A Reassessment of Obsidian Hydration Ages of Projectile Point Types from the Coso Volcanic Field

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Abstract

Data relating projectile point types, obsidian hydration, and radiocarbon dating of artifacts from the Coso Volcanic Field have played a significant role in reconstructing cultural sequences in the western Great Basin and Mojave Desert. This paper re-evaluates the obsidian hydration data published by Gilreath and Hildebrandt (1997) in light of better estimates of effective hydration temperature, and concludes that the previously assessed ages are too young, sometimes by significant amounts. This affects assessments of the time of introduction of the bow and arrow, which appears to be 2000+ rcybp instead of the conventionally-assumed 1500 rcybp.

Introduction

Gilreath and Hildebrandt (1997), in their comprehensive study of obsidian use at the Coso Volcanic Field, have provided a widely-used data base for Coso obsidian studies. Their research related, *inter alia*, projectile point types with obsidian hydration measurements and radiocarbon ages. In particular, their data have been used to infer the periods of use of various projectile point types in the Coso region.

It has long been known that obsidian hydration is a temperature-sensitive process, (e.g., Friedman and Long, 1976), so it is necessary to take account of temperature in comparing hydration rims between sites. The analysis by Gilreath and Hildebrandt employed the best information and methods available at the time for including the effects of temperature; however, subsequent developments in the theory of hydration have indicated that their temperature assumptions were incorrect. This paper reports a correction to the temperature calculation, and reanalyzes the hydration rim data in this light.

Background to the Issue

Studies of Coso obsidian hydration typically take the Lubkin Creek site (CA-INY-30) as the reference site, which lies at an altitude of approximately 3000 feet above mean sea level (amsl). Gilreath and Hildebrandt (1997) assumed that the effective hydration temperature (EHT) difference between sites would be roughly proportional to the difference in mean annual temperature of the sites. They used a mean annual temperature of 13.5° C for Lubkin Creek, and 15.7° C for Haiwee, and further assumed that the temperature at Haiwee represents that at the Coso Volcanic Field (Gilreath and Hildebrandt 1997:16, also 164, Table 83). Based on these assumptions, they computed a rim correction factor of 0.8723, using the methodology of Basgall (1990) (Gilreath and Hildebrandt 1997:16). Since they assumed the Coso Volcanic

Field temperature to be 2.2° C *warmer* than the reference site, hydration would proceed more rapidly and any rim at Coso would correspond to a *younger* age than the same rim at Lubkin Creek. However, it is shown in this study that the temperature assumption is incorrect, and the Coso Volcanic Field is actually 3.1° C *cooler* than Lubkin Creek. This implies that hydration would have proceeded more slowly at Coso than at Lubkin Creek, which significantly alters the ages assigned to the rims.

Gilreath and Hildebrandt also used the Basgall equation for converting rim thickness to age (Gilreath and Hildebrandt 1997:16). Although this equation is not supported by physical theory, and gives excessively old ages for large rims, it does not differ significantly from the quadratic form for more recent ages. This equation is not the source of the problem here.

Theory

Obsidian Hydration

The use of obsidian hydration to estimate age of an obsidian artifact was first suggested by Friedman and Smith (1960). Hydration of obsidian has both a physical and a chemical aspect, and is known as a diffusion-reaction process (Doremus 1994, 2000, 2002). All that is known of the physics and chemistry of the process suggests the relationship between age and rim thickness should be quadratic, i.e., of the form

$$x^2 = Dt \qquad (1)$$

where t is age in calendar years, x is rim thickness in microns, and D is a constant, the diffusion or hydration coefficient (e.g., Ebert, Hoburg, and Bates 1991; Zhang, Stolper, and Wasserburg 1991; Doremus 2000, 2002; Stevenson, Carpenter, and Scheetz 1989; Stevenson, Mazer, and Scheetz 1998). No other form of functional dependence is currently suggested by theory; Haller observed in 1963 that, if any dependence other than quadratic is found, “it is more likely the fault of the experiment rather than any inherent feature of the diffusion process” (Haller 1963:217). When obsidian data are expressed in radiocarbon years before the present (rcybp, by convention referenced to 1950), the quadratic form is still the best fit, giving the smallest overall error in age estimation, but the rate constant is different (Rogers 2006).

The hