor in this study, the precise time that the samples were manufactured, is now fixed. In 1986, when hydration thin sections reported here were prepared, Ishi's flakes were about 71 years old. A second critical variable, temperature history, is also known. According to Dr. Norick the specimens have been stored at a stable temperature regime between 66 and 68 degrees F. (18.9 to 20.0 degrees C.). The remaining variable, obsidian source, needed to be addressed.

An initial examination of the Ishi flakes was made in order to characterize them on the basis of their physical (visual) attributes. Attributes such as color, clarity, texture, and presence/absence of inclusions are variables used to assign some obsidian specimens to their geologic sources in certain parts of California (Bettinger et al. 1984; Origer and Waechter 1987). Visual examination of the Ishi chipping debris indicated that several types of obsidian were present: two varieties from Napa Valley, two varieties from Mt. Konocti in Lake County, and one from the Medicine Lake Highland in Siskiyou County. Another source, Borax Lake (Lake County) was tentatively identified based on the observation of only a few small specimens in the collection. Table 1 lists visual characteristics of the samples selected for hydration dating.

These visual sourcing results raised an interesting, albeit unresolved, question: why was obsidian from so many sources, some more than 320 km apart, represented in an afternoon's chipping demonstration by Ishi? Napa Valley obsidian may have been ubiquitous in the Ishi collection because it was in close proximity to San Francisco and it provided a ready source of raw material. Although published literature (Nelson 1916; Pope 1918) sheds little light on the question of why so many sources are present, it is known that among the obsidians found archaeologically in Yahi territory are Tuscan and varieties from the Medicine Lake Highland. While speculative, it is interesting to conjecture that while Ishi lived in San Francisco he was at least provided with some obsidians that he was familiar with.

X-ray fluorescence (XRF) analysis, summarized in Table 2 and reported in concentration values (i.e., parts-per-million by weight) confirmed the visual source assignments for all but one specimen. One flake, which based on visual criteria was tentatively assigned to the Borax Lake source, was assigned to the Tuscan chemical group (cf. Hughes 1986: Appendix 2) on the basis of XRF data. XRF trace-element values for flakes visually assigned to the Medicine Lake Highland were attributed to the Grasshopper Flat/Lost Iron Well/ Red Switchback chemical group (GF/LIW/RS; see Hughes 1986: Appendix 2).

OBSIDIAN HYDRATION ANALYSIS

Once the three variables of manufacture date, temperature history, and glass geochemistry (source) were resolved, hydration analysis was undertaken. All hydration bands were measured using a 100 power oil emersion objective and a 10 power filar micrometer eyepicece for a total magnification of 1000X. At this magnification, the measurements have an error factor of ± 0.2 micron due to normal limitations of the optical equipment (see Scheetz and Stevenson 1988; Stevenson and Scheetz [this volume]). Each thin section was measured at a minimum of three and at as many as six loci along the hydration band. Hydration band measurements are averaged to two decimal places and reported with other pertinent data in Table 3, while Table 4 summarizes these by source.

Inspection of Tables 3 and 4 shows that while the hydration band mean values for Napa Valley and Mt. Konocti obsidians are statistically identical (given the ±

TABLE 2
SOURCE DATA FOR 42 OBSIDIAN SPECIMENS TAKEN FROM THE ISHI COLLECTION

Cat.No.	CHSQ	PB	TH	RB	SR	Y	ZR	NB	Source
BCR-1	3.7	12.6	0.0	47.3	325.2	36.1	182.6	10.2	
		+-2.1	+-0.0	+-2.6	+-4.7	+-3.2	+-4.4	+-3.7	
19874-M-A	4.8	39.4	18.8	210.0	8.7	54.7	253.9	8.8	NapaValley
		+-2.1	+-3.7	+-3.5	+-1.8	+-3.1	+-4.0	+-3.2	
-B	5.3	33.0	17.0	189.2	9.5	45.1	227.2	13.6	"
		+-1.9	+-3.2	+-3.1	+-1.6	+-2.8	+-3.5	+-2.9	
-C	4.5	35.4	17.3	178.3	6.7	42.9	216.2	8.4	"
		+-2.3	+-3.8	+-3.6	+-1.8	+-3.3	+-4.2	+-3.4	
-D	5.1	34.4	18.1	178.2	8.6	45.6	213.4	9.5	"
		+-2.0	+-3.4	+-3.3	+-1.6	+-3.0	+-3.8	+-3.1	
-E	4.7	38.6	22.3	205.1	9.4	56.1	247.6	6.3	"
		+-2.2	+-3.7	+-3.5	+-1.8	+-3.2	+-4.1	+-3.3	
-F	6.1	39.6	19.7	188.7	8.9	45.3	219.3	6.9	"
		+-1.9	+-3.1	+-3.0	+-1.6	+-2.7	+-3.5	+-2.9	
-G	5.1	37.3	19.2	201.0	7.1	51.3	233.6	10.4	"
		+-2.0	+-3.3	+-3.3	+-1.6	+-2.9	+-3.7	+-3.0	
-H	6.3	41.5	19.4	191.0	7.0	48.7	245.5	5.1	"
		+-1.9	+-3.2	+-3.1	+-1.6	+-2.8	+-3.6	+-2.9	
-I	5.3	34.0	23.7	187.3	6.7	49.2	233.5	13.3	"
		+-1.9	+-3.3	+-3.3	+-1.7	+-2.9	+-3.8	+-3.1	
-J	4.4	34.9	22.5	173.3	5.3	43.3	214.5	11.5	"
		+-2.3	+-3.8	+-3.6	+-1.9	+-3.3	+-4.2	+-3.5	
19874A-N-A	5.4	36.8	19.2	196.3	8.6	47.7	225.1	13.2	"
		+-1.9	+-3.3	+-3.1	+-1.6	+-2.8	+-3.6	+-2.9	
-B	5.4	34.6	17.3	179.6	8.1	49.1	240.8	11.3	"
		+-1.8	+-3.2	+-3.1	+-1.5	+-2.8	+-3.7	+-2.9	
-C	5.2	36.5	23.2	207.1	6.1	52.5	240.3	13.1	"
		+-2.0	+-3.5	+-3.4	+-1.7	+-3.1	+-3.9	+-3.1	
-D	4.5	39.1	19.6	200.4	8.4	51.0	234.1	7.7	"
		+-2.2	+-3.9	+-3.6	+-1.9	+-3.3	+-4.2	+-3.4	
-E	5.6	39.1	15.6	193.0	7.7	48.8	225.3	10.0	NapaValley
		+-2.0	+-3.4	+-3.3	+-1.7	+-3.0	+-3.8	+-3.1	
-F	5.8	35.0	25.4	190.8	6.1	48.3	235.3	10.0	"
		+-1.9	+-3.2	+-3.1	+-1.6	+-2.8	+-3.7	+-3.0	
-G	4.7	37.8	17.1	184.4	6.4	45.4	225.4	10.0	"
		+-2.1	+-3.5	+-3.4	+-1.7	+-3.0	+-3.9	+-3.1	
-H	5.0	34.6	20.0	181.1	6.5	47.9	217.8	4.8	"
		+-1.9	+-3.3	+-3.2	+-1.6	+-2.9	+-3.7	+-3.0	
-I	4.7	39.8	18.5	216.2	8.3	50.0	251.5	13.5	"
		+-2.2	+-3.6	+-3.6	+-1.8	+-3.2	+-4.1	+-3.3	
BCR-1	4.2	13.4	0.0	48.4	340.6	39.7	179.8	9.5	
		+-1.8	+-0.0	+-2.5	+-4.6	+-3.1	+-4.3	+-3.6	
19874-N-J	5.7	34.5	21.3	182.7	8.3	50.7	225.5	11.8	NapaValley
		+-1.8	+-3.1	+-3.0	+-1.5	+-2.8	+-3.5	+-2.9	

BCR-1 = U.S. Geological Survey international rock standard. See Hughes 1986 for further details pertaining to these analyses.

TABLE 2, CONTINUED

Cat.No.	CHSQ	PB	TH	RB	SR	Y	ZR	NB	Source
19874-K-A	5.1	27.8	20.5	205.5	77.9	36.1	188.3	14.0	Mt.Konocti
		+-1.9	+-3.4	+-3.3	+-2.4	+-2.9	+-3.6	+-3.1	
-B	4.3	31.4	21.9	202.1	76.9	37.2	190.6	11.2	"
		+-2.1	+-3.7	+-3.6	+-2.6	+-3.1	+-3.9	+-3.3	
-C	4.1	36.0	18.6	204.0	87.4	36.8	186.5	14.7	"
		+-2.1	+-3.9	+-3.7	+-2.8	+-3.2	+-4.0	+-3.4	
-D	3.6	31.3	30.1	205.1	71.0	32.6	185.4	10.6	"
		+-2.4	+-4.2	+-4.1	+-2.8	+-3.5	+-4.4	+-3.7	
-E	5.3	34.6	23.2	228.1	84.1	41.4	208.0	9.0	"
		+-1.9	+-3.5	+-3.5	+-2.4	+-2.9	+-3.7	+-3.1	
-F	3.3	33.4	28.7	200.6	83.0	37.3	185.4	11.4	"
		+-2.4	+-4.4	+-4.1	+-3.0	+-3.6	+-4.5	+-3.8	
-G	4.5	36.8	29.1	230.3	88.6	42.5	212.0	9.5	"
		+-2.2	+-4.0	+-3.9	+-2.8	+-3.4	+-4.2	+-3.6	
-H	4.2	33.8	23.5	209.2	82.9	34.7	197.0	9.7	"
		+-2.0	+-3.7	+-3.6	+-2.6	+-3.1	+-3.9	+-3.3	
-I	4.4	34.3	29.2	214.7	81.0	36.9	194.7	10.6	Mt.Konocti
		+-2.1	+-3.8	+-3.7	+-2.6	+-3.1	+-3.9	+-3.3	
-J	4.3	33.3	27.6	212.5	84.5	40.7	191.7	5.5	"
		+-2.2	+-4.1	+-3.9	+-2.8	+-3.4	+-4.2	+-3.6	
19874-TJ-A	4.3	30.8	0.0	79.4	93.7	19.8	61.3	7.4	Tuscan
		+-2.1	+-0.0	+-2.8	+-2.8	+-2.9	+-3.2	+-3.4	
TJ-B	2.6	30.2	17.2	202.0	10.2	38.4	74.6	7.2	BoraxLake
		+-3.2	+-5.6	+-5.4	+-2.8	+-4.7	+-4.6	+-4.9	
19874-Z-A	5.0	27.3	20.5	146.5	73.4	32.5	181.5	15.2	GF/LIW/RS
		+-1.8	+-3.2	+-2.9	+-2.3	+-2.7	+-3.5	+-3.0	
-B	4.3	27.4	12.5	140.1	73.4	28.4	167.9	11.0	"
		+-1.9	+-3.4	+-3.0	+-2.4	+-2.9	+-3.7	+-3.2	
-C	3.7	33.9	21.3	145.4	72.4	27.0	174.8	8.3	"
		+-2.4	+-4.3	+-3.7	+-3.0	+-3.5	+-4.4	+-3.9	
-D	5.3	29.0	18.4	142.3	73.3	27.7	170.9	9.3	"
		+-1.7	+-3.1	+-2.8	+-2.2	+-2.6	+-3.4	+-2.9	
-E	5.5	28.0	16.7	140.6	75.6	29.1	175.2	7.4	"
		+-1.7	+-3.1	+-2.8	+-2.2	+-2.6	+-3.4	+-2.9	
BCR-1	4.7	12.0	0.0	48.2	343.3	33.5	173.9	13.0	
		+-1.9	+-0.0	+-2.4	+-4.6	+-3.1	+-4.3	+-3.6	
19874-Z-F	3.6	26.4	14.8	153.3	78.4	30.2	185.7	8.5	"
		+-2.1	+-3.9	+-3.6	+-2.8	+-3.3	+-4.3	+-3.7	
-G	4.8	25.9	15.0	154.2	78.4	30.8	176.3	13.2	"
		+-1.9	+-3.5	+-3.1	+-2.5	+-2.9	+-3.7	+-3.2	
-H	4.2	28.4	16.2	137.2	73.7	29.2	168.8	10.0	"
		+-2.1	+-3.6	+-3.2	+-2.6	+-3.0	+-3.9	+-3.4	
-I	5.0	26.3	16.5	131.3	70.9	27.0	167.2	5.5	"
		+-1.7	+-3.0	+-2.7	+-2.2	+-2.6	+-3.3	+-2.9	
-J	4.5	26.6	15.9	158.4	77.7	31.6	191.0	9.0	"
		+-2.0	+-3.6	+-3.2	+-2.6	+-3.0	+-3.9	+-3.3	

TABLE 3: HYDRATION DATA FOR THE ISHI SAMPLE

CA-ISHI STUDY — Submitted by Thomas Origer - SSU — Dec 84-Mar 86

Lab#	Catalog#	Description	Provenience	MuseumRemarks	Readings	Mean	Source
01	19874-N-A	flake	Lowie Museum	none	0.6 0.7 0.7 0.7 0.7 0.7	0.68	NV G1(x)
02	19874-N-B	flake	Lowie Museum	none	0.7 0.7 0.7 0.7 0.7 0.7	0.70	NV G1(x)
03	19874-N-C	flake	Lowie Museum	none	0.7 0.7 0.7 0.7 0.7 0.7	0.70	NV G1(x)
04	19874-K-A	flake	Lowie Museum	none	0.6 0.6 0.6 0.6 0.7 0.7	0.63	K G1(x)
05	19874-K-B	flake	Lowie Museum	none	0.6 0.6 0.6 0.6 0.6 0.7	0.62	K G2(x)
06	19874-N-E	flake	Lowie Museum	none	0.6 0.6 0.6 0.6 0.6 0.6	0.60	K G1(x)
07	19874-N-D	flake	Lowie Museum	none	0.7 0.7 0.7 0.7 0.7 0.8	0.72	NV G1(x)
08	19874-N-E	flake	Lowie Museum	none	0.7 0.7 0.7 0.7 0.7 0.8	0.72	NV G1(x)
09	10984-N-E	flake	Lowie Museum	none	0.7 0.7 0.7 0.7 0.7 0.7	0.70	NV G1(x)
10	19874-N-G	flake	Lowie Museum	none	0.7 0.7 0.8 0.8 0.8 0.8	0.77	NV G1(x)
11	19874-N-H	flake	Lowie Museum	none	0.7 0.7 0.7 0.7 0.7 0.7	0.70	NV G1(x)
12	19874-N-I	flake	Lowie Museum	none	0.7 0.7 0.7 0.7 0.7 0.8	0.72	NV G1(x)
13	19874-N-J	flake	Lowie Museum	none	0.7 0.8 0.8 0.8 0.8 0.8	0.78	NV G1(x)
14	19874-K-D	flake	Lowie Museum	none	0.6 0.6 0.6 0.6 0.7 0.7	0.63	K G1(x)
15	19874-K-E	flake	Lowie Museum	fb	0.5 0.5 0.6 0.6 0.6 0.6	0.57	K G1(x)
16	19874-K-F	flake	Lowie Museum	1st b	0.5 0.6 0.6 0.6 0.6 0.7	0.60	K G2(x)
16	19874-K-F	flake	Lowie Museum	2nd	3.0 3.0 3.1 3.1 3.1 3.2	3.08	K G2(x)
17	19874-K-G	flake	Lowie Museum	none	0.6 0.6 0.6 0.6 0.6 0.6	0.60	K G1(x)
18	19874-K-H	flake	Lowie Museum	none	0.5 0.5 0.5 0.5 0.5 0.6	0.52	K G1(x)
19	19874-K-I	flake	Lowie Museum	none	0.5 0.5 0.6 0.6 0.6 0.7	0.58	K G1(x)
20	19874-K-J	flake	Lowie Museum	none	0.6 0.6 0.6 0.6 0.6 0.6	0.60	K G1(x)
21	19874-M-A	flake	Lowie Museum	none	0.7 0.7 0.7 0.7 0.8 0.8	0.73	NV G2(x)
22	19874-M-B	flake	Lowie Museum	none	0.7 0.7 0.7 0.7 0.7 0.7	0.70	NV G2(x)
23	19874-M-C	flake	Lowie Museum	none	0.7 0.6 0.7 0.7 0.8 0.8	0.73	NV G2(x)
24	19874-M-D	flake	Lowie Museum	none	0.6 0.7 0.7 0.7 0.7 0.7	0.68	NV G2(x)
25	19874-M-E	flake	Lowie Museum	none	0.6 0.6 0.7 0.7 0.7 0.7	0.67	NV G2(x)
26	19874-M-F	flake	Lowie Museum	none	0.7 0.7 0.7 0.7 0.8 0.8	0.73	NV G2(x)
27	19874-M-G	flake	Lowie Museum	none	0.7 0.7 0.8 0.8 0.8 0.8	0.77	NV G2(x)
28	19874-M-H	flake	Lowie Museum	none	0.7 0.7 0.7 0.7 0.7 0.7	0.70	NV G2(x)
29	19874-M-I	flake	Lowie Museum	none	0.7 0.7 0.8 0.8 0.8 0.8	0.77	NV G2(x)
30	19874-M-J	flake	Lowie Museum	none	0.7 0.7 0.7 0.7 0.7 0.7	0.70	NV G2(x)
31	19874-TJ-A	flake	Lowie Museum	none	0.9 1.0 1.0 1.0 1.0 1.0	0.98	T(x)
32	19874-TJ-B	Biface frag.	Lowie Museum	none	0.9 0.9 0.9 0.9 1.0 1.0	0.93	BL(x)
33	19874-Z-A	flake	Lowie Museum	none	0.8 0.8 0.8 0.8 0.8 0.8	0.80	GF(x)
34	19874-Z-B	flake	Lowie Museum	none	0.8 0.8 0.8 0.8 0.8 0.8	0.80	GF(x)
35	19874-Z-C	flake	Lowie Museum	none	0.8 0.8 0.9 0.9 0.9 1.0	0.88	GF(x)
36	19874-Z-D	flake	Lowie Museum	none	0.8 0.8 0.8 0.8 0.9 0.9	0.83	GF(x)
37	19874-Z-E	flake	Lowie Museum	none	0.9 0.9 0.9 0.9 0.9 0.9	0.90	GF(x)
38	19874-Z-F	flake	Lowie Museum	none	0.8 0.8 0.8 0.9 0.9 0.9	0.85	GF(x)
39	19874-Z-G	flake	Lowie Museum	none	0.7 0.8 0.8 0.8 0.8 0.9	0.80	GF(x)
40	19874-Z-H	flake	Lowie Museum	none	0.8 0.8 0.8 0.8 0.8 0.8	0.80	GF(x)
41	19874-Z-I	flake	Lowie Museum	none	0.7 0.7 0.7 0.8 0.8 0.9	0.77	GF(x)
42	19874-Z-J	flake	Lowie Museum	none	0.8 0.8 0.8 0.9 0.9 1.0	0.87	GF(x)

Lab Accession No.: 84-H363
NV G1 = Napa Valley (Group 1)
NV G2 = Napa Valley (Group 2)
K G1 = Mt. Konocti (Group 1)
K G2 = Mt. Konocti (Group 2)

Technician: Thomas Origer
BL = Borax Lake
T = Tuscan
GF = Grasshopper Flat/Lost Iron Well/Red Switchback

0.2 measurement error factor), the mean values for GF/LIW/RS, Borax Lake, and Tuscan are larger, although they overlap.

DISCUSSION

The Ishi collection provided a unique opportunity to examine hydration band development on obsidian. In this case, time of manufacture (age), temperature history, and geochemistry are all known. The results of this study show that hydration bands do develop on very recent glass surfaces and that the bands are detectable and measurable using standard laboratory techniques. To some degree the data support the proposition that hydration band width development varies according to obsidian chemistry under conditions of relatively constant environmental temperature.

Clark's (1961) suggestion that the initial micron of hydration develops within 100 years is supported by the results of the present study. Optically discernible hdyration bands form rapidly — within approximately 70 years — on varieties of obsidian represented in this study. The rarity of thin hydration bands on archaeological samples is attributed to a lack of archaeological investigation of very recent Native American sites. Thomas Jackson's (1984: 121) thought that initial hydration development might be uniform is not supported by the results of this study, although it is acknowledged that mean hydration values for some obsidians (e.g., North Coast Ranges obsidians) in the Ishi collection overlap when a measurement error of ± 0.2 micron is considered.

Because temperature is a critical factor in hydration band formtion it has been advocated that corrections be made when comparing hydration measurements of specimens with different thermal histories (Friedman and Smith 1960). For example, a hydration rate constant for Napa Valley obsidian has been calculated to be 153.4 at an effective hydration temperature (EHT) of 16.1 degrees C. (Origer 1982). Using this rate constant in the diffusion formula ($T=kx^2$) the Napa Valley hydration mean converts into a date of 70 ± 7.9 years before present (B.P).

The range of dates for manufacture of the Ishi materials, based on the hydration rate constant for Napa Valley obsidian, is 71.1 to 86.9 years B.P. The more recent age conforms well with the age of the Ishi materials as estimated from information at the Lowie Museum; however, the mean date and the range generally are slightly older than anticipated. This could reflect the fact that the EHT of the area where the rate constant was developed is different from the Lowie Museum environment: 16.1 degrees for Santa Rosa, California, versus 19.4 degrees for the museum. Given this, a correction factor of approximately 10% rate adjustment per degree C. difference (as recommended by Trembour and Friedman 1984: 79) was applied. With the 10% correction, an age of 58 years B.P. was obtained for the Ishi flakes. This is an incorrect age; calculations based on the Ishi data suggest a tempera-

TABLE 4
SUMMARY OF ISHI COLLECTION HYDRATION MEASUREMENTS BY SOURCE

Source	Measurements (in microns)	Mean	S.D.
Napa Valley (Group 1)	.68 .70 .70 .70 .70 .72 .72 .72 .77 .78	0.72	0.030
Napa Valley (Group 2)	.67 .68 .70 .70 .70 .73 .73 .73 .77 .77	0.72	0.032
Mt. Konocti (Group 1)	.52 .57 .58 .60 .60 .60 .63 .63	0.59	0.033
Mt. Konocti (Group 2)	.60 .62	0.61	0.010
GF/LIW/RS[1]	.77 .80 .80 .80 .80 .83 .85 .87 .88 .90	0.83	0.041
Borax Lake	.93	0.93	——
Tuscan	.98	0.98	——

[1] Grasshopper Flat/Lost Iron Well/Red Switchback chemical group (see Hughes 1986:300-301)

ture correction factor of 4-6%. A correction factor of this magnitude (i.e., 4-6%) is also supported by previous work comparing Napa Valley obsidian artifacts from coastal and interior settings (Origer 1982: 78).

CONCLUSION

Detectable and measurable hydration bands form on obsidian artifacts in less than 100 years. Differential hydration development (rates) for geochemically different obsidians is suggested, even at this early stage (ca. 70 years) of hydration development, by the slightly different mean measurements. The paucity of artifacts from archaeological sites with hydration bands measuring less than 1.0 micron probably is a function of the relative lack of archaeological investigation of recent historic-era Native American sites, or at least a lack of samples from such sites submitted for hydration dating. Analysis of the Ishi material indicates that a hydration rate temperature correction factor of approximately 4-6% is in order when comparing hydration results of artifacts with different temperature histories.

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LATE PREHISTORIC OBSIDIAN PRODUCTION AND EXCHANGE IN THE NORTH COAST RANGES, CALIFORNIA

Thomas L. Jackson

INTRODUCTION

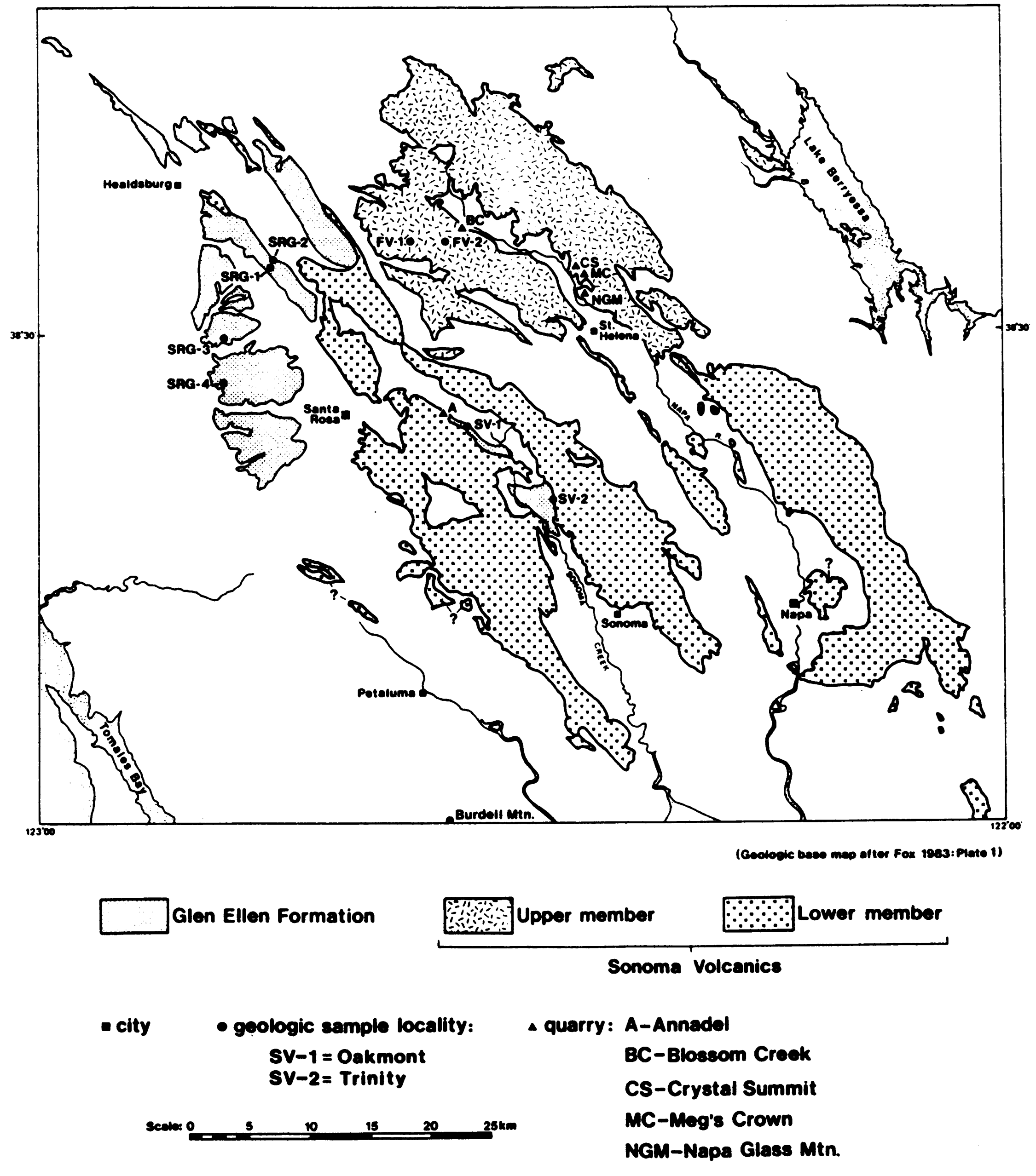
This is a paper of three parts. The first part examines the geological distribution of obsidian in the North Coast Ranges. A number of obsidian quarries and other potential sources not previously reported are described and their trace-element geochemistry summarized. Secondly, I review the history and concept of obsidian artifact "sourcing" by archaeologists and geologists. Although the discussion relates specifically to North Coast Ranges obsidian, the example is appropriate to a much broader audience concerned with determining the original source of raw material for any lithic artifact. I offer a "cautionary tale" about how we come to "know" where obsidian was obtained by prehistoric people. A number of semantic conundrums arise and I make a recommendation for greater care in the use of terminology. Finally I discuss the selective exploitation of obsidian in the North Coast Ranges by late prehistoric populations. Although there are numerous obsidian sources in the region, not all were exploited for the manufacture of all types of chipped stone artifacts. For example, only certain obsidian types were used for projectile (arrow) points, while a broader inventory of obsidians was used for other artifact types. Available data strongly suggest that the production and distribution of certain obsidian artifacts was closely controlled by social elites.

OBSIDIAN SOURCES IN THE NORTH COAST RANGES

Obsidian in the North Coast Ranges originates in either the Sonoma Volcanics or the Clear Lake Volcanics (Figures 1 and 2). Obsidian fragments from the volcanic fields are also found as clasts in the gravels of younger alluvial deposits along the fringes of the volcanics. In the Sonoma Valley and in areas west and north of Santa Rosa, obsidian pebbles "apparently derived through erosion of obsidian in the upper member of the Sonoma Volcanics" are definitive of the Glen Ellen Formation (Fox 1983:11). Erosion of the Sonoma Volcanics and the Glen Ellen Formation has, in turn, resulted in the incorporation of obsidian pebbles into localized Quaternary alluvial and fluvial deposits.

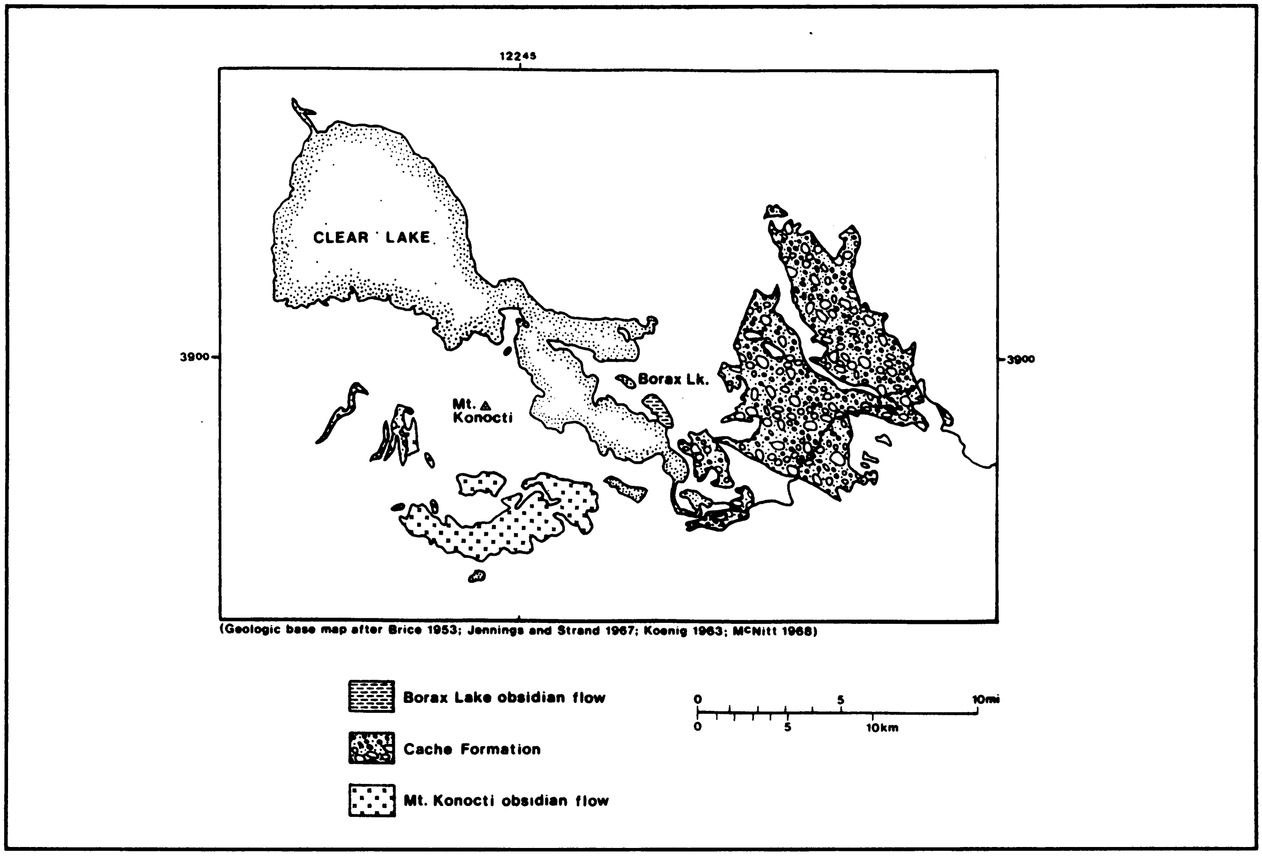
Fox (1983:10) has divided the Sonoma Volcanics into two units, according to their age: "The lower member occupies most of the southern part of the volcanic field as it is exposed today. The member consists chiefly of silicic basalt, andesite, and dacite flows, with subordinate interlayered ash flows and rhyolite flows, and thus contrasts with the predominately tuffaceous rock of the younger part of the field to the north" (Figure 2). Rocks of the lower member of the Sonoma Volcanics date from 5.5 million years (m.y.) to >7.1 m.y., and the youngest dated material in the Sonoma Volcanics is assigned an age of ca. 2.9 m.y.

FIGURE 1
DISTRIBUTION OF SONOMA VOLCANICS AND OBSIDIAN LOCALITIES IN THE SOUTHERN NORTH COAST RANGES.



(Geologic base map after Fox 1983: Plate 1)

FIGURE 2
OBSIDIAN FLOWS IN THE CLEAR LAKE VOLCANICS



(Geologic base map after Brice 1953; Jennings and Strand 1967; Koenig 1963; McNitt 1968)

(Fox 1983:11; Mankinen 1972:2065). Obsidian occurs in association with rhyolitic rocks in both members of the Sonoma Volcanics.

Obsidians of the Clear Lake basin were produced during eruptions of the Clear Lake volcanics, and are largely confined to the basin itself. The Clear Lake Volcanics are much younger than the Sonoma Volcanics, generally dated as less than ca. 2 m.y. Obsidian flows of the Clear Lake Volcanics have been radiometrically dated, and range from ca. 1.01 m.y. to .088 m.y., the younger date being for the Borax Lake obsidian flow (Donnelly 1977:3-4; Donnelly-Nolan et al. 1981). Obsidian occurs as massive flows, domes and brecciated tuffs on the south side of Mt. Konocti (Brice 1953; McNitt 1968)). Borax Lake, on the east side of Clear Lake, was created when the small basin in which the lake is situated was sealed by an olivine dacite flow, which is capped by a rhyolite obsidian flow (Anderson 1936). Obsidian pebbles are a minor constituent of Cache Formation deposits southeast of Clear Lake (Brice 1953:33; Figure 2).

There is some confusion regarding the number and location of obsidian "quarries" in the North Coast Ranges. Heizer and Treganza (1944) examined the ethnographic and archaeological literature to determine the sources of various rocks and minerals (including obsidian) used by native Californians. Their inventory of obsidian quarries contains numerous errors, stemming in part from their identification of certain chert quarries as obsidian sources. Ball (1941) reports a number of obsidian sources in the study area but locational data are minimal. Efforts at correlating more recently discovered quarries in the Napa Valley region with Ball's inventory are stymied for lack of precise map data. Elsewhere (Jackson 1973; 1974) I have discussed the problems related to sorting out the lists of archaeologically reported obsidian sources in the region.

Other terminological and comparative problems arise. For example, Ericson's (1977:101) obsidian samples reportedly from "Napa Glass Mnt." were, in fact, collected not only from Glass Mountain itself, but also from "E. Dago Valley", "W. Dago Valley", and "Hill 450+". Obsidian collected by Ericson from Dago

Valley (ca. 1.4 kilometers north of Glass Mountain) would almost certainly have been material eroded from the source I call "Crystal Summit" (discussed below). The location of his "Hill 450+" is uncertain, as there are several hills near Glass Mountain with summit altitudes in excess of 450 feet. The point is not to denigrate Ericson's important efforts, but with increased resolution in our knowledge of the complexity of the geology (apart from the semantic problems discussed earlier), there is a need for explicit geographical mapping of sources with a concern for distinguishing among in situ versus redeposited obsidian.

Obsidian occurs throughout much of the Sonoma Volcanics field, for the most part, as very small pebbles ("Apache tears") unsuited for tool manufacture. I make no attempt to discuss these occurrences, except those for which I am aware that obsidian pebbles are of sufficient dimensions to possibly have been used in tool manufacture. I concentrate on obsidian in those areas where there is evidence for prehistoric quarrying. Likewise, I do not attempt to describe the geographical distribution of obsidian which occurs as float in stream channels. For example, obsidian is a constituent of gravels in the Napa River and in the streams which drain the area of the Mt. Konocti obsidian flow.

Burdell Mountain

A highly weathered obsidian crops out on the southwest slope of Burdell Mountain in Marin County (Figure 1). This obsidian consists of a black glassy matrix containing a nearly equal volume of crystalline inclusions, primarily feldspar. The obsidian is exposed over an area of approximately 20 square meters, with no evidence of quarrying. A recent excavation for a water tank adjacent the outcrop reveals isolated, nearly disintegrated obsidian masses to a depth of more than 3 meters, suggesting that the remains are the last vestiges of a small obsidian extrusion which has been nearly obliterated by weathering.

The obsidian and associated rhyolitic tuffs have not been recognized in published geologic mapping. The area of the obsidian and tuffs has been mapped as part of serpentine and marine sedimentary units of the Franciscan Complex (cf. Fox 1983; Koenig 1963; Sims et al. 1973). Fox (1983:Plate 1) maps Burdell Mountain basalts as part of the Tolay Volcanics (Morse and Bailey 1935) after Mankinen (1972) who reports a K-Ar age date for the basalts of Burdell Mountain of ca. 11.8 m.y. The stratigraphic position of the Burdell Mountain obsidian remains undefined but it is unlikely to be older than the basalts and is perhaps contemporary with the lower member of the Sonoma Volcanics.

Burdell Mountain obsidian is not suitable for tool manufacture, and has not been detected in archaeological collections. The obsidian is chemically unique (Figure 3), and its distinctive physical appearance would make it conspicuous in any collection of debitage or artifacts.

OBSIDIAN IN THE LOWER MEMBER OF THE SONOMA VOLCANICS

Obsidian occurs in both the upper and lower members of the Sonoma Volcanics. The best known obsidian in the lower member occurs in the vicinity of Annadel State Park in the upper Sonoma Valley. In addition to this archaeologically well known obsidian at least two other chemically discrete obsidian types are now recognized: Los Guilicos and Trinity.

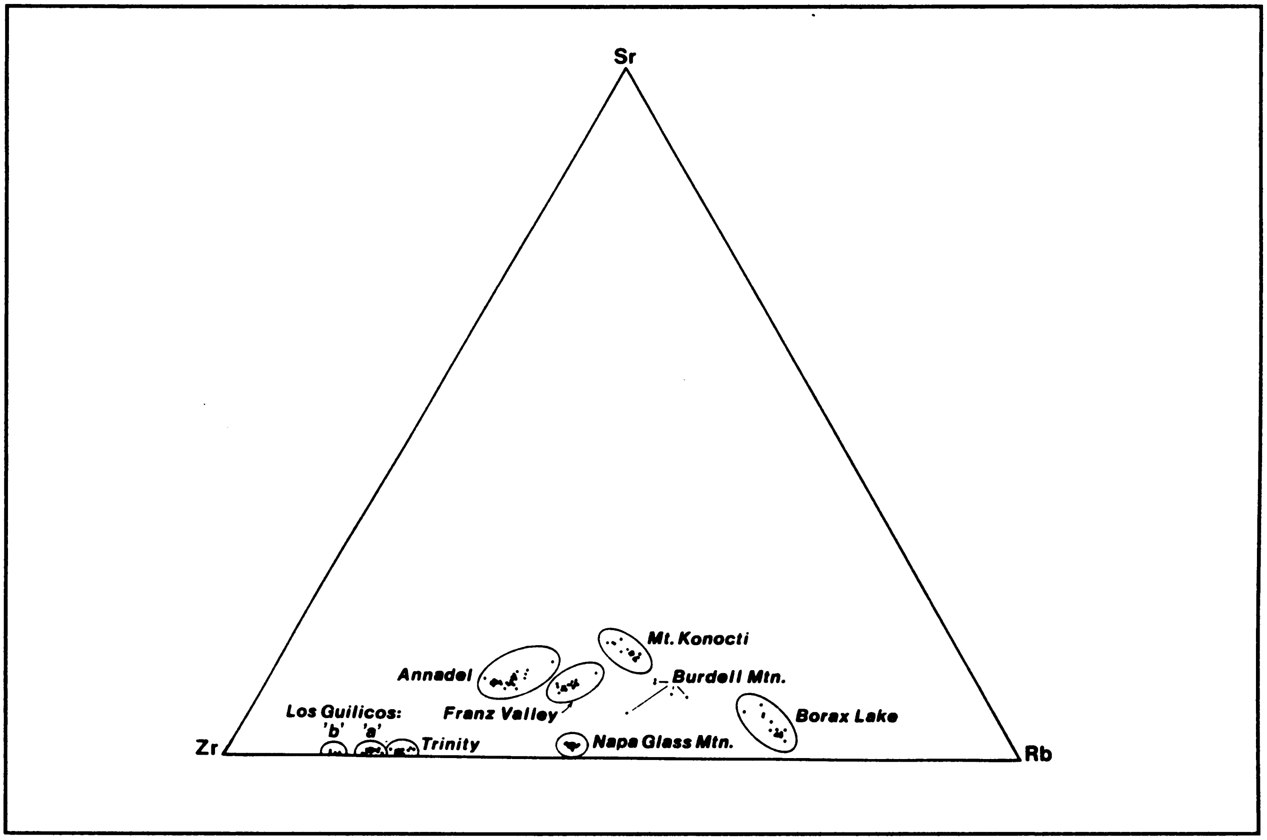
In the upper member of the Sonoma Volcanics we find the famous "Napa Glass Mountain" quarry and several other newly documented quarries which I call Blossom Creek, Crystal Summit, and Meg's Crown. These quarries all yield obsidian which is chemically and physically very similar, although slight chemical variability exists among them. In addition to these quarries, a chemically distinctive obsidian is found in tuffs of the upper member of the Sonoma Volcanics near Franz Valley. Other quarries are likely to exist.

Annadel

The Annadel obsidian quarry is located in what is now Annadel State Park in Sonoma County. The aboriginal quarry area is still covered with with vast amounts of obsidian flakes, partially completed tools, and rejected raw material. Heizer and Treganza (1944:304) cite a personal communication with L. L. Loud, pioneering California anthropologist, to the effect that quarry depressions excavated by the Indians were still visible ca. 1940. More recently Parkman (1983) indicates that some of these features remain. It is certainly true that distinct lithic reduction activity areas are still discernible at the site. Although the Annadel quarry has been explored by many archaeologists over the years, to my knowledge no comprehensive mapping of the quarry exists. A map of the main quarry area made by archaeology classes from Santa Rosa Junior college is on file at the Northwest Information Center, Sonoma State University.

Although obsidian is available in considerable volume at Annadel, the glass occurs ordinarily as relatively small pieces within a matrix of deeply weathered brecciated perlite (Higgins 1983:240). Obsidian pieces larger than fist-size are unusual in the quarry areas, although obsidian cobbles measuring as much as 30 centimeters in diameter can be found in

FIGURE 3
RELATIVE CONCENTRATION OF RB, SR, AND ZR IN NORTH COAST RANGES OBSIDIAN TYPES



nearby Santa Rosa Creek. Unmodified obsidian pieces are usually encrusted with a stubborn cortex which must be removed in the process of tool manufacture.

In its physical appearance Annadel obsidian tends to a matte or "greasy" luster, and the color is gray-black, often with distinctive banding, and a brownish tint. Occasionally one encounters Annadel obsidian of exceptional quality, exhibiting nearly vitreous luster, with a rather dense black color in reflected light. Rarely Annadel obsidian will have a reddish-brown color through thin edges when held before a strong light. The majority of Annadel obsidian is opaque. Origer (1982:194) has described Annadel obsidian as having a "dirty" color, and given the brownish tinge to the general grayish color often observed, this impression is appropriate. Origer's suggestion that Annadel obsidian is sometimes "greenish" is possibly in reference to obsidian which is recognized now as chemically distinct from the obsidian of the main Annadel quarry area and which I call Los Guilicos.

Annadel obsidian is also found in the Glen Ellen Formation, for example at the Oakmont collection locality (Figure 1: SV-1; Jackson 1986:53). It also occurs in more recent alluvial and fluvial deposits which incorporate material eroded from the Annadel quarry vicinity (e.g., along Santa Rosa Creek).

Los Guilicos

Two peralkaline obsidians (Los Gulicos A and B), distinguished by physical appearance and chemistry, are found in the southern portion of Annadel State Park, along the eastern slopes of Bennett Mountain, and as redeposited material in the Glen Ellen Formation on the west side of the Sonoma Valley. The in situ context of the obsidians is not yet established. The geographical distribution of the glasses would suggest that they are possibly eroding from the base of units mapped as "perlitic rhyolite" by Fox et al. (1973) in the Annadel State Park vicinity. Samples have been collected from Buick Meadow, Frey and Schulz Canyons and Glen Ellen Formation deposits at Oakmont (Figure 1).

Los Guilicos A is distinguished by its dull, greasy luster and typically gray to gray-green color. This obsidian generally lacks any inclusions. Pebbles of the glass I have observed rarely exceed 4 centimeters in greatest diameter. Los Guilicos A makes up the majority of the obsidian collected at the Oakmont sampling locality. Trace element chemistry of the obsidian is given in Jackson (1986:198, samples Oak2-Oak7, Oak11-Oak12, and Oak15-Oak18). To my knowledge there is no evidence that this material was actually quarried by aboriginal people. It is more likely that pebbles were collected off the ground if potentially useful pieces were encountered. Artifacts of this material have been found at CA-SON-455 and at sites in the Sonoma Valley.

Los Guilicos B is very similar in appearance to some Mt. Konocti obsidian, with a brilliant luster, numerous phenocrysts, and a black color in reflected light. Quite unlike Mt. Konocti glass, Los Guilicos B has a very definite green color when held before a strong light source. Pebbles of this material at the Oakmont collection locality rarely exceed 2 centimeters in greatest diameter. Trace element chemistry for Los Guilicos B samples from the Oakmont locality is given in Jackson (1986:198, samples Oak8, 9, 14, and 19).

I believe that Amaroli (1982; see Parkman 1983) was the first investigator to report the recovery of what I call Los Guilicos (generic) obsidian in an archaeological context. In his x-ray fluorescence analysis of obsidian from CA-SON-995, about 4 kilometers southeast of the main Annadel quarry area, Amaroli identified obsidians with what he perceived to be three distinct "trace element profiles." Unfortunately, Amaroli's analyses cannot be reproduced because he did not provide quantitative element concentration data, nor were his analyses calibrated against international rock standard values. Two of Amaroli's "trace element profiles" probably correspond to the typical Annadel obsidian chemical fingerprint, and the third to the chemical characteristics of what I call Los Guilicos, at least for the elements Rb, Sr, and Zr, which were the elements he employed.

Trinity

This obsidian has been found eroding from the base of rhyolitic flows on the east side of Sonoma Valley in the Calabazas Creek-Trinity Road area (Figure 1). Obsidian generally occurs at approximately the 400-foot elevation east of Highway 12. Trinity obsidian is a fine, dense black glass with minor inclusions. Phenocrysts (up to 3 mm long) sometimes appear elongated. In a few samples the glass has an almost metallic sheen. Banding is common, and luster ranges from a textured, greasy appearance, to vitreous. Light passing through thin shards reveals a predominately gray color with a distinctive gold-brown tint.

Trinity obsidian is found as rounded fragments up to ca. 15 centimeters in maximum diameter, although the vast majority of fragments are less than a third that size. The in situ obsidian occurs in a rhyolitic matrix, apparently the contact zone between units mapped by Fox et al. (1973) as rhyolitic flows ("Tsr") resting upon "andesitic to basaltic lava flows" ("Tsa"). This obsidian is also found in Glen Ellen Formation deposits in the west side of Sonoma Valley near Oakmont. This suggests that the geographical distribution of the obsidian extends north and south along the eastern edge of the Sonoma Valley from the collection locality.

Pebbles of Trinity obsidian from the base of the rhyolitic flow often exhibit a distinctive vesicular cortex typical of material rapidly chilled in a basal flow environment. Pebbles of Trinity obsidian in the Glen Ellen Formation are sufficiently rounded that this characteristic cortex is often obliterated.

While no clear evidence of aboriginal quarrying of Trinity obsidian has been found, neither has there been any concerted effort to locate any quarries of this glass. The area near the intersection of Trinity Road and Highway 12 remains, to my mind, the most likely area in which any such quarry might exist. Alternatively, it is possible that this material was simply scavenged from the landscape. Until we have a better understanding of the nature of the in situ occurrence of this glass we will not fully understand the methods of its procurement. Artifacts made of Trinity obsidian have been found at the collection locality and from CA-SON-120 approximately 1 km northwest of the Trinity Road locality.

OBSIDIAN IN THE UPPER MEMBER OF THE SONOMA VOLCANICS

Four major obsidian quarries are now known in the upper Napa Valley. For practical purposes these are indistinguishable in both physical (visual) and chemical (trace element) attributes. Unlike the foregoing discussion of obsidians in the lower members of the Sonoma Volcanics which focused on the unique physical and chemical properties of each obsidian, the following description is based on the differentiation of geographically discrete aboriginal quarries and their distribution within specific geologic map units.

Obsidian from the vicinity of Franz Valley, west of Napa Valley, is chemically unique among the obsidians from the upper member of the Sonoma Volcanics. Two localities where this material occurs have been sampled.

Glass Mountain

One of the best known sources of obsidian in central California is at Glass Mountain (often called "Napa Glass Mtn."), in the northern Napa Valley near the town of St. Helena (Figure 1). The mountain is dotted with quarry pits excavated by aboriginal miners. Heizer and Treganza (1944:304) estimated that "at least 100,000 cubic feet of obsidian flake refuse" blanket the slopes of the quarry area (cf. Heizer 1951:40, 42). This is probably a conservative estimate.

Glass Mountain obsidian is found in a matrix of tuff and perlite. Fox (personal communication 1984) believes that this locality represents a volcanic vent (cf. Fox et al. 1973). Obsidian from Glass Mountain is usually found as relatively small pieces throughout the ashy matrix, rarely exceeds 30 cm in maximum diameter, and most pieces are less than half that size. Much of the obsidian is encrusted with a rough cortex.

Obsidian from this source is typically very dense black, glossy to vitreous in luster, and opaque in all but the thinnest fragments. The glass is of a very high quality for knapping, and is generally free of inclusions and vesicles. Color of the obsidian varies and in addition to the common dense black, there are various shades of dark coffee brown, and, rarely, reddish brown. Flakes of Glass Mountain material which show a streaked, reddish-brown (rust) coloration when held before a strong light also occur. Another characteristic obsidian is a very fine glass, tending to a vitreous luster, more translucent, pale charcoal gray, and sometimes transparent in samples up to 3 mm thick.

Meg's Crown

Approximately 1.7 km NNE of the Glass Mountain quarry is an obsidian quarry area which I call Meg's Crown (Figure 1). Obsidian is exposed along the very steep south and east-facing slope of the narrow ridge which separates Dago Valley and Pratt Valley. The slopes of the hillsides are very densely covered by a mixed evergreen forest community liberally populated with poison oak. The lower southern and western slopes are planted in vineyards. No effort was made to map the extent or distribution of either the geology or cultural remains at this locality which is on private properties held by many owners.

Fox et al. (1973) map the area of Meg's Crown within a pumicitic ash-flow tuff unit. Much obsidian on the east slope of the ridge has been redistributed by landslides, and a bulldozer track cut to the summit of the hill has displaced large amounts of debitage and bifacially worked artifacts. Much worked material is found in the vineyards extending into Pratt Valley. I saw no evidence of quarry pits during my visits to the locality.

The obsidian at Meg's Crown is, in part, like the opaque, black obsidian so characteristic of Glass Mountain, but much more of the Meg's Crown material displays flow banding as gray swirls and sharp bands through the black glassy matrix. In thin sections the obsidian is primarily pale gray, with darker banding. The various opaque brown shadings known at Glass Mountain are apparently absent here. A small percentage of the glass is superb, flawless material with a very pale brown tint. This latter obsidian is transparent in sections up to 5 mm thick.

Crystal Summit

Approximately 2.4 km north of Glass Mountain and 1.4 km northwest of Meg's Crown is the Crystal Summit obsidian quarry (Figures 1 and 2). I thank Dr. John Rick, Stanford University, for bringing this locality to my attention. As with Meg's Crown, I have made no attempt to conduct a detailed mapping of the site, which is mostly wooded and covered with stands of poison oak.

The obsidian at Crystal Summit is exposed as small chunks and fragments generally less than 8 cm in greatest diameter, although larger pieces may occur. Fox et al. (1973) map this area in the same geologic unit as Glass Mountain. The obsidian apparently occurs in a rhyolitic tuff which caps a rhyolite flow. There is abundant evidence of aboriginal tool manufacture but no quarry pits were seen on my visit.

The obsidian at Crystal Summit is much like that at Meg's Crown and is characteristically banded. Unlike Meg's Crown and Glass Mountain a notable proportion of the Crystal Summit material has gas voids. I observed numerous preforms and other partially worked artifacts of obsidian with obvious defects of this sort. In many examples the defects were quite conspicuous and yet an effort had been made to complete a tool.

Blossom Creek

The Blossom Creek quarry is 3.8 km northwest of central Calistoga, in the upper Napa Valley (Figure 1). This locality was originally recorded as an archaeological site (CA-NAP-509) by Mrs. Yolanda Beard, although it was not initially recognized as a quarry. Suspicions that the site might be a quarry were first voiced to me by Thomas M. Origer, Sonoma State University, and his intuition was confirmed when we visited the site for a first-hand examination.

The geology of the Blossom Creek quarry is more complicated than that of the other Napa Valley sources.

Fox et al. (1973) include the area of the quarry in a unit mapped as Quaternary gravels. It is clear, however, that rhyolite tuffs occur in the quarry area and that obsidian is probably in situ in these tuffs. However, there are also redeposited gravels within the quarry area and obsidian is an important constituent of these gravels.

Franz Valley

Fox et al. (1973) map an extensive area surrounding Franz Valley as pumicitic ash-flow tuff. Obsidian in these tuffs is chemically and physically distinctive. Two localities in the Franz Valley area have been sampled. Obsidian at these localities occurs as rounded obsidian pebbles and cobbles in variable concentrations throughout the tuff deposits.

The FV-1 locality is on the east-facing slopes overlooking Franz Valley in the Devils Kitchen area. Obsidian fragments here are generally less than 3 cm in diameter, with a maximum surface density of approximately 15 per square meter. By contrast, at the FV-2 locality, on the Napa-Sonoma County line where it is crossed by Franz Valley School Road, obsidian pebbles litter the surface over an area in excess of 500 square meters at a density in excess of 100 pebbles per square meter. Most pebbles are less than 5 cm in diameter, however, pebbles in the 10-15 cm range are not uncommon, and cobbles up to 20 cm diameter have been collected. Despite the availability of raw material there is no evidence of tool manufacture at either of the Franz Valley localities. Projectile points made of Franz Valley obsidian have been found at CA-MRN-307 although those three projectile points are the only such artifacts from the southern North Coast Ranges demonstrated to be made of this obsidian (Jackson 1986).

Obsidian from the Franz Valley area is physically and chemically peculiar in some respects. Obsidian of a unique green-brown color with a vitreous luster accompanies the more common solid black and banded black with gray typical of Napa Valley sources. Obsidian of a solid "battleship gray" color with a matte luster is found at the FV-2 locality. Glass with mottled black and gray coloration also occurs. Franz Valley obsidian is chemically differentiated from Napa Valley obsidians by barium element concentrations in excess of 600 ppm (Jackson 1986).

GLEN ELLEN FORMATION NORTH AND WEST OF SANTA ROSA

I noted previously that obsidians from the Annadel, Los Guilicos and Trinity sources are found in Glen Ellen Formation deposits in the Sonoma Valley. As mapped by Fox (1983; cf. Gealey 1951) there is a series of exposures of Glen Ellen Formation deposits north and west of Santa Rosa. I have collected and chemically analyzed samples from four different locations in the Glen Ellen Formation near Santa Rosa (Figure 1). The sample localities are identified by the prefix "SRG."

Obsidian is ubiquitous in the general area around the SRG-1 and SRG-2 localities, but appears to diminish rapidly northward toward Healdsburg. Obsidian specimens at these two localities larger than 5 cm in diameter are rare. However, obsidian pebbles at SRG-1 and SRG-2 are consistently larger than those found at SRG-3 and SRG-4. Obsidian pebbles in Glen Ellen Formation deposits on the west side of the Santa Rosa valley tend to be quite small, rarely as much as 2.5 cm in maximum diameter. Although I have observed larger pebbles, they are invariably highly fractured and virtually disintegrate when one attempts to remove them from their conglomerate matrix. Travis (1952:22) estimates that obsidian makes up some 3% of the material in his "Pleistocene Gravel" unit in the Sebastopol quadrangle near Santa Rosa. This unit has been incorporated, for the most part, into the Glen Ellen Formation by Fox (1983).

Because there are no primary obsidian sources to the west of the Glen Ellen Formation in the Santa Rosa area, the obsidian in those deposits must have been derived from Sonoma Volcanics to the east. This assumption is supported by trace-element chemistry (Jackson 1986) which indicates that that the obsidian in the Glen Ellen Formation near Santa Rosa is of both Napa Valley and Franz Valley chemical types, with Napa Valley material in the majority.

At none of the collection localities is there any evidence of prehistoric quarrying. Given the typically small size of obsidian pebbles in the Glen Ellen Formation it seems unlikely that it would have been a regular source of raw material for aboriginal tool manufacture. However, archaeological collections of artifacts and debitage should be examined closely in order to detect the distinctive cortex which forms on these well-rolled pebbles. Recovery of debitage with such cortex will serve as an index to the extent to which such secondary sources were exploited, possibly for expedient tools.

TABLE 1
TRACE-ELEMENT CONCENTRATION VALUES FOR BURDELL MOUNTAIN OBSIDIAN AND OBSIDIAN FROM THE LOWER MEMBER OF SONOMA VOLCANICS

	Obsidian Source				
Trace-element	Burdell Mtn. (n=5)	Annadel (n=37)	Guilicos A (n=12)	Guilicos B (n=4)	Trinity (n=15)
Rb	159.2	135.8	173.9	146.2	147.1
Sr	29.6	50.3	7.7	2.8	3.6
Y	37.0	46.9	123.3	156.5	72.5
Zr	130.4	271.5	748.8	895.9	513.8
Nb	2.5	14.4	33.0	41.0	25.4
Ba	552.7	595.3	217.9	192.8	313.1
La	31.5	25.5	52.5	54.9	38.6
Ce	67.8	54.4	119.1	123.7	83.2

Notes: Mean values of Ba, La, and Ce for Annadel are for 19 samples; Burdell Mtn. element concentration values are extremely variable due to surface effects and values presented here are rough approximations.

OBSIDIAN IN THE CLEAR LAKE VOLCANICS

Two primary sources of obsidian in the Clear Lake area are Mt. Konocti and Borax Lake. These sources were of great importance to prehistoric people in the region and their economic significance would be difficult to overestimate. Like obsidian in the Sonoma Volcanics, we are not fully aware of all geographical occurrences of volcanic glass in the Clear Lake basin. Therefore we are not able to document with confidence the prehistoric extraction of this resource.

Mt. Konocti

A general description of the obsidian flow on the south side of Mt. Konocti has been given in the introduction to this section. Obsidian in the Mt. Konocti area is available over an area of more than 50 square kilometers (Figure 2), but to my knowledge there are no clearly defined aboriginal quarries per se. The obsidian is readily obtained without excavation. Blocks of obsidian more than 1 meter in greatest dimension have been observed.

The quality of Mt. Konocti obsidian is generally inferior to that of most of the obsidian from sources previously discussed because it contains numerous phenocrysts and tends to be quite brittle. Nevertheless the obsidian was widely employed for the manufacture of the full range of lithic artifact forms known for the region. Mt. Konocti glass ranges in color in reflected light from gray, to brown-black, to brick red-brown.

Borax Lake

The Borax Lake quarry is one of the most famous obsidian sources in California (cf. Heizer and Treganza 1944). This source yields a glass of variable quality, ranging from pumiceous material to a relatively dense glass. The glass ranges from a dark gray-black to a gray "frothy" appearance depending on the amount of gas voids in a given piece. The obsidian has a distinctive texture which also derives from the presence of gas voids in the glass. Obsidian pieces at the source have been observed up to 50 cm in greatest dimension.

TABLE 2
TRACE-ELEMENT CONCENTRATION VALUES FOR OBSIDIAN FROM THE UPPER MEMBER OF THE SONOMA VOLCANICS AND CLEAR LAKE VOLCANICS

	Obsidian Sources						
Trace-element	Blossom Creek (n=41)	Crystal Summit (n=20)	Meg's Crown (n=20)	Napa Glass Mountain (n=37)	Franz Valley (n=30)	Borax Lake (n=19)	Mount Konocti (n=19)
Rb	189.6	185.7	191.4	195.2	168.4	220.6	211.7
Sr	11.4	5.7	4.9	6.7	45.0	14.8	75.4
Y	44.2	42.8	44.4	46.2	37.7	45.6	38.8
Zr	238.4	224.0	225.2	240.8	235.1	94.4	203.6
Nb	13.7	13.5	14.4	14.3	13.2	15.1	14.5
Ba	471.2	440.7	426.4	414.7	619.8	34.3	626.0
La	28.6	29.8	31.9	31.8	30.0	22.6	30.9
Ce	62.8	64.5	65.4	64.2	63.4	50.8	64.8

Notes: Mean values of Ba, La, Ce for Blossom Creek are for 40 samples.

OBSIDIAN TRACE ELEMENT CHEMISTRY

There is a growing literature on the elemental chemistry of obsidian from the North Coast Ranges. For more comprehensive discussions I direct the interested reader to the following references: Anderson (1936: Borax Lake; Mt. Konocti); Bowman, et al. (1973: Borax Lake; Mt. Konocti); Ericson (1977: Annadel; Borax Lake; Mt. Konocti; Napa Glass Mtn.); Jackson (1986: Annadel; Blossom Creek; Borax Lake; Burdell Mtn.; Crystal Summit; Franz Valley; Los Guilicos; Meg's Crown; Konocti; Napa Glass Mtn.; Trinity). Tables 1 and 2 summarize trace element concentration values of obsidian from different sources, while Figure 3 is a ternary graph showing the separation achieved by Rb:Sr:Zr ratio of concentration values.

Obsidian "Sourcing" in the North Coast Ranges

Studies by Weaver and Stross (1965), Parks and Tieh (1966), Jack (1976), and Jack and Carmichael (1969) represent early efforts by North American chemists and geologists to demonstrate a correspondence between a geological "source" of obsidian and prehistoric obsidian artifacts. Such studies were developed in conjunction with geological studies of techniques to chemically "fingerprint" acid volcanic rocks. Not surprisingly, these geologists approached artifactual raw material source identification in much the same way they approached the general problem of geochemical characterization of other volcanic rocks. A "source" of raw material (e.g., obsidian) is described principally in terms of a geological map unit.

As non-anthropologists, these investigators were not necessarily oriented to the full anthropological implications of their research beyond the simple correlation of original geological source and end point of deposition for an artifact. Thus for example, the discovery of a projectile point of Casa Diablo obsidian in Contra Costa County signaled long-distance trade relations between coastal populations and groups living east of the Sierra Nevada summit. Implicit in these early studies was the assumption that obsidian artifacts were traded as finished items. There also was a lack of concern for discriminating artifacts from different time periods. However, some more anthropologically oriented topics of study, for example, discovering any correlations between "ethnic" groups and distributions of artifacts of obsidian from different sources (Jack 1976), are still of considerable interest to archaeologists.

For the geologist a source attribution is sufficient provided there is a correlation between the chemistry of an artifact and the chemistry of a provenienced obsidian. This is acceptable to the archaeologist as a starting point, but the demonstration of the location and means of resource extraction is mandatory if we are to understand a lithic production system. For the archaeologist and the geologist determining the "source" of lithic raw material exploited by prehistoric people should mean two different things. Geologically it is adequate simply to determine the presence of the material at specific geographical localities. While this is useful for the archaeologist, it is necessary that the term "source" actually relate to a locality where it can be explicitly demonstrated that the raw material was extracted or collected. Here the term "quarry" is appropriate where it can be demonstrated that lithic material was actually mined. "Quarry," however, is technically incorrect to describe a situation in which obsidian pebbles lying on the ground simply are collected. We might better term the latter a "lithic collection locality."

Determining the "source" of obsidian has taken on another meaning with regard to chemical characterization of volcanic glasses. In both geology and archaeology geochemical "sourcing" of obsidian means, in practice, to demonstrate a sufficiently close correspondence in elemental composition that an artifact of an "unknown" obsidian type can be correlated with a chemically described obsidian of known provenience. It is often the case that the chemistry of volcanic glasses is better known than their geographical distribution. It is, therefore, essential that archaeologists differentiate studies which match obsidian artifacts with chemically known obsidian types from studies which actually demonstrate the location from which the obsidian was obtained by prehistoric people.

Two examples make this point more explicitly. The "Napa Glass Mountain" obsidian source is one of the best known in the western United States. Obsidian found at Glass Mountain apparently is geochemically unique for a number of trace element concentrations, and prehistoric artifacts can be distinguished as being of Glass Mountain obsidian rather easily; we can make a correlation between the chemistry of the artifactual obsidian and that of obsidian from Glass Mountain. It has been assumed, by most archaeologists working in the region, that "Napa Glass Mountain" was the source of obsidian in the Napa Valley region and this was supported by the extensive evidence of prehistoric quarry activity at Glass Mountain.

It is now known that Glass Mountain is only one quarry area in the Napa Valley. The recent identification of the Blossom Creek, Crystal Summit, and Meg's Crown quarries in the upper Napa Valley demonstrates that equating obsidian chemical type with an (implied) quarry source of raw material can be misleading. Because the obsidian from these other quarries shows close similarities in chemical and physical attributes with Napa Glass Mountain obsidian their presence in the archaeological record went unrecognized. Obsidian artifacts formerly assigned as "Napa Glass Mountain" now must be attributed as "Napa Valley" since this geographical appellation encompasses all of the known, chemically undifferentiated, obsidian quarries in the area.

However, the upper Napa Valley quarries are not the only locations from which prehistoric people obtained obsidian of the generic Glass Mountain chemical type. Obsidian pebbles are found in Napa River gravels at least as far south as the city of Napa, and these pebbles were exploited as raw material for tools (Jackson 1978). Geochemically these pebbles are identical to Glass Mountain obsidian but they are found more than 30 km south of that quarry. There is no evidence to suggest that the pebbles were extracted from the river gravels by any means other than simple collection methods.

This latter example serves to emphasize the necessity of differentiating between lithic materials found in contexts of original deposition versus materials from contexts of secondary deposition. Quarries and collection localities can represent lithic extraction in either of these contexts. It is important archaeologically to be able to distinguish between the two potential sources of raw material. Technical studies of lithic debris from archaeological sites can very often distinguish raw material derived from different depositional contexts, as for example the difference between cortex on water-worn pebbles and obsidian found in ash tuffs or as massive flows (i.e., in the original depositional environment).

As generally employed, "sourcing" refers to the determination of the geochemical or physical characteristics of artifactual obsidian, and the comparison of these attributes with those of obsidians from known geological localities. I urge, however, that only if the physical or chemical attributes of an obsidian are unique to a specific quarry or collection locality should we claim to have determined the actual source of the raw material from which an artifact is made. Artifacts of glass from the Borax Lake quarry would meet these criteria because that source is both geographically discrete and chemically unique. Otherwise analyses of artifactual obsidian only provide a general provenience for the known geographical distribution of all chemically similar obsidian within a region. As I will discuss in the last part of this paper, a precise understanding of the geography of obsidian sources is a necessary condition of effective obsidian exchange studies.

STRUCTURE OF PREHISTORIC OBSIDIAN PRODUCTION AND EXCHANGE

In this section I offer some preliminary hypotheses based on extant data, conjure some speculative proposals, and open topics for future research. In an effort to place obsidian production and exchange in a broader social and economic context I present an abbreviated comparison of developments in obsidian projectile point and shell bead production ca. A.D. 1500 in west central California.

Selective Use of Obsidian Types

Of nine chemically distinct obsidians found in the North Coast Ranges there is archaeological evidence for the extensive use of only four types for the manufacture of arrow points: Annadel, Napa Valley, Borax Lake, and Mt. Konocti. Of a sample of approximately 2,000 projectile points only three of Franz Valley glass are demonstrated to be of another obsidian type. Glass quality is not a determining factor except when obsidian occurs as pebbles too small for point manufacture (Jackson 1986).

One implication of the evidence for selective use of obsidian types is that social or political means existed to restrict obsidian use by projectile point (or arrow) makers. Precisely how this might have operated is unclear. Another line of evidence, consistency in percentages of obsidian types represented at archaeological sites within a given tribelet territory and among sites representing multiple neighboring tribelets (Jackson 1986), suggests that some mechanism for management operated at local (village- or tribelet-specific) and regional (multi-tribelet) levels. Extrapolating from ethnography, we could conclude that the political and economic authority of village leaders was sufficient to exercise very explicit and pervasive control through the redistribution of resources. Also implied is a political unity and perhaps a class distinction among these social elites. Maintenance of that class and its authority may have been through the regulation of exchange in general, including the exchange of wealth items like clam disk beads (cf., e.g., Brumfiel and Earle 1987; Cohen 1983; Earle 1982; Kohl 1975; Pires-Ferreira and Flannery 1976).

As I have demonstrated (Jackson 1986), obsidian exchange can be linked to inter-group marriage patterns. But exchange commensurate with marriage is only one aspect of the regional exchange system. For example Wappo tribelets of the Napa Valley, who had no marriage ties with the Gualomi Pomo who controlled the Annadel obsidian quarry, were extremely successful in preventing the import of Annadel obsidian projectile points into the Napa Valley. By contrast, all Pomo tribelets which controlled obsidian sources also imported projectile points (and possibly some raw material) made of obsidian from sources outside their territories (Jackson 1986).

There is no demonstrably consistent correlation between geographical distribution of projectile points made of specific obsidian types and "ethnic" or "ethnolinguistic" groups per se. Obsidian point distributions reflect social and economic ties between tribelets, and regional exchange must be understood at this scale of social interaction (see Hughes and Bettinger 1984).

The importance of the exchange of obsidian projectile points is emphasized by the selective use of lithic materials for projectile points in general. Obsidian is not the only lithic material in the North Coast Ranges from which projectile points could be manufactured, but, in the southern North Coast Ranges, arrow points are made predominately of obsidian, even when alternate materials (e.g., chert) are available.

Bouey (1986:Appendix 4a) has demonstrated a preference for obsidian projectile points at sites in the Lake Sonoma area even though local chert quarries were mined and employed for other tool types, including arrow points. Artifact data from CA-MRN-471 are another example. A chert quarry is ca. 1.6 km away and chert occurs in the stream bed adjacent the site. Nevertheless, of 165 projectile points from the site only nine are of chert; the rest are made of either Annadel or Napa Valley obsidian. The closest Napa Valley quarry and the Annadel quarry are 48 km and 41 km north of CA-MRN-471, respectively.

It is not clear how obsidian use for other tool types corresponds with, or differs from, the selectivity demonstrated for arrow points. Functional considerations aside, there are preliminary data from which to argue that some obsidian types were restricted for local consumption and did not circulate generally in regional exchange systems. Trinity, Los Guilicos, and possibly Franz Valley obsidian are examples. It would seem prudent in future studies to recognize that obsidian type proportions may vary according to artifact type, and that this sort of variability may differ between regions or individual consumer groups.

Ethnographic accounts (e.g., Barrett 1952; McKern 1922) indicate that craft specialists, including arrow (point) makers, net makers, and bead makers were part of native societies and that these individuals were social elites. Craft specialization for obsidian projectile point manufacture is not clearly demonstrated in the central California archaeological record using the materialist criteria for identifying craft specialization advocated by, for example, Arnold (1984). However, several more indirect lines of evidence could support an argument for craft specialization in late prehistory.

There is evidence in the archaeological record for the distribution of shell and obsidian raw material as unfinished artifact forms. The exchange of raw material or partially completed items for both obsidian point and clam disk bead manufacture may have served to sustain the position of "craft specialist" in villages where inhabitants were without direct access to obsidian or shell raw material. You can't have an operational craft specialist if the individual has nothing upon which to practice his craft.

If artifacts were made only by specialists in tribelets which controlled sources of raw material, or within short distance of such groups, then there could be no production by specialists in outlying tribelets. I suggest that raw material and partially completed artifacts were traded among specialists to maintain them as social elites and to perpetuate the social relations of production. Whether specialists were independent of, attached to, or one-and-the-same-as the political leadership is another issue (see Brumfiel and Earle 1987:5-6 for an excellent summary discussion).

With regard to both obsidian projectile points and clam disk beads an interesting development occurred ca. A.D. 1500 in central California. Knappers began producing projectile points that were morphologically simpler; the serrations which characterize arrow points of the preceding several centuries were no longer made. Projectile points became somewhat smaller, were made from thin triangular flake blanks, and show progressively less invested knapping effort, especially in the latest prehistoric times. The basic form of arrow points in the southern North Coast Ranges after A.D. 1500 is a relatively uniform corner-notched or corner-removed shape which could be modified easily to accommodate the aesthetic/stylistic demands of a range of consumer societies.

Clam disk beads also represent a move toward simplification of production, but they also demarcate increased social complexity. The advent of these beads may signal development of a wealth item reserved for manipulation by social elites. Unlike Olivella shell beads which had become pervasive in a socially less differentiated economy, the principal role of clam disk beads was in maintaining status among elites engaged in inter- tribelet exchange (cf. Miller 1982; King 1971). Ethnographically bead makers were social elites (e.g., Barrett 1952; Gifford 1926; McKern 1922).

I suggest that elites controlled production of both clam disk beads and arrow points and maintained their control in the face of increased population growth, and resulting demand, by simplifying production (in the case of clam disk beads by instituting an entirely new form). Simplified forms allowed increased production with the same investment of labor, i.e., efficiency was increased. Standardization of point and bead forms allowed a greater latitude of materials to move in regional exchange systems without precluding local specialists from making finished artifacts which conformed to local stylistic considerations. In the example of clam disk beads, however, stylistic variation was minimized in consideration of the very extensive geographical distribution of these wealth items.

Volume of Production

Although there have been no serious efforts at quantifying the production of obsidian from North Coast Ranges sources, either in terms of volume of raw material extracted or artifact manufacture and consumption, it seems clear that the recent discovery of several major obsidian quarries should substantially increase whatever intuitive sense of production volume we may have. There are significant methodological problems inherent in attempts at measuring production volume. In most central California sites we lack the refined stratigraphy or relatively precise dating which are hallmarks of, for example, sites in the Southwest. Without precise temporal control, estimating obsidian volume in sites is extremely speculative. Nevertheless, even crude measures of production volume are an essential component of exchange studies which focus on aspects of the economy other than consumption (cf. Torrence 1986).

CONCLUSION

The recent discovery of several new obsidian quarries in the Napa Valley illustrates the difficulty of carrying out archaeological research concerning obsidian production in prehistory. Geologists, who have done extensive and detailed mapping of many areas of the United States, do not consistently differentiate obsidian from other rhyolitic or related rocks for mapping purposes. If they did, our job would be made considerably easier. But they don't, so a duplication of effort occurs each time an archaeologist searching for obsidian re-surveys an area mapped by geologists.

Survey in the rapidly developing urban and suburban areas of the North Coast Ranges is becoming increasingly difficult. The landscape is being steadily divided into smaller and smaller privately-held tracts, access to which is increasingly hard to gain. Efforts to systematically survey large-size areas with owners's permission are bogged down by attempts to obtain authorization to trespass. Yet if we cannot acquire a true sense of the geographical extent and intensity of prehistoric obsidian exploitation we cannot reasonably expect to understand this critical topic in archaeological exchange studies.

Exchange studies also require precision in the use of terminology. "Sourcing" obsidian by geochemical methods does not necessarily advise us of the quarry or collection locality for the raw material in the sense that we typically employ that term. As we come to recognize that prehistoric people may have obtained obsidian from <u>some</u> but <u>not all</u> localities on the landscape it behooves us to differentiate among these potential sources to understand how prehistoric populations created and exercised behavioral options.

We are only beginning to define the cultural context of prehistoric obsidian exchange in central California. At present there is tantalizing evidence to suggest that obsidian exchange took place within closely regulated redistribution systems. There was no monolithic "obsidian exchange system." Obsidian was only one commodity moving in regional systems, and obsidian in different forms very likely was distributed in very different ways.

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SPATIAL AND TEMPORAL PATTERNING OF OBSIDIAN MATERIALS IN THE GEYSERS REGION

David A. Fredrickson

INTRODUCTION

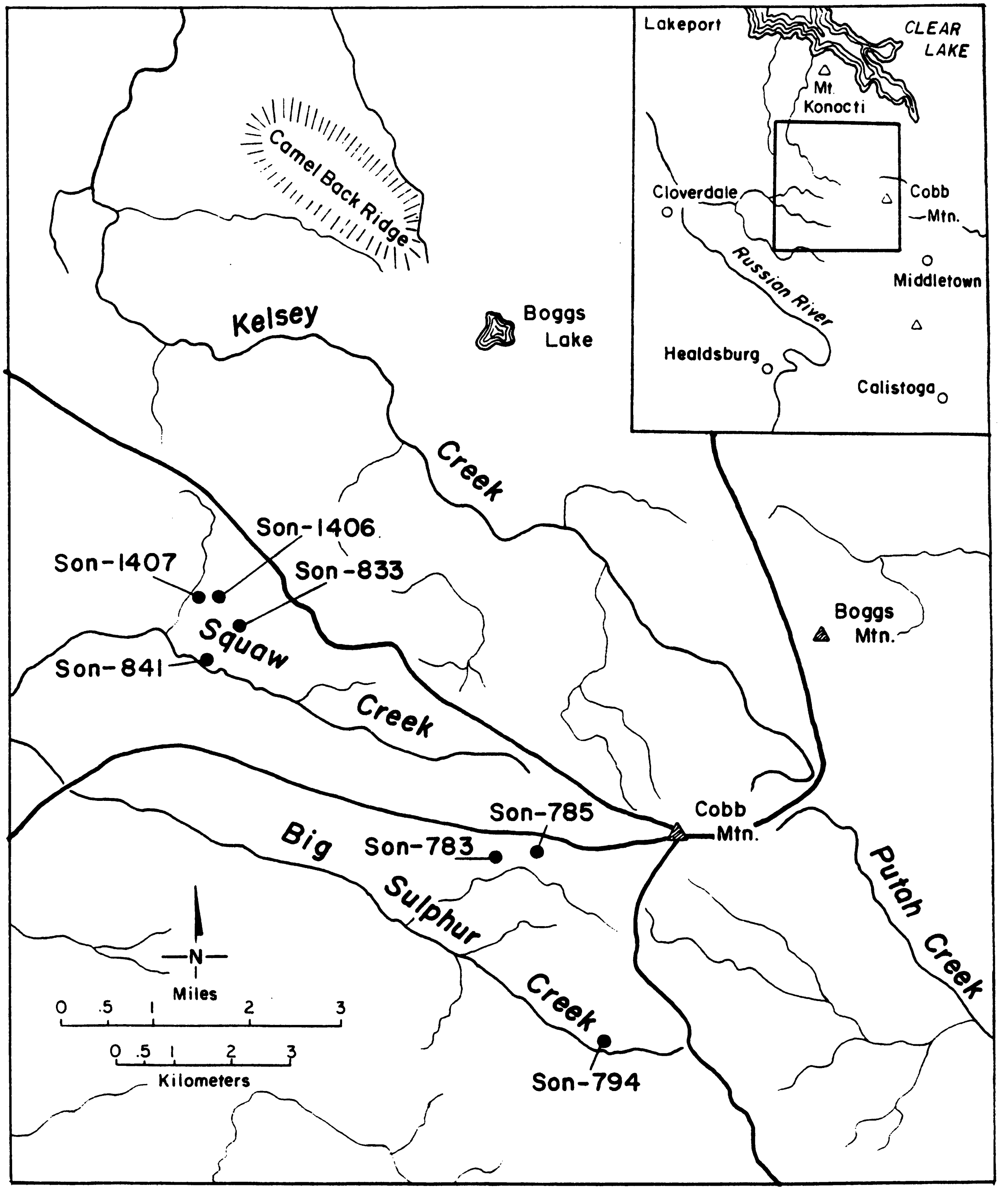
This paper focuses upon the archaeology of the geothermal region of northeastern Sonoma and adjoining portions of Lake and Mendocino counties, California, referred to here as the Geysers region, and draws from information and materials obtained over a period of 14 years during more than 100 separate archaeological field investigations implemented as a result of environmental protection regulations that helped guide the development of geothermal resources in the region (see Fredrickson 1985). While field work was an activity of cultural resource management, the integrative and synthetic work is an academic endeavor (cf. Lipe 1974). The present study further illustrates the contributions that small, often ephemeral, archaeological sites (in this example, ones located in a hinterland locality) can provide to the understanding of a region's prehistory (see Whalen 1986; Glassow 1985). Obsidian sourcing and hydration studies offer an indispensible key to such understanding when employed not only to obtain temporal control but also to gain estimates of interrelatedness, or relative social distance, between adjacent localities (Kay 1975; Wilmsen 1973).

THE STUDY AREA

Although the geothermal resource area within which the Geysers region is located is much larger, the area under study here consists of about 100 contiguous square miles in the Mayacmas Mountains within northeastern Sonoma and adjoining portions of Lake and Mendocino counties (Map 1). The approximate center of the area is about 75 air miles north of San Francisco, with Clear Lake located an additional 15 miles to the north. The study area trends roughly 20 miles in a northwesterly direction, with its widest portion of about 12 miles trending northeasterly through a central point formed at the joined corners of the three counties. The regions is comprised for the most part of the Mayacmas uplands, contrasting with the surrounding lowlands of Kelsey and Putah creeks, and the Russian River. Terrain is usually rugged, lacking broad valleys, with numerous slopes greater than 60 percent. Although slopes often rise steeply from stream bottoms, occasional narrow valleys and low rolling hills offer more gentle terrain.

For purposes of the present work, the study area has been stratified with respect to major stream drainages. To the north, wholly within Lake County, are the drainages of High Valley and Kelsey creeks, together referred to as the Kelsey Creek locality; in the central area totally in Sonoma County are Squaw Creek and the lower portion of Big Sulphur Creek, whose drainages are referred to here as the Squaw Creek locality; to the south, also totally in Sonoma County, is the upper portion of Big Sulphur Creek, referred to as the Big Sulphur Creek locality; to the west, in Lake County, is Putah Creek, whose lands are referred to as

MAP 1
MAP OF GEOTHERMAL STUDY AREA SHOWING MAJOR DRAINAGES AND ARCHAEOLOGICAL SITES



the Putah Creek locality.

The region is marked by a complex floral mosaic, consisting of various combinations of chaparral, cypress forest, grassland, oak woodland, Douglas fir-oak woodland, and yellow pine forest (Simons 1985). Although all these vegetation communities are present within each of the four localities, different localities are dominated by different plant associations, a circumstance that affects the relative frequency of different site types. Chaparral and cypress forest associations dominate much of the Kelsey Creek locality, while grassland and oak woodland cover a great deal of the Squaw Creek locality. Flake scatters, assumed to be associated with hunting, dominate Kelsey Creek, while sites with more extensive cultural deposits, assumed to be indicative of upland camps, are most common at Squaw Creek. In short, the study area forms a rugged upland backcountry, usually dominated by chaparral and yellow pine forest, as contrasted with the more gentle and generous terrain which surrounds the area. As already mentioned, the study area also contains geothermal resources, the development of which has prompted the archaeological work reported here.

Territories of four ethnographic Native American communities converge within the region, with Geysers Rock at the head of Squaw Creek forming the approximate point of convergence. An Eastern Pomo community with its major villages along the lower reaches of Kelsey Creek controlled the Kelsey Creek locality. A Southern Pomo community with its major village located on the Russian River near Cloverdale controlled the Squaw Creek portion. The upper Big Sulphur Creek portion was controlled by a Western Wappo community whose major village is believed to have been at the Geysers proper. The Putah Creek locality was controlled by the community at Middletown, consisting of either Lake Miwok or Northern Wappo, or both (Kroeber 1932: 366ff.; Merriam 1955: 43ff.).

THE DATA BASE

Systematic and intensive archaeological survey associated with geothermal resources development began in 1973 (e.g., Fredrickson 1973; Peak 1973). Since then, numerous surveys have generated more than 200 reports, letters, and environmental documents pertaining to archaeological resources. As a result of this work, more than 100 contiguous square miles have been surveyed and more than 340 prehistoric archaeological sites have been recorded. Of these, about 63 percent are flake scatters while about 37 percent are believed to have subsurface deposits. Because these evaluations are based primarily upon observable surface attributes and have only occasionally been tested by subsurface investigations, the actual numbers for each category are subject to change as subsurface data become available.

It was recognized during initial work in the geothermal region that obsidian flakes occurred at virtually all of the identified archaeological sites. Indeed, a significant majority of sites was marked by obsidian flakes alone, with even bifacially worked tools apparently absent (Fredrickson 1974: 13ff.). Limited subsurface investigation did little to change this perception (Fredrickson 1985: 29). Because geothermal development is land intensive, it was also recognized that impacts to archaeological resources, both anticipated and locationally unanticipated, could occur as a result of implementation of any one of the many different projects under development (Fredrickson 1974: 16ff.). Although each power plant utilizes only a few acres, it draws upon steam from wells contained within a leasehold averaging about 800 to 1000 acres in size. Considering that about 30 power plants are now operating, under construction, or in the permitting stages, a significantly large ground surface area is affected. Within each leasehold are about 10 to 15 steam wells required to furnish steam to operate the power plant, a complex network of pipelines to transport the steam, support roads, and power transmission lines. Add to this service centers, disposal areas, and other geothermal features, and the potential threat to archaeological resources through land disturbance activities becomes acute.

In view of these circumstances, an explicit plan that focused upon analysis of archaeological obsidian was initiated in 1973 to complement the archaeological surveys required by law (Fredrickson 1974: 29). Although preliminary analyses of obsidian data have been reported previously (e.g., Eisenman and Fredrickson 1980; Jackson 1974), a more thorough analysis was made possible during the preparation of an archaeological management plan for the geothermal area by Sonoma State University's Anthropological Studies center (Fredrickson 1985) under contract to the U.S. Bureau of Land Management (see acknowledgements).

ASSUMPTIONS

Our studies have attempted to control for two major variables, space and time. The spatial dimension has been controlled as described above through stratifying by major drainage. The temporal dimension has been controlled, though only to a limited extent because of cost constraints, through source-specific obsidian hydration studies. Because no satisfactory hydration rates have been developed for the obsidian sources under consideration, we have resisted the temptation to convert obsidian hydration readings into calendric dates. However, at this point in the research, source-specific hydration data reported in microns provide a satisfactory framework for relative dating.

The spatial stratification of the study area by major drainages (rather than vegetation or geomorphology) is not an arbitrary procedure. Territorial boundaries in ethnographic California were frequently at divides between watersheds. This was certainly the case within the present study area. To place this geomorphological variable within a larger context, we can see that in at least some cases the topographic features that marked the division between past sociopolitical units, i.e., ethnographic village-communities, even today mark the division between present day sociopolitical units, i.e., contemporary counties.

The study of boundary behavior is of special theoretical importance in the evolution of hunters and gatherers. Given the natural imbalance in both temporal and spatial occurrences of resources needed by humans, the presence of such boundaries is a sign that at least implicit agreements have been reached between neighbors to regulate resource use. It follows from this that there is at least implicit agreement to make reciprocal use of each other's resources, presumably through both formal and informal exchange networks, visits to the resource site, reciprocal gift giving, or other means by which goods unevenly distributed in nature become redistributed culturally. The shift from a condition without firm social and territorial boundaries to one with such boundaries (and vice versa), or any shift in boundary location, then, can be taken to mark a major shift in local sociopolitical organization.

The analytical division of the study area into four localities allows testing of hypotheses pertaining to social distance. Wilmsen (1973: 15) suggested that archaeological data could be used to measure social distance, or "social interaction intensity between groups occupying different territories," because archaeological data can be both quantified and denoted by spatial coordinates. Following Wilmsen, Kay (1975), in a study of interrelatedness among central Missouri Hopewell settlements, suggested that "social distance between peoples is reflected in the degree of similarity between artifacts commonly found." In the present study, I assume that interrelatedness, or social distance, can be estimated on the basis of patterning of obsidian tools and debitage, stratified by source. I also assume that the extent of interrelatedness between two communities is inversely proportional to the extent of fall off (the term applied to the decline in material from one locality as compared with an adjoining one) between the communities. For example, if a series of commodities are more or less equally distributed within two communities, then fall-off is low by definition and interrelatedness is assumed to be high.

Several simple assumptions, none of which is necessarily true, have been made in drawing inferences from the distributional data. First, the principle of least effort is assumed. For example Borax Lake obsidian is assumed to have entered the region from the northeast, where its parent source is located, rather than by a more round about route from the south. Second, it is assumed that materials will move from the locality with a greater quantity into a locality with a lesser quantity. Third, materials will move from one locality into an immediately adjoining locality, rather than from one locality into another that is one step or more removed (such as from Squaw Creek into Putah Creek).

Because the local obsidian sources occur at four different locations separated by as few as nine and as many as 40 miles, it may be that obsidian from each source moves into the region by means of a different set of social transactions and possibly along a different route. Similarities in the distribution of the different sources within each pair of localities is then assumed to be reflective of social interaction between these localities. Similarly, obsidian in different forms (e.g., trade blanks, finished projectile points) may enter a locality as a result of various and sometimes contrasting types of social interaction. Although some points were imported into the several localities as finished objects, it is also likely that other points and bifacially worked tools were manufactured within their find locality.

The argument here is that close social interrelatedness is indicated when there are similarities in proportions of different obsidians, by source and form, at contiguous sites, and that similar social behavioral patterns contributed to the similarities in obsidian distribution. Relative social distance among adjoining localities, then, can be estimated by observing differences and similarities in the patterning of obsidian materials.

There is evidence that the form in which the obsidian occurs is important, since different forms may enter a locality in different ways (see Hughes and Bettinger 1984). However, in the present study we control only for flakes and bifacially worked tools. Other variables such as flake characteristics (a function of technological processes) and point type (whether manufactured locally or imported ready-made) may also prove to have significance with respect to the processes that affect the movement of obsidian in space.

Empirical evidence gained from obsidian studies within the study area supported the preliminary finding that archaeological sites within any one locality are more similar to one another with respect to the distribution of obsidian by source and form than they are to sites in adjoining localities (Eisenman and Fredrickson 1980). The data assembled here support findings that within the study area: (1) each locality has its own distinctive patterning of obsidian distributions, (2) there is more connectedness between some pairs of localities than between others, and (3) the movement of the different obsidians between communities can be reconstructed from fall-off patterns.

STUDY FINDINGS

The obsidian sample which constitutes the basis for findings reported here consists of 1265 flakes and 269 points and other bifacially worked tools obtained from 154 archaeological sites located within the study area. Although identification of geological sources for the obsidian was carried out largely using macroscopic criteria, i.e., visually observable characteristics that distinguish one parent source from another, geologic sources for about 22 percent of the sample have been determined by x-ray fluorescence (XRF). Two additional data sets were employed in the temporal analysis presented here. One includes source specific hydration measurements from an additional 223 specimens (including both flaked tools and débitage) obtained from excavations at four sites within the Squaw Creek locality (Peak and Associates 1985; Farber 1987); the other includes hydration measurements from 46 specimens (including only flakes) obtained from excavations at three sites within the Big Sulphur Creek locality. None of these 269 specimens are included in the major sample of flakes and points described above.

The following topics are discussed below: (1) distribution of obsidian by source within each of the four localities, controlling for differences between flakes and bifacially worked tools, but not distinguishing further among variables such as flake characteristics, flake tools, and tool form; and (2) possible routes of entry for obsidian from each of the four represented sources into each of the four localities, as inferred from the patterning of fall-off.

Obsidian Source Distributions

The present study area is within each reach of the four principal North Coast Ranges obsidian sources. Mt. Konocti obsidian occurs within the Kelsey Creek locality at an outcrop about six miles north of Geysers Rock, Borax Lake obsidian is available about 15 miles to the northeast, and Annadel and Napa Valley obsidians occur about 27 miles to the south. There are no natural barriers, such as large rivers or exceptionally difficult terrain, between the source localities and the present study area.

If the principal of least effort were applied to the distribution of obsidian without regard to other selection factors, one would predict abundant Mt. Konocti obsidian, somewhat lesser amounts of Borax Lake materials, and about equal but small quantities of Napa and Annadel (cf. Ericson 1977). These expectations were not met. Most noteworthy of several findings is the over-representation of Napa Valley obsidian in the Big Sulphur Creek locality and of Borax Lake obsidian at Putah Creek, and the under-representation of Annadel obsidian.

Jackson (1974) was the first to recognize that Napa Valley obsidian within the Big Sulphur Creek locality was over-represented with respect to the distance-decay (fall-off) hypothesis, and subsequent studies have confirmed and added to this initial observation (Eisenman and Fredrickson 1980; Fredrickson 1985). These findings are supported by data presented in Tables 1-4. Table 1 presents the distribution of obsidian flakes by source and major drainage within the study area; Table 2 depicts this distribution through a histogram. Table 3 shows the distribution of obsidian points and bifaces by the same variables; Table 4 depicts the point/biface distribution through a histogram. Implications of the data provided in the tables are discussed below, incorporating information obtained from obsidian hydration studies.

The spatial distribution of 1265 obsidian flakes whose sources have been determined is shown in Tables 1 and 2. The distribution generally follows that predicted by the distance-decay hypothesis in that numbers become less as distance from source increases. However, significant differences in fall-off rates occur between localities. The amount of Mt. Konocti obsidian in the tested flakes falls off dramatically (from about 85- to 52%) across the border from the Kelsey Creek and Squaw Creek localities into either the Big Sulphur Creek or Putah Creek localities. Conversely, both Borax Lake and Napa fall off significantly in the reverse direction (from about 23% Borax Lake at Big Sulphur to 9% at Squaw Creek and from 19.4% Napa at Big Sulphur to 5% at Squaw Creek). Annadel is noteworthy by its virtual absence (less than 0.1%; only 5 of more than 1200 flakes in the total sample) in all localities.

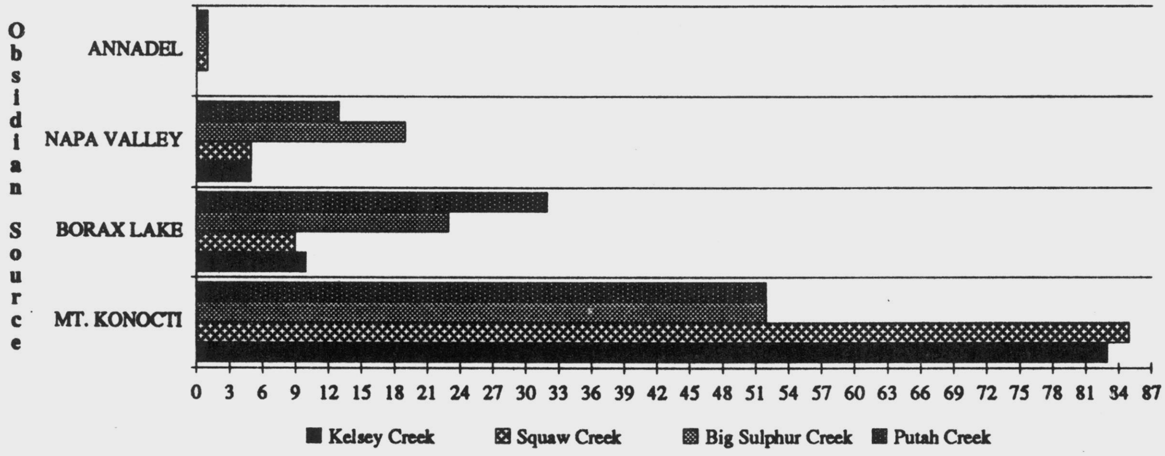
Also important are the close similarities in the frequencies of the different obsidian sources within the Kelsey Creek and Squaw Creek localities, as well as within the Big Sulphur and Putah Creek localities. If the guiding assumptions of this study are correct, the obsidian distributions within any pair of localities are

TABLE 1
DISTRIBUTION OF OBSIDIAN FLAKES BY SOURCE AND MAJOR DRAINAGE WITHIN THE GEOTHERMAL REGION OF LAKE AND SONOMA COUNTIES

	Mt. Konocti	Borax Lake	Napa Valley	Annadel	Unknown	Totals
Kelsey Creek	349/83%	43/10%	23/ 5%	0	8/2%	423
Squaw Creek	430/85%	44/ 9%	27/ 5%	3/1%	4/1%	508
Big Sulphur Creek	99/52%	45/23%	37/19%	1/1%	10/5%	192
Putah Creek	58/52%	36/32%	15/13%	1/1%	2/2%	112
totals	936/76%	168/14%	102/8%	5/<.1%	24/2%	1235

1. Number/Percent
2. Chi Square calculated only for Mt.Konocti, Borax Lake, and Napa Valley sources.
3. Number = 1206.
4. Chi Square = 128.714.
5. Probability of Chance = 0.0000.

TABLE 2
HISTOGRAM OF OBSIDIAN FLAKES BY SOURCE AND MAJOR DRAINAGE WITHIN THE GEOTHERMAL REGION OF LAKE AND SONOMA COUNTIES



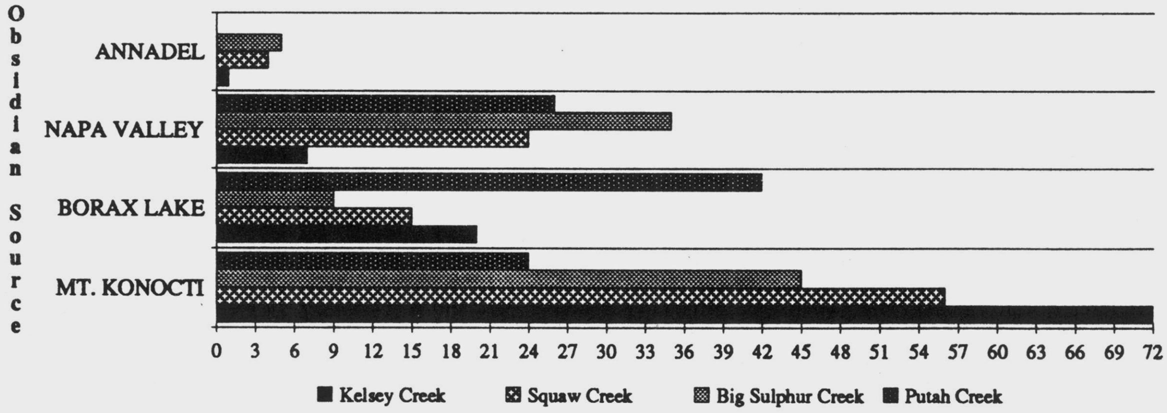
1. Bar graphs depict percentage of each source within each locality. 2. Histogram generated from data in Table 1.

TABLE 3
DISTRIBUTION OF OBSIDIAN BIFACES BY SOURCE AND MAJOR DRAINAGE WITHIN THE GEOTHERMAL REGION OF LAKE AND SONOMA COUNTIES

	Mt. Konocti	Borax Lake	Napa Valley	Annadel	Unknown	totals
Kelsey Creek	63/72%	18/20%	6/ 7%	1/1%	0	88
Squaw Creek	44/56%	12/15%	19/24%	3/4%	0	78
Big Sulphur Crk	29/45%	6/ 9%	23/35%	3/5%	4/6%	65
Putah Creek	9/24%	16/42%	10/26%	0	3/8%	38
totals	145/54%	52/19%	58/22%	7/3%	7/3%	269

1. Number/Percent
2. Chi Square calculated only for Mt. Konocti, Borax Lake and Napa valley sources.
3. Number = 255
4. Chi Square = 42.4277
5. Probability of Chance = 0.0000

TABLE 4
HISTOGRAM OF OBSIDIAN POINTS AND BIFACES BY SOURCE AND MAJOR DRAINAGE WITHIN THE GEOTHERMAL REGION OF LAKE AND SONOMA COUNTIES



1. Bar graphs depict percentage of each source within each locality. 2. Histogram generated from data in Table 3.

reflective of social interaction between these localities. Thus, the Kelsey Creek and Squaw Creek localities form an interaction unit and the Big Sulphur and Putah Creek localities form an interaction unit. It can be inferred, then, that there is greater social distance between the two units than between the subsets of each unit.

The findings of the present study also show significant differences between the distribution of obsidian points and bifaces by source when compared to the distribution of flakes (see Hughes and Bettinger 1984). Tables 3 and 4 depict the spatial distribution, again without reference to chronology, of 269 points and bifaces, similarly stratified by locality and source. Although the distributional patterns for points and bifaces differ from those of flakes, they complement rather than contradict one another. In the main it is likely that the point distributions differ from flake distributions because the point distributions are influenced by the movement of particular point forms as well as by raw materials. Table 4 illustrates well the concept of fall-off between contiguous localities, showing that the use of Mt. Konocti obsidian for points and bifaces declines dramatically from one locality to another, presumably as effective distance from source increases.

The figures for points and bifaces clearly show that Mt. Konocti obsidian, as expected, dominates the Kelsey Creek drainage (72%), but it falls-off markedly in the Squaw Creek drainage (56%); the close similarities observed with flakes is not repeated. Mt. Konocti falls-off again and ceases to be a majority (45%) within the Big Sulphur Creek drainage, where Napa Valley is significantly represented in the assemblage (35%). Putah Creek differs even more, with Borax Lake dominating this assemblage (42%) while Mt. Konocti, with outcrops located no more than seven miles away, constitutes only a small proportion (24%).

To this point, relatively little data exist regarding the time depth of these patterns. Table 5 presents hydration readings from 223 specimens (including both flakes and points/bifaces) obtained from four sites tested by excavation within the Squaw Creek locality (Peak and Associates 1985; Farber 1987). Table 6 contains reading from 46 specimens (including flakes only) from three sites tested by excavation in the Big Sulphur Creek locality. Because it is not yet possible to correlate hydration readings from different sources with equivalent chronological ages, we must be cautious in asserting that one source appeared in the region earlier than others: in addition the present hydration sample is too limited to allow many reliable generalizations.

The heavy bias of the Squaw Creek hydration sample in favor of points and bifaces and the Big Sulphur Creek bias in favor of flakes can be accounted for to some extent not only by the sampling methods of the investigators but also by differences in each series of sites that were investigated. The Squaw Creek sites had depth up to a meter or more and contained flaked stone artifacts and milling tools and were likely to have been seasonally occupied camps. On the other hand, two of the Big Sulphur Creek sites were sparse flake scatters with little depth and few if any bifacially worked tools; the third was equivalent to those at Squaw Creek in representing a seasonally utilized camp. These differences are reflected in the tables in that 67% of the Squaw Creek sample and none of the Big Sulphur Creek sample is made up of points and bifaces. It is likely that the non-Mt. Konocti obsidian at Squaw Creek represents projectile points that were imported into the locality as finished tools. The sparse flake scatter context of the Big Sulphur Creek specimens also suggests that the non-Mt. Konocti obsidian there represents repair and maintenance flakes rather than manufacturing debris.

Although Borax Lake obsidian in the Big Sulphur Creek sample has substantially greater hydration readings than the other two sources, we must be cautious in assigning that source temporal priority. Several lines of contextual evidence elsewhere in the North Coast Ranges suggest that the hydration rate for Borax Lake obsidian is somewhat more rapid than the rates of either Mt. Konocti or Napa. The data in Tables 5 and 6 suggest that despite Mt. Konocti's probable dominance during all time periods, both Borax Lake and Napa Valley obsidian appear to have been utilized in both localities at a substantially early date. However, data presented in Table 1 indicate that both Borax Lake and Napa Valley obsidian were quantitatively more important in the Big Sulphur Creek locality as compared with the Squaw Creek locality. Annadel obsidian appears to have been brought into the region only during the late period and then only in extremely small quantities.

Movement of Obsidian into the Geothermal Region

Tables 7-10 present reconstructions of the movement of obsidian from the four local sources into and within the geothermal region employing data on flake distributions for one set of reconstructions and on points and bifaces for a second set. The arrows in the tables indicate what are reconstructed to be the most likely routes of movement. Although it is presently not possible to separate the data on imported points and bifaces from locally manufactured specimens, distributional differences suggest that imported objects at times had entry routes different from those of the raw

TABLE 5
DISTRIBUTION OF OBSIDIAN HYDRATION READINGS FROM FOUR SITES WITHIN THE SQUAW CREEK LOCALITY

Microns	Mt. Konocti	Borax Lake	Napa Valley	Annadel
0.0-1.0	-	-	-	-
1.1-1.3	1	-	1	1
1.4-1.6	8	1	1	-
1.7-1.9	14	1	2	1
2.0-2.2	16	2	3	-
2.3-2.5	23	2	5	1
2.6-2.8	29	1	5	-
2.9-3.1	19	1	1	-
3.2-3.4	17	-	-	-
3.5-3.7	11	-	-	-
3.8-4.0	5	1	1	-
4.1-4.3	11	2	-	-
4.4-4.6	9	1	1	-
4.7-4.9	4	-	-	-
5.0-5.2	7	1	-	-
5.3-5.5	1	1	-	-
5.6-5.8	1	-	-	-
5.9-6.1	2	1	-	-
6.2-6.4	-	-	-	-
6.5-6.7	1	-	-	-
6.8-7.0	-	1	-	-
7.1-7.3	1	1	-	-
7.4-7.6	1	-	-	-
7.7-7.9	1	-	-	-
8.0-8.2	-	-	-	-
8.3-8.5	-	-	-	-
8.6-8.8	-	-	1	-
totals	182	17	21	3

1. Data from Farber 1985, Peak and Associates 1987.
2. Specimens from both surface and subsurface of Son-833, -841, -1406, -1407.
3. (Points-bifaces)/(cores-flake tools-flakes-shatter) as follows: Mt. Konocti, 11/71; Borax Lake, 16/1; Napa Valley, 20/1; Annadel, 2/1.

TABLE 6
DISTRIBUTION OF OBSIDIAN HYDRATION READINGS FROM THREE SITES WITHIN THE BIG SULPHUR CREEK LOCALITY

microns	Mt. Konocti	Borax Lake	Napa Valley
0.0-1.0	-	-	-
1.1-1.3	4	-	-
1.4-1.6	1	1	1
1.7-1.9	-	-	-
2.0-2.2	2	-	-
2.3-2.5	2	-	-
2.6-2.8	1	-	-
2.9-3.1	-	-	-
3.2-3.4	2	-	3
3.5-3.7	2	-	4
3.8-4.0	2	3	-
4.1-4.3	1	-	1
4.4-4.6	-	1	-
4.7-4.9	-	-	-
5.0-5.2	1	-	-
5.3-5.5	-	1	2
5.6-5.8	-	1	-
5.9-6.1	-	5	-
6.2-6.4	-	1	-
6.5-6.7	-	-	-
6.8-7.0	-	2	-
7.1-7.3	-	-	-
7.4-7.6	-	-	-
7.7-7.9	-	-	-
8.0-8.2	-	1	-
8.3-8.5	-	-	-
8.6-8.8	-	1	-
totals	18	17	11

1. Data from files of the Obsidian Laboratory, Sonoma State University.
2. Specimens from both surface and subsurface of Son-783, -785, -794.
3. Specimens include flakes and chunks only.
4. No Annadel specimens were identified at these sites.

materials. The distributional data suggest the following reconstructions.

Mt. Konocti obsidian, assumed to derive from the source within the Kelsey Creek locality, appears to have been moved freely into Squaw Creek and less freely into Putah Creek. Certainly the number of Mt. Konocti points found in the Putah Creek locality is less than expected considering its proximity to the source. From Squaw Creek, Mt. Konocti obsidian was then moved into Big Sulphur Creek where the raw material may have moved freely between Big Sulphur and Putah. Points and bifaces, however, were more likely to have moved from Big Sulphur into Putah than the reverse.

Borax Lake obsidian was transported from its source separately into both the Kelsey Creek and Putah Creek localities. If obsidian were moved between these two localities, it would have been more likely from Putah into Kelsey than the reverse. Although Big Sulphur may have received finished tools from both Squaw and Putah, raw material would have been moved from Big Sulphur into Squaw, as well as from Kelsey into Squaw.

Napa Valley obsidian was moved from its source separately into both Big Sulphur and Putah; if there was movement between the two localities, it was more likely from Big Sulphur into Putah than the reverse. From Big Sulphur, this obsidian was moved into Squaw and subsequently into Kelsey. Kelsey may also have received Napa Valley obsidian from Putah.

Annadel obsidian may have entered the region through Big Sulphur Creek and from there to Kelsey creek by way of Squaw Creek; it may also have entered Squaw Creek independently of Big Sulphur.

TABLE 7

RECONSTRUCTED MOVEMENTS OF OBSIDIAN BETWEEN KELSEY AND SQUAW LOCALITIES BY SOURCE AND FORM

	Kelsey Creek..................Squaw Creek
MT. KONOCTI OBS:	
Flakes	>>————————————>>
Points/Bifaces	>>————————————>>
BORAX LAKE OBS:	
Flakes	<<————————————>>
Points/Bifaces	>>————————————>>
NAPA VALLEY OBS:	
Flakes	<<————————————>>
Points/Bifaces	<<————————————<<
ANNADEL OBS:	
Flakes	?
Points/Bifaces	<<————————————<<

1. Arrows, e.g., >>————>>, indicate direction of movement.
2. Table based on data from Tables 1 through 4.

TABLE 8
RECONSTRUCTED MOVEMENT OF OBSIDIAN BETWEEN KELSEY AND PUTAH LOCALITIES BY SOURCE AND FORM

	Kelsey Creek.......................Putah Creek
MT. KONOCTI OBS:	
Flakes	>>——————————————>>
Points/Bifaces	>>——————————————>>
BORAX LAKE OBS:	
Flakes	<<——————————————<<
Points/Bifaces	<<——————————————<<
NAPA VALLEY OBS:	
Flakes	<<——————————————<<
Points/Bifaces	<<——————————————<<
ANNADEL OBS:	
Flakes	?
Points/Bifaces	?

1. Arrows, e.g., >>————>>, indicate direction of movement.
2. Table based on data from Tables 1 though 4.

CONCLUSIONS

The findings to date prompt the hypothesis that a portion of the boundary between the spheres of influence for Mt. Konocti and Borax Lake obsidian, and possibly Napa Valley as well, resides within the present study area. Minimally, however, it can be stated with regard to routine obsidian use that there was little social distance between the Kelsey Creek and Squaw Creek drainages over an extended period of time. Greater social distance during this time span existed between these two localities as a unit and the Big Sulphur and Putah Creek drainages as a unit.

Insofar as the distribution of obsidian monitors social relationships, it appears that during all time periods the Annadel source locality was more removed in social distance from the study area than was the Napa Valley despite the fact that both sources are about equidistant over similar terrain from the study area. This may be related to the fact that Wappo communities controlled both Big Sulphur Creek (and possibly Putah Creek) and the Napa Valley obsidian sources. Although these communities were politically separate from one another, intermarriage may have facilitated the movement of obsidian from its source to the study area (see Jackson 1986; Jackson [this volume]).

It is evident that raw material, from whatever source, was moved with relative freedom between the Kelsey and Squaw localities and between the Big Sulphur and Putah localities. However, the distribution of points and bifaces shows no such symmetry, with their fall-off patterns suggesting more controlled movement between adjoining localities.

The obsidian fall-off patterns outlined above are proportional to the extent of social distance between adjoining localities. This suggestion forms a hypothesis for which implications may be developed that can be tested by data sets that are independent of obsidian

TABLE 9
RECONSTRUCTED MOVEMENT OF OBSIDIAN BETWEEN SQUAW AND BIG SULPHUR LOCALITIES BY SOURCE AND FORM

	Squaw Creek..................Big Sulphur Ck
MT. KONOCTI OBS:	
Flakes	>>————————————>>
Points/Bifaces	>>————————————>>
BORAX LAKE OBS:	
Flakes	<<————————————<<
Points/Bifaces	>>————————————>>
NAPA VALLEY OBS:	
Flakes	<<————————————<<
Points/Bifaces	<<————————————<<
ANNADEL OBS:	
Flakes	?
Points/Bifaces	<<————————————<<

1. Arrows, e.g., >>———>>, indicate direction of movement.
2. Tables based on data from Tables 1 and 4.

sourcing data. For example, when we infer that the Kelsey and Squaw localities have less social distance between them than between either the Big Sulphur or Putah localities, we can test the inference, now as an hypothesis, by the implication that other artifact forms will also fall-off at the same juncture. Successful testing of the hypothesis may then prompt us to seek a higher level of explanation as to why such social distance is found between some localities and not between others.

Overall, the findings outlined here are consistent with observations made by Hughes and Bettinger (1984) regarding the influence of prehistoric sociocultural systems on the distribution of obsidian. They have suggested that obsidian is not only a utilitarian commodity, it is also a socioceremonial one. They also suggested that the village-community (rather than the ethnolinguistic unit) would be the social unit responsible for obsidian distribution and use, and consequently the one most likely to be reflected in archaeological obsidian distributions. In the present study, although the ethnographic inhabitants of each of the territories under consideration had a different ethnolinguistic affiliation, each also constituted a separate village-community. Finally, at the current level of understanding, we can concur with Hughes and Bettinger (1984) that obsidian study provides "a potentially powerful tool for the investigation of prehistoric sociocultural systems."

ACKNOWLEDGMENTS

The contributions of the U.S. Bureau of Land Management to this study is hereby acknowledged. Especially important were those of Francis Berg, BLM archaeologist, who conceived of the geothermal management plan and supported its development. Also acknowledged are the services of Richard Hughes and

TABLE 10
RECONSTRUCTED MOVEMENT OF OBSIDIAN BETWEEN BIG SULPHUR AND PUTAH LOCALITIES BY SOURCE AND FORM

	Putah Creek....................Big Sulphur Ck
MT. KONOCTI OBS:	
Flakes	<<——————————>>
Points/Bifaces	<<——————————<<
BORAX LAKE OBS:	
Flakes	>>——————————>>
Points/Bifaces	>>——————————>>
NAPA VALLEY OBS:	
Flakes	<<——————————<<
Points/Bifaces	<<——————————<<
ANNADEL OBS:	
Flakes	?
Points/Bifaces	?

1. Arrows, e.g., >>————>>, indicate direction of movement.
2. Tables based on data from Tables 1 and 4.

Thomas Jackson, who carried out XRF trace element analyses on obsidian specimens that allowed their attribution to specific parent sources, as well as serving as tests for visual sourcing, i.e., the identification of parent sources on the basis of macroscopic characteristics. The assistance of Jan Keswick in carrying out visual sourcing is also acknowledged. Acknowledgement is due Thomas Origer, who performed the obsidian hydration work reported here, who supervised visual sourcing efforts, and who, over the years, participated in much of the field work upon which the present study is based. The hydration readings for the obsidian sample reported by Peak and Associates (1985) and Farber (1987), cited in this paper, were made by R.J. Jackson; XRF source identifications for about half of these specimens were made by Paul D. Bouey; XRF sourcing for the remaining half was conducted by Richard E. Hughes. Other researchers whose work contributed directly to the present study include Lynn Eisenman, Mark Hale, John Hayes, Thomas Kaufman, Pat Mikkelsen, James Quinn, Nelson Thompson, and Kim Tremaine. Archaeological consultants and consulting firms whose field work contributed to this study include Peak and Associates, Archaeological Resource Services, Archaeological Services, Professor Delbert True, Pacific Bioarchaeology Laboratory, and Sonoma State University's Anthropological Studies Center. Archaeological reports and site records generated through their studies are on file with the Northwest Information Center of the California Archaeological Inventory at Sonoma State University, Rohnert Park, CA 94928.

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OBSIDIAN ACQUISITION AND USE IN PREHISTORIC CENTRAL EASTERN CALIFORNIA: A PRELIMINARY ASSESSMENT

Mark E. Basgall

INASMUCH AS THE DOMINANT CULTURAL REMAINS encountered at archaeological sites within most of California and the Desert West typically constitute flaked stone artifacts, successful decipherment of prehistoric behavior depends largely on evaluation of such debris. Especially critical is an ability to track the spatio-temporal dimensions of stone tool use across large regions. Although many raw materials employed by past populations continue to thwart efforts at reliable source characterization, techniques developed over the past two decades have provided a means of assigning obsidian to parent formations with some assurance. This has enabled archaeologists in California, where volcanic glass is both abundant and saw widespread native use, to explore a wide range of culture- historical and processual issues (Bouey and Basgall 1984; Ericson 1981; Hughes 1984; 1986; Jack 1976; T. Jackson 1974; 1986). It is the case, of course, that obsidian distributions reflect directly only geographic displacement of material from its place of origin, yet many archaeologists persist in viewing regional source profiles as relatively straightforward signatures of trade, territoriality, and other behaviors that operate within a strong sociological matrix. Numerous treatments of obsidian in California exemplify this perspective. In their study of stone- working activities at the Bodie Hills quarry, for example, Singer and Ericson (1977) suggest that "analysis of production at quarry sources offers a relatively inexpensive and comprehensive means to investigate prehistoric trade," employing the results of their analysis to "estimate the quantities of items produced for export" as a function of time (1977: 171). The clear presumption here is that most or all debris found at the quarry locality relates to activities carried out by specialized task groups producing items intended for long-distance, intergroup exchange.

Patterns of obsidian dispersion do in some instances reflect fairly elaborate processes of intra- and intergroup interaction, particularly with regard to complex social formations (cf. Torrence 1986), but among many hunter-gatherer populations lithic procurement is a fundamental component of subsistence-settlement organization and occurs primarily or wholly within that context. Seen in this light, source profiles often relate more directly to aspects of residential stability and group provisioning than to specialized collection forays or formalized socioeconomic exchange relationships. This is, of course, what Binford (1977, 1979) has referred to as the "embeddedness" of raw material acquisition.

Preliminary assessment of obsidian source profiles in central-eastern California suggests that acquisition/ use patterns shifted dramatically over time, and that the behavioral processes responsible for source composition during different periods relates, variously, to both incidental raw material procurement and regularized access through exchange.

Data from three archaeological localities are compared in an effort to identify both localized use trajectories and regional trends in obsidian procurement. The results have implications for long-term change in subsistence-settlement organization, as well as for the structure and magnitude of social interaction across the region.

THE GEOLOGICAL CONTEXT

Eight major obsidian sources have been identified in central-eastern California that were exploited by prehistoric populations (Figure 1). From north to south these are Bodie Hills, Mt. Hicks (in extreme western Nevada), Mono Craters, Truman/Queen, Mono Glass Mountain, Casa Diablo, Fish Springs, and the Coso volcanic field (cf. Ericson 1977; Ericson, Hagan, and Chesterman 1976). There are further indications that several of these occur in secondary depositional contexts (though in proximity to primary outcrops), that more limited float sources occur in some areas (usually constituting small nodules of limited utility), and that as yet undiscovered, chemically distinct sources (with high quality glass) may exist (see below). Viewed from a synchronic vantage, previous archaeological analyses suggest that three of the known quarry areas, Bodie Hills, Casa Diablo, and Coso, supplied obsidian to much of west-central and/or southwestern California (Bouey and Basgall 1984; Ericson 1977, 1982; Jack 1976). Truman/Queen and Mt. Hicks, in contrast, appear to have provided volcanic glass primarily to populations in west-central and central Nevada (Hughes 1983, 1985; Hughes and Bennyhoff 1986). Finally, with few exceptions, materials from Fish Springs, Mono Glass Mountain, and Mono Craters were used only in restricted zones surrounding the quarries (cf. Bettinger 1982; Hughes and Bettinger 1984; R. Jackson 1985; Hughes [this volume]). Such a synchronic perspective has obvious limitations in a region with 9000-12,000 years of time depth, and it is diachronic variability that provides insight into changing patterns of subsistence-settlement organization and intergroup interaction.

THE ARCHAEOLOGICAL CONTEXT

Obsidian source characterization in central-eastern California, like elsewhere in the West, has seen limited application in all but a few of the archaeological investigations conducted. Further, many studies have focused on so-called trans-Sierran exchange, the large-scale movement of volcanic glass from the western Great Basin into the California heartland (Basgall 1983; 1984; Bouey and Basgall 1984; Ericson 1981; Hall 1983; 1984; R. Jackson 1984; T. Jackson 1984), rather than the implications of intra-regional source profiles. The present assessment concentrates on implications of obsidian dispersion within the area, looking at data from three localities that essentially span the north-south axis of the greater central-eastern California (Owens Valley to Mono Lake) region. Data are examined from: (1) CA-Iny-30, an extensive, multi-component occupation site in the extreme south of Owens Valley; (2) a series of sites within Long Valley caldera, located between Owens Valley and the Mono Basin; and (3) CA-Mno-446, situated on the southwestern edge of the Mono Lake basin (Figure 1).

CA-INY-30

Major excavations at Iny-30, on Lubkin Creek immediately northwest of Owens Lake, resulted in identification of several spatio-temporally discrete occupations that span the last 7000-9000 years (Basgall and McGuire 1988). These components were assigned to each of the temporal periods recognized in central-eastern California (e.g., Bettinger and Taylor 1974) using radiometric assay, obsidian hydration, and time-sensitive artifact forms: the Lake Mohave/Little Lake interval (pre-3200 B.P.); the Newberry period (ca. 3200-1350 B.P.); the Haiwee period (ca. 1350-650 B.P.); and the Marana period (ca. 650-100 B.P.).

Lake Mohave/Little Lake Component

The earliest component at Iny-30 is represented by a mixed deposit containing material attributable to both the Lake Mohave and Little Lake periods. Associated projectile points include two edge-ground Lake Mohave stem fragments, as well as one definite and two provisionally classified Little Lake series specimens. Obsidian hydration values from this portion of the site are consistently old: 19 measurements on artifacts sourced to the Coso volcanic field average 11.2 microns (sd = 1.3) and six characterized as Casa Diablo obsidian average 12.4 microns (sd = 1.2).

The deposit is generally sparse and poorly developed, containing few organic residues and a functionally restricted artifactual inventory. In addition to the points, materials assigned to the component include bifaces in different stages of manufacture, both formal and casual flake tools, flake cores, a number of core-cobble implements, considerable quantities of debitage, and a handful of animal bone fragments. Flaked stone debitage (of obsidian, cryptocrystalline, and fine-grained igneous material) is dominated by tertiary percussion flakes produced during biface reduction; pressure retouch debris is conspicuous by its near

FIGURE 1

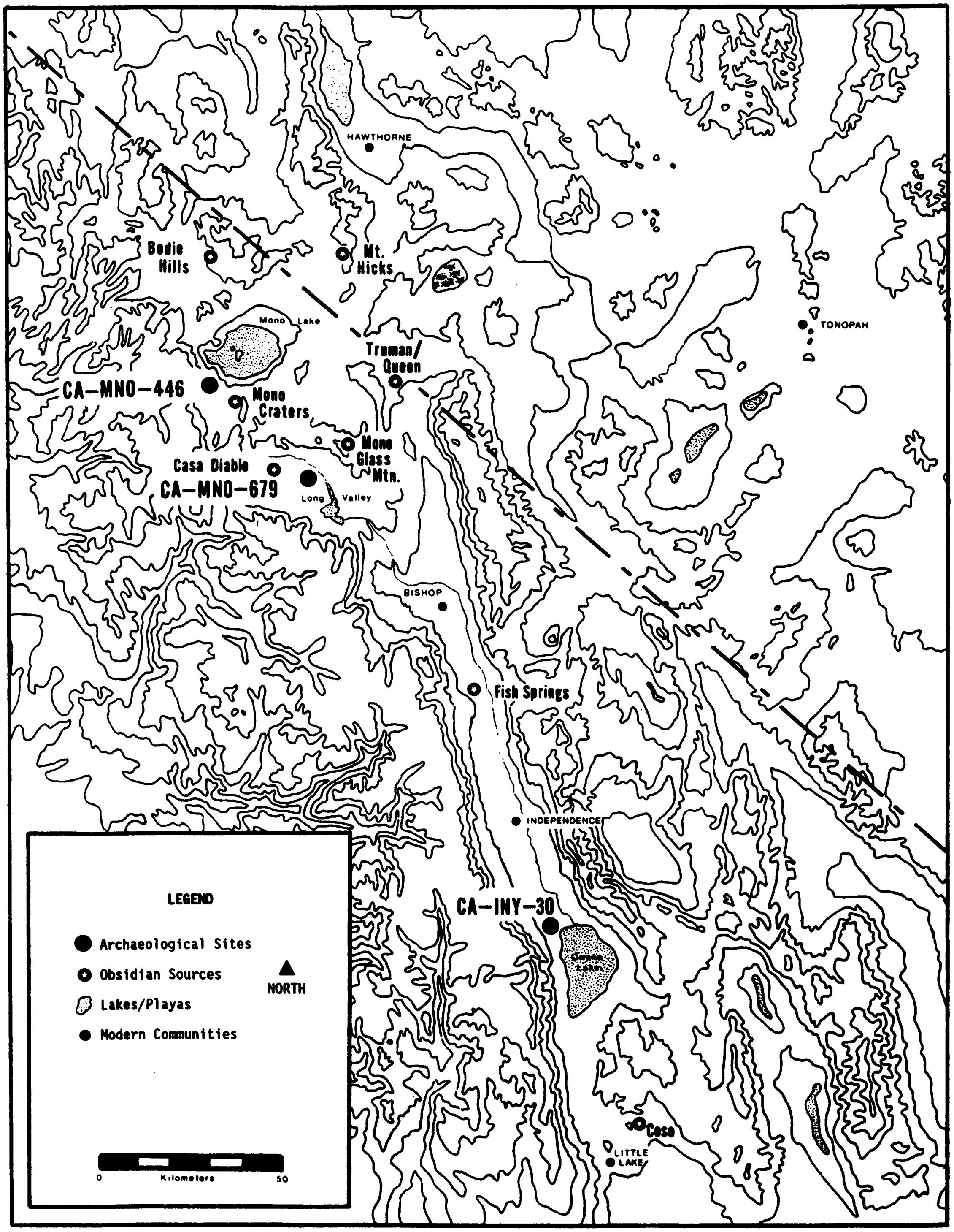

FIGURE 1. Map of Central-Eastern California

absence. Faunal detritus from the Lake Mohave/Little Lake component includes artiodactyl, rodent, waterfowl, and reptile remains; large mammal forms comprise slightly over one-third of the assemblage, small mammal/bird bone the bulk of the remainder.

Newberry Component

Apart from some scattered debris on the site surface, Newberry occupation at Iny-30 is represented by four buried houses, one refuse pit, and associated cultural materials. Projectile points from these contexts include ten Elko series, 20 Humboldt Basal-notched, and a single Humboldt Concave-base form. Six radiocarbon determinations from the structures range from 1860 ± 70 B.P. (Beta-20518) to 1220 ± 70 B.P. (Beta-12660). Obsidian hydration measurements available for three house features average 5.3-5.4 microns (55 specimens; sd = 0.5-1.0) for glass attributed to Coso and 4.9-5.0 microns (13 specimens; sd = 0.3-0.8) for artifacts sourced to the Casa Diablo quarry. Diagnostic beads recovered from this deposit include Saucer Olivella (Type G2 by the Bennyhoff and Hughes [1987] typology), common in the Great Basin in assemblages dating from ca. 2150-1850 B.P. Taken together, these chronological data suggest an occupational peak within the late Newberry period (Basgall and McGuire 1988).

The four houses are consistently large (ca. 4-5 m in diameter), with well-developed floors and collapsed structural supports, and contain a large quantity of tools, debitage, and organic remains. Caches of still serviceable artifacts, including projectile points, bifacial preforms or blades, milling equipment, and bone awl (deer metapodial) blanks were present in three of the structures. The inclusive artifact inventory encompasses a wide variety of finished and unfinished biface forms, casual and formal flake tools, cores, core-cobble implements, milling stones and handstones, drills, beads, and bone tools. Co-dominant amounts of biface thinning and pressure retouch debris reflect emphasis on both tool production and finishing/resharpening. The substantial milling assemblage from Newberry contexts (47 items) is characterized by tools that are well-shaped, heavily used, and appear to have been extensively curated. Fauna recovered from the four structures and trash pit include a range of artiodactyls, lagomorphs, rodents, birds, reptiles, and fish. The principal taxa, however, comprise mountain sheep (78% of identifiable artiodactyl remains), black-tailed jackrabbit (78% of lagomorphs), and grebes (84% of avifauna). A rich inventory of flotation-derived paleobotanical remains shows an emphasis on resources from dryland habitats. Abundant Poaceae include Sporobolous (dropseed) and Oryzopsis (ricegrass), while non-grasses are dominated by Chenopodium (goosefoot), Lycium (box-thorn), and Mentzelia (blazing-star). Not insignificant quantities of pinyon were recovered as well.

Haiwee Component

Unfortunately, little discrete Haiwee period deposit was encountered at Iny-30. The most intact context dating to this interval consisted of a deep pit, underlying a more extensive Marana component, which contained well-developed midden and fire-affected rock. Dating is based on five Rose Spring projectile points, radiocarbon assays of 960 ± 100 B.P. (Beta-12663) and 760 ± 100 B.P. (Beta-12664), and obsidian hydration measurements on Coso artifacts that average 4.4 microns (13 specimens; sd = 0.6).

Apart from projectile points, artifacts associated with the limited Haiwee deposit include percussion and pressure flaked bifaces, casual flake tools, several milling implements, and a couple pieces of modified bone. Debitage from the component shows increasing emphasis on pressure retouch and flake-based (as opposed to biface) technologies. Faunal debris reflects use of both dryland and wetland habitats, focused on the former. Although artiodactyl, lagomorph, rodent, waterfowl, reptile, and fish bone are present, rabbits appear to comprise the principal prey taxa. Paleobotanical remains reflect exploitation of diverse microenvironments, Sporobolous, Scirpus (bulrush), Juncus (rush), and Mentzelia constituting the most abundant charred seed forms. Given the likelihood that the pit feature producing Haiwee period remains represents a rather specialized, temporally restricted event, inferences regarding general patterns of behavior during this period are, of course, highly suspect.

Marana Component

By all measures, aboriginal occupation of Iny-30 appears to have reached its zenith during the Marana period. Three clusters of housepit depressions were identified at the site, together with a large bedrock milling area and several extensive midden accumulations. The magnitude of late prehistoric/protohistoric use is exemplified in the recovery of over 4500 Owens Valley Brown Ware sherds from the surface of the deposit (1250 more from subsurface situations). Chronometric data from Marana contexts include a suite of 11 radiocarbon dates from seven structures that range from 710 ± 70 B.P. (Beta-22294) to 180 ± 60 B.P. (Beta-20521) (a statistically "modern" assay probably relates to protohistoric occupation judging by associated glass trade beads, but could also represent a recent root burn episode). Some 17 Desert Side-notched and 21 Cottonwood series points were recovered from intact Marana deposit, together with 102 late period shell beads (mostly Thin Lipped [E1a and E1b], Ground [H1a] and Semi-Ground Disk [H1b], and Cupped [K1] and Bushing [K2] Olivella [Bennyhoff and Hughes 1987]) and 23 Steatite Disk beads. Seven hundred ninety-three of the 800 potsherds recovered from intact stratigraphic contexts were attributable to the Marana period. Finally, obsidian hydration values on Coso artifacts from late prehistoric deposit average 2.3-3.5 microns (44 specimens; sd = 0.1-0.8).

Artifactual remains from Marana deposits at Iny-30 include a range of biface forms, drills, various kinds of flake tools, cores, core-cobble implements, an extensive milling inventory, bone tools, ceramics, as well and numerous ornament types (of shell, bone, and stone). Flaked stone debitage suggests a flake-based orientation, and evidence of more standard biface reduction is limited. Unlike the Newberry assemblage, milling tools from the Marana component tend to be little modified and expedient. Subsistence residues, both faunal and floral, show a decided wetland orientation. Although the same broad suite of resources are present, waterfowl (ducks and grebes) constitute nearly 50% of the assemblage; freshwater mussel (Anodonta) shell occurs in abundance during this period for the first time. The paleobotanical inventory is less diverse than that from Newberry features, with few grasses and most seeds deriving from various shrubs and herbs (especially Descurainia [tansy mustard], Ruppia [ditch-grass], Scirpus [bulrush], Juncus [rush], and Typha [cattail]). Pinyon nutshell was both moderately abundant and ubiquitous across sampled Marana contexts.

Long Valley Caldera

Data from Long Valley derive from a series of excavation and survey projects that together encompass much of the caldera. Providing a monitor of obsidian use during the earliest period of human occupation is the Komodo site (Mno-679), a Paleoindian encampment in the central part of the valley (Basgall 1987; n.d.). Containing a series of basally-thinned, edge- and basally-ground concave-base projectile points, the site has been provisionally dated to the early Holocene on the basis of artifact typology and source-specific obsidian hydration measurements. A sample of 20 points chemically attributed to the Casa Diablo source yielded hydration values between 7.5-12.2 microns, averaging 9.6. These readings are considerably larger than the maximum measurements obtained on Little Lake series points in the area, and the mean corresponds to an age of 8100 B.P. using the curvilinear rate proposed by Hall (1984; Hall and Jackson, this volume). Other materials from the site include biface preforms and a variety of formal and casual flake tools; neither milling equipment nor organic remains were recovered (Basgall 1987, n.d.).

The other excavated sites incorporated into the Long Valley sample, Mno-529 (Basgall 1983), Mno-561 (Hall 1983), Mno-714 (Basgall 1984; R. Jackson 1986), and Mno-1529 (Basgall 1984) are all situated on the western edge of the caldera, within the modern town of Mammoth Lakes. Although each location has produced some evidence for the pursuit of typical subsistence and maintenance activities, the assemblages are dominated by debris that relates to extensive stoneworking and, apparently, exchange-related biface production (e.g., Bouey and Basgall 1984; Hall 1984). These localities date primarily to the interval between 3150 and 1350 B.P. as indicated by artifact typology (Elko and Humboldt series points) and obsidian hydration.

Finally, some of the source data used to construct projectile point and debitage profiles are drawn from an extensive survey conducted in the central and eastern portions of the caldera (R. Jackson 1985). The sites, being spatially removed from major trans-Sierran exchange corridors, may provide a more reliable reflection of intra-regional obsidian acquisition/use patterns. Both point forms and micron values on debitage from these locations span the last 7000 years.

CA-MNO-446

The Lee Vining Creek site, Mno-446, is situated on the lower reaches of the aforementioned drainage, about three kilometers southwest of Mono Lake. With an areal expanse of about 2700 sq m, excavations at the site yielded a relatively diverse inventory of flaked, ground and battered stone tools, and copious quantities of unmodified chipping debris. Organic preservation was poor, but a small assemblage of faunal remains was also recovered. Following E. L. Davis (1964:261), Bettinger (1981) characterized Mno-446 as a seasonally occupied base camp, from which plant and animal procurement activities were staged and exchange-related obsidian production was implemented.

The site has been subjected to considerable depositional churning, as reflected in both the vertical distribution of time-sensitive artifacts and obsidian hydration measurements (Bettinger 1981:20-21, 57); however, two gross temporal components can be identified. Hydration readings for Casa Diablo obsidian from the upper 50 cm of deposit average 3.1 microns, corresponding to an age of roughly 1000 B.P. as

TABLE 1
DISTANCE FROM ARCHAEOLOGICAL LOCALITIES TO KNOWN OBSIDIAN SOURCES (IN KM)

	CA-Iny-30	Long Valley	CA-Mno-446
Bodie Hills	210	70	40
Mt. Hicks	200	65	45
Mono Craters	170	25	10
Truman/Queen	160	40	55
Mono Glass Mtn.	145	5	40
Casa Diablo	140	0	40
Fish Springs	60	75	125
Coso	55	200	245

computed from Hall's (1984; Hall and Jackson, this volume) rate. Values from below 50 cm in depth average 4.5 microns, in accordance to ca. 2000 B.P. by the same formulation. Finally, temporal parameters of all diagnostic projectile points from the site (i.e., Elko, Humboldt, Little Lake, and wide-stem) fall prior to 1350 B.P., and appear related to the earlier, deeper component (Bettinger 1981; Hughes and Bettinger 1984).

THE SOURCE PROFILES

Obsidian source profiles have been constructed for each of the three archaeological localities using the results of several X-ray fluorescence (XRF) trace element analyses. Sample sizes for each site are as follows: Iny-30, 420 specimens; Long Valley, 718 artifacts (34 from Mno-679, 684 other); and Mno-446, 70 items. Distances from the archaeological localities to known obsidian sources represented in the samples are presented in Table 1.

CA-INY-30

Obsidian samples, both debitage and tools, were obtained from each of the components described previously. The nearest source of abundant, high-quality glass is the Coso volcanic field, located some 55 km to the south (see Hughes 1988). The Fish Springs quarry lies about the same distance (60 km) away; however, obsidian from that source occurs in more limited quantities and is often of poorer quality (i.e., nodules are smaller and inclusions more prevalent). Other known sources present in the Iny-30 collection are at least 140 km distant.

Lake Mohave/Little Lake Component

The obsidian assemblage from the earliest cultural component at Iny-30 exhibits several distinctive patterns (Table 2). The assemblage has the highest source diversity observed at the site, containing ten kinds of glass with a wide geographic dispersion. This diversity cross-cuts both the tool and debitage classes, even in groups represented by only a few specimens. Finally, chemically "unknown" obsidian types are common in the assemblage, all five groups occurring and comprising fully 23% of the analyzed sample. If obsidian from the Coso volcanic field can be considered the "local" material of choice, being close at hand, abundant, and of high quality, then it is significant that 51% of the overall assemblage derives from elsewhere (Table 3). This relationship remains virtually constant in both the tool and debitage classes.

Newberry Component

The source profile reconstructed for the Newberry occupation provides a marked contrast to the previous pattern (Table 2). In the first place, there is increased use of Coso obsidian and lesser diversity in the assemblage with respect to both the number of source groups present (eight) and their geography. Non-local glasses originate primarily from the Long Valley area, some 150 km to the north, with the intermediate Fish Springs quarry contributing far less material than the Truman/

TABLE 2
OBSIDIAN SOURCE COMPOSITION BY COMPONENT, CA-INY-30

	LM-LL			NEW			HAI		MAR		Total		
	FT	CT	DB	FT	CT	DB	FT	DB	FT	DB	FT	CT	DB
Coso/Coso?	8	8	20	41	21	95	18	11	44	35	111	29	161
Fish Springs	2	3	3	2	-	3	2	5	3	12	3	11	
Truman/Queen	1	-	-	7	-	1	-	1	1	-	9	-	2
Casa Diablo	1	1	8	12	-	16	-	-	1	-	14	1	24
Mono Glass Mtn	-	-	-	1	-	1	-	-	-	1	1	-	2
Bodie Hills	-	-	2	-	-	-	-	-	-	-	-	-	2
Unknown #1	3	4	3	8	-	-	2	1	1	-	14	4	4
Unknown #2	-	-	1	-	-	5	-	-	-	1	-	-	7
Unknown #3	-	1	1	-	-	1	-	-	-	-	-	1	1
Unknown #4	1	-	2	-	-	-	-	-	1	-	2	-	2
Unknown #5	-	-	1	-	-	-	1	-	-	-	1	-	1
Total	16	17	41	71	21	122	24	15	53	40	164	38	218

Note: LM-LL, Lake Mohave-Little Lake component; NEW, Newberry; HAI, Haiwee; MAR, Marana; FT, formal tool; CT, casual tool; DB,debitage; Coso?, denotes specimens with PPM values similar to,but not identical with, source standards established for theCoso volcanic field. Data derived from Basgall and McGuire(1988).

TABLE 3
PROPORTIONAL REPRESENTATION OF EXOTIC (NON-COSO) OBSIDIAN BY COMPONENT, CA-INY-30 (IN PERCENT)

	Combined Sample	Formal Tool	Casual Tool	Debitage
Lake Mohave-Little Lake	51.3	50.0	52.9	51.2
Newberry	36.3	42.3	0.0	22.1
Haiwee	25.6	25.0	—	26.7
Marana	15.0	17.0	—	12.5
All Components	28.3	32.3	23.7	26.1

Queen or Casa Diablo localities. Secondly, there is significant imbalance in the profiles between tools and debitage, 42% of the former deriving from non-Coso sources but only 22% of the chipping debris (Table 3). Lastly, "unknown" chemical types are conspicuous by their near absence in the sample; the group falls from 23% to 6% representation in the assemblage.

Haiwee and Marana Components

Given their similarities, source profiles for the Haiwee and Marana components are examined together. Both exhibit further shifts in obsidian acquisition/use patterns (Table 2). The overall representation of glass attributed to the Coso volcanic field increases, especially in the tool category. Source diversity remains essentially constant; however, more northern localities (i.e., in the Long Valley region) all but disappear from the assemblage. There is likewise better balance between the source profiles of tools and debitage, the proportion of "exotic" glasses varying by no more than 4.5% (Table 3). The "unknown" chemical types continue to occur in minimal quantities, constituting 10% of the Haiwee sample and only 3% of the Marana artifacts analyzed. Non-Coso obsidians comprise between 15% and 23% of the respective samples, but it may be significant that approximately one-tenth of this material can be traced to the Fish Springs locality (Tables 2 and 3).

Implications

The shifts apparent in the above source profiles have a number of implications for obsidian procurement and use patterns in southern Owens Valley. Perhaps the most striking aspect of the Lake Mohave/ Little Lake profile is the proportion of "unknowns" represented — 23% of the sample total. With the exception of the Komodo site (Mno-679) in Long Valley (see below), occurrence of geologically intractable obsidian appears to be relatively rare in the central-eastern California region; one of these glass types (Unknown #1) is present at Mno-679, the others remain apparently unreported. While it is, of course, risky to speculate on the disposition of such sources, the fact that the glasses have not been regularly encountered in the region suggests the possibility that some or all of them originate to the east (i.e., Nevada), areas more poorly documented geochemically. The large amount of Casa Diablo and Fish Springs obsidian in the early component (23%), together with traces of Truman/Queen and Bodie Hills material (4%), appears to reflect regularized interaction with areas to the north; the representation of Coso (49%) indicates contacts with the south. All in all, the Lake Mohave/Little Lake profile suggests lithic procurement over an extremely broad area, extending north-south for a distance of at least 265 km.

The fact that obsidian groups present in the Lake Mohave/ Little Lake assemblage generally occur in the form of both formal tools and debitage may indicate one of several things: first, that early populations were highly mobile, visiting numerous quarry areas frequently, but acquiring raw material within the matrix of an extensive subsistence-settlement system (i.e., an "embedded" strategy in Binford's sense); second, that these people made forays to a diverse set of quarry locations for the express purpose of procuring lithic raw materials (i.e., direct access); or third, that these groups were involved in formalized exchange relationships that regularly provided glass from many areas in an indirect fashion (i.e., formal social exchange).

In light of current data available concerning cultural adaptation during this temporal period, the first possibility seems the more likely. Lacking a developed midden and having only a sparse, functionally restricted artifactual inventory, the Lake Mohave/Little Lake component hardly appears consistent with the kind of centralization expectable were either regular forays made to procurement areas (with return) or materials being imported through exchange on a regular basis. Indeed, given the wide temporal range attributed to the early deposit at Iny-30, it almost certainly represents a palimpsest of residue discarded over several thousand years of time. Materials discarded during one episode reflect foraging near one quarry area (e.g., to the north), whereas those left during a later occupation relate to exploitation of entirely different resource areas (e.g., to the south or east).

Implications of the Newberry period obsidian assemblage are rather different. If it is assumed that some or all of the "unknown" glass types originate in the east, then their absence from the sample would seem to imply much reduced interaction with such areas. Instead, regular acquisition appears to have been along a north-south axis — a bipolar system, if you will. Further, the high proportion of "northern" tools (28%), but reduced amounts of debitage attributable to those sources, suggests that interaction with the Long Valley area was micro-temporally disjunct. This is to say that the debitage pattern (as that of casual flake tools), indicative of on-site production activities, is consistent with more immediate, perhaps regularized, access to glass from the Coso volcanic field.

Given that the overall Newberry period artifactual assemblage was characterized by a wider range of tool forms (including curated milling equipment), abundant ecofactual debris, and, most significantly, formal

TABLE 4
SOURCE COMPOSITION OF ARTIFACT SAMPLE FROM THE KOMODO SITE, CA-MNO-679

	Projectile Point	Biface	Uniface	Total
Casa Diablo	21	3	2	26
Truman/Queen	-	-	1	1
Mono Glass Mtn	1	-	-	1
Fish Springs	8	-	-	8
Unknown A	1	2	-	3
Unknown B	-	2	-	2
Unknown C	-	-	2	2
Total	31	7	5	4

Note: Unknown A at Mno-679 provides a chemical match with Unknown #1 at Iny-30; other "unknowns" from the two sites appear to be geochemically distinct. Data unpublished.

structures with evidence of caching behavior, it is tempting to view the north-south interaction in terms of redundant residential shifts that probably occurred on a seasonal basis; both climatic parameters in the two areas and diagnostic subsistence remains within the Newberry deposit (Basgall and McGuire 1988) suggest southern occupation during the warmer part of the year.

The Haiwee and Marana period source profiles exhibit the greatest degree of regularity. The reliance is on Coso, the nearest, high-quality obsidian, but the general balance between tools and debitage of all glass types indicates increased formalization of flaked lithic acquisition patterns. Were obsidian being procured primarily during the course of residential movements, tool and flake profiles would be expected to show greater divergence. This relationship is best illustrated in the case of Fish Springs material, which occurs in near equal proportions within both classes. The decrease in "unknown" glasses in the Marana sample likely reflects further reduction in the zone of regular interaction.

It is becoming increasingly evident that the resource intensification and settlement centralization characteristic of the historic period in Owens Valley (e.g., Steward 1933, 1938) emerged sometime after 1300 B.P. (Basgall and McGuire 1988; Basgall, McGuire, and Gilreath 1986; Bettinger 1977; 1982; 1989). The territorial control of Fish Springs obsidian reported by Bettinger (1982) in the Big Pine area begins about this time, and shell bead frequencies increase dramatically after 650 B.P. (86% of reported occurrences date to the Marana period; see, Basgall, McGuire, and Gilreath 1986). In all, it seems likely that the Haiwee and Marana source profiles follow from formalized exchange relationships, and reflect regularized social interaction with other Paiute populations to the north and Shoshone groups to the south (and, perhaps, east).

Long Valley Caldera

Attempts to develop reliable source profiles for the Long Valley locality are complicated by two factors: first, many of the sites that have been investigated in detail are aligned with major exchange-related obsidian production, and hence offer a poor reflection of more typical, intra-regional acquisition/use patterns; and second, with the exception of these stoneworking camps closely related to trans-Sierran exchange, few sites have been excavated which contain contextually sound, well-dated assemblages. Nonetheless, available data do provide a basis for characterizing some facets

TABLE 5
SOURCE COMPOSITION FOR PROJECTILE POINTS BY TEMPORAL PERIOD, LONG VALLEY CALDERA

	Lake Mohave	Little Lake	Newberry	Haiwee	Marana	Total
Casa Diablo	3	8	57	9	8	85
Truman/Queen	1	2	17	6	-	26
Mono Glass Mtn	-	2	8	-	2	12
Fish Springs	2	-	3	2	1	8
Mt. Hicks	1	-	1	-	1	3
Bodie Hills	-	-	3	-	-	3
Total	7	12	89	17	12	137

Note: Point forms are attributed to periods as follows: Lake Mohave, Great Basin Stemmed series; Little Lake, Little Lake series; Newberry, Elko and Humboldt series; Haiwee, Eastgate and Rose Spring types (Rosegate series); Marana, Desert Side-notched and Cottonwood types (Desert series). Data derived from Basgall (1983, 1984) and R. Jackson (1985).

of source structure.

CA-Mno-679

Geochemical and "megascopic" (Bettinger, Delacorte, and Jackson 1984) analyses have been performed on obsidian from the Komodo site. The x-ray fluorescence results display a number of parallels with the early, Lake Mohave/Little Lake component at Iny-30 (Table 4). In the first place, a large proportion (32%-60%) of the specimens within each of the artifact categories derive from non-local sources. Secondly, the source composition suggests considerable interaction with a number of areas (though the focus of stoneworking is clearly on retooling with local, Casa Diablo glass). And third, there is a significant representation of "unknown" obsidians in the assemblage (at 16%).

Unfortunately, no XRF data are available for debitage from the site, hence precise comparisons between tools and flakes are impossible. It is worth noting, however, that visual characterization of a sample from Mno-679 (following criteria developed by Bettinger, Delacorte, and Jackson [1984]) suggests that the representation on non-Casa Diablo obsidian is dramatically higher than at most, chronologically later sites studied in the caldera. It appears that at least Fish Springs, Truman/Queen, and one of the "unknowns" occur in the associated chipping debris (given limitations in visual characterization of small flakes, further sources could easily be present in the assemblage).

Other Data from Long Valley

A population of 137 projectile points (excluding those from Mno-679) from sites in Long Valley shows some basic shifts in source representation through time (Table 5). Although the sample of diagnostic points is limited for most temporal periods, available data document the most extensive use (57%) of non-local glass during the Lake Mohave interval (ca. 7000-5000 B.P.). Such obsidian originates at quarries located some 65 km to the north and 75 km to the south. If not a function of the increased sample relative to earlier periods, diversity in the Newberry sample may reflect an enlarged annual range and more frequent interaction with areas to the north (i.e., Bodie Hills and Mt. Hicks). Still, the fact that local glasses (i.e., Casa Diablo and Mono Glass Mountain) together comprise 73% of the total indicates regular tool replacement with raw materials from the caldera. Only during the Haiwee period is there a high proportion of "exotic" obsidian represented; 35% of the glass derives from Truman/Queen, 40 km to the northeast, and 12% from Fish Springs, some 75 km to the south.

Source data available for debitage assemblages across Long Valley consistently indicate that Casa Diablo, the local glass of choice, is the principal material being worked at virtually all sites during every time period (Table 6). It does appear to be the case that a larger number of "early" (Newberry and pre- Newberry) collections contain higher proportions of nonlocal obsidian, but the pattern is far from uniform. Samples from sites A61 and A60, for example, both with early components, contain no non-Casa Diablo glass. Since the analyzed flaking debris more often relates to tool production/replacement than refurbishment, heavy representation of Long Valley material is not unexpected.

Implications

Unevenness in the quality of source data for all periods and artifact categories in Long Valley preclude in-depth evaluation of acquisition and use patterns. Nonetheless, several trends are worth highlighting. Tools from pre-5000 B.P. components (at Komodo and points from the Lake Mohave interval) show a diversity of source types, many showing consistent representation. As with the Lake Mohave/Little Lake component at Iny-30, this profile probably relates to an extensive settlement strategy that regularly brought populations in proximity to a variety of raw material sources. That tools from distant quarries remained in the tool-kits suggests that they had been obtained relatively recently.

TABLE 6
SOURCE COMPOSITION OF DEBITAGE FROM SELECTED SITES IN LONG VALLEY CALDERA BY TEMPORAL PERIOD.

	Period	CD	QN	MGM	BH	UNK	Total
F160	LM	23	2	11	-	-	36
A60	LM-LL	22	-	-	-	-	22
A61	LL	15	-	-	-	-	15
Mno-529	N	98	-	1	-	1	100
Mno-561	N	63	-	2	-	-	65
Mno-1529	N	60	-	-	-	-	60
A33	N	46	3	1	-	53	53
A40	N-H	22	-	1	-	-	23
F149	N-H	16	-	10	-	-	26
Mno-714	H	15	-	-	-	-	15
A48	H	23	-	1	-	-	24
A43	H	28	-	-	-	-	28
A45	H	37	-	-	-	-	37
F156	H-M	23	2	3	-	-	28
A42	M	21	-	3	-	-	24
Total		512	7	35	1	1	556

Note: Age ascriptions are based on obsidian hydration data for specimens attributed to the Casa Diablo source; LM, Lake Mohave; LL, Little Lake; N, Newberry; H, Haiwee; M, Marana (two notations denote a temporally mixed assemblage); CD, Casa Diablo; QN, Truman/Queen; MGM, Mono Glass Mountain; BH, Bodie Hills; UNK, unknown. Data derived from Basgall (1983, 1984), Hall (1983), and R. Jackson (1985).

TABLE 7

SOURCE COMPOSITION OF OBSIDIAN SAMPLES FROM MNO-446

	Debitage		Projectile	
	0-50 cm	50+ cm	Point	Total
Bodie Hills	4	2	4	10
Mt. Hicks	1	-	-	1
Truman/Queen	-	1	2	3
Casa Diablo	14	27	4	45
MGM/MC	7	1	2	10
Unknown	-	-	1	1
Total	26	31	13	70

Note: Mono Glass Mountain and Mono Craters obsidian were not chemically distinguished in this study. Data from Bettinger (1981) and Hughes (1981).

Data for the Little Lake period in Long Valley (ca. 5000-3000 B.P.) are rather at odds with expectations: both tools and debitage reflect near exclusive use of local glass which, at face value, would imply marked residential stability. This, however, may largely follow from the small sample available for examination.

The pattern evident in points attributable to the Newberry period is, again, somewhat similar to that found at Iny-30. Glass was being obtained from a series of quarries some distance from the caldera, and the source composition is suggestive of an extensive subsistence-settlement system. Evidently, populations were interacting with areas 65-75 km to the north and south. The large proportion of Truman/Queen specimens present in the Haiwee period point sample, though not matched in debitage profiles, seems to indicate regular contact or movement between Long Valley and upland zones 40 km to the northeast. Given the rather ambiguous position of Long Valley vis-a-vis permanent occupation during the historic period (e.g., Basgall 1983; Hall 1983), it is possible that these materials were deposited by groups that typically resided in areas outside the caldera. Finally, Marana period profiles are consistent with primary reliance on local obsidian.

CA-Mno-446

Source profiles from Mno-446 exhibit some dramatic differences. Looking first at the debitage, the assemblage recovered from depths of greater than 50-cm (most of which dates to the Newberry period [3150-1350 B.P.], but some likely earlier) is dominated by glass from sources located to the south. Within this group, 87% of the obsidian derives from Casa Diablo, with trace amounts (3% each) originating at Truman/Queen and either Mono Glass Mountain or Mono Craters (see Hughes [this volume]). Only 7% of the obsidian debitage was attributable to northern localities, all from the Bodie Hills quarry (Table 7).

Although southern sources continue to dominate flaking debris from the uppermost 50 cm of site deposit (dated post-1350 B.P.), a significant proportion of the glass is traced to the north (Table 7). The representation of Casa Diablo material drops to 54%, and the Mono Glass Mountain/Mono Craters category comprises 27% of the assemblage. However, nearly 20% of the late prehistoric debitage is attributable to either Bodie Hills (15%) or Mt. Hicks (4%).

The projectile point profile is considerably more varied than that of the chipping debris from either temporal component. While southern source localities are also predominant, there is more even representation of the different quarries, and Bodie Hills provides its peak contribution of 31% of the total (Table 7). As well, the only "unknown" from the site occurs within the projectile point category (unfortunately, no data are available that might permit relating this chemical type to "unknown" glasses from previously discussed archaeological localities).

Implications

Bettinger (1981; Hughes and Bettinger 1984) has explored the implications of these data. With regard to shifts in the debitage profiles, he proposes that they reflect changing boundary conditions that caused a disruption in direct access to the Casa Diablo obsidian source. Two specific processes could account for these patterns: either some adjustment to the limits of a well-demarcated territory held by groups inhabiting Mono Basin proper; or, alternatively, some alteration to the annual foraging range of those populations (Hughes and Bettinger 1984:165). The later possibility is given greater credence insofar as there is no evidence to suggest that late prehistoric/historic populations in the Mono Basin were formally land-holding.

Chronologically later materials, showing an increased reliance on both more local glass (Mono Craters?) and northern quarries (Bodie Hills and Mt. Hicks), do appear to indicate less interaction with the Long Valley area, perhaps as a result of both increased volcanic activity and territorial control by resident groups (cf. Bouey and Basgall 1984; Hall 1983; 1984). It remains unclear, however, whether the subsistence-settlement system was drastically altered or direct access to Casa Diablo obsidian became increasingly restricted.

In accounting for divergence in the source profiles of projectile points and debitage during the pre-1350 B.P. period, it has been argued that the two artifact categories operated within separate "sociocultural" subsystems or matrices. The debitage is thought to represent "refuse of a utilitarian tool production system" expected to "conform to the principle of least effort" (Hughes and Bettinger 1984:168), and hence should be dominated by glass from the nearest source. By contrast, it is proposed that "individual hunters may have fashioned projectile points from obsidian obtained at sources near their places of birth, either because they were more familiar with (them) or because it was an act of socioreligious significance" (Hughes and Bettinger 1984: 168). In this case, source variability follows from non-virilocal post-marital residence patterns.

Viewed from the perspective underpinning the present examination, it seems far more likely that the greater diversity of glass types in the Mno-446 projectile point assemblage relative to associated debitage is a function of disjunctions in raw material procurement episodes. That is, materials represented in the tool class (92% of which are small, spent, proximal fragments; see Bettinger [1981:27, Figure 6]) were acquired during an earlier portion of the foraging cycle, being discarded during retooling activities and replaced with points produced from more recently acquired glass. The large proportion of items made from obsidian originating to the south (67%) suggests that access to the Long Valley area was temporally proximal, which may also account for the high percentage of Casa Diablo glass in the flake assemblage. In sum, it is unnecessary to posit the existence of elaborate sociological processes to account for the disparity in point and debitage source profiles. Indeed, both artifact categories represent utilitarian products and would, ceteris paribus, be expected to move within the same "sociocultural" context.

CONCLUDING OBSERVATIONS

This preliminary characterization of diachronic variability in obsidian acquisition and use within central-eastern California has shown that source diversity for earlier temporal periods appears to be, in general, greater than later in the occupational sequence. It has been suggested that this reflects the existence of relatively more mobile, extensive subsistence-settlement systems that brought groups in proximity to a wider range of lithic resources during their annual foraging cycle. Within later time periods, there is more regular use of obsidian from nearby sources. Such a pattern is probably tied to the concomitant emergence of intensive land-use strategies (including pronounced territorial control) and formalized intergroup exchange relationships. Distant lithic resources were increasingly brought to consumers rather than the reverse. Further evaluation of prehistoric obsidian dispersion within central-eastern California, using enlarged samples from a greater number of archaeological contexts, will no doubt amplify and refine the patterns identified in the present study.

Two final observations, methodological in scope, are in order. The behavioral reconstructions offered in this paper are heavily dependent on source analysis of multiple artifact classes, minimally involving both formalized tools and unmodified chipping debris. A number of previous studies have demonstrated that different artifact types often have dramatically divergent source profiles. In northwest California and southwest Oregon, for example, Hughes (1978; Hughes and Bettinger 1984) has shown that large blades inferred (on the basis of ethnographic counterparts) to have operated within "socioceremonial" spheres were consistently manufactured from obsidian originating at great distance from their final context, whereas utilitarian tools (i.e., typical bifaces and projectile points) derive from quarries more proximal to the subject sites. The use of "exotic" glass in the former group is thought to reflect strictures on blade coloration, as well as a greater "worth" attributed to more costly, difficult to obtain material. In this case, a sociological argument (bolstered by a specific ethnographic analog) provides a seemingly parsimonious explanation for observed discontinuities in source representation. However, in other cases where similar proposals have been made — such as that outlined by Bettinger (1981; Hughes and Bettinger 1984) to account for diversity in projectile point and debitage profiles in central-eastern California — recourse to such arguments is unnecessary and almost certainly misleading. Rather, source variation is more effectively viewed as a consequence of settlement and technological organization (e.g., Bamforth 1986; Basgall and McGuire 1988; Basgall, Hall, and Hildebrandt 1988; Gramly 1980; White 1984). It is emphasized that in neither case would it be possible infer the specific processes involved without examining multiple kinds of artifactual residue.

A second observation relates to the importance of identifying the mode of lithic acquisition operative within a given archaeological context. An extremely mobile, wide-ranging subsistence-settlement adaptation is capable of producing relatively great geographic displacement in lithic raw materials in the absence of trade or formalized, intergroup exchange. As one means of approaching this problem, it has been argued here that exchange-related acquisition will be marked by the regularized occurrence of source types, and by their equitable representation in both tool and waste classes. Alternatively, incidental procurement carried out in the context of settlement relocation will be reflected by disjunction in the source profiles of tools and debitage. Distant material sources (exploited at an earlier stage of the foraging cycle) will occur primarily in the form of broken, reworked, and expended tools, whereas more proximal sources (presumably visited more recently) will be represented by more serviceable tools and manufacturing residues.

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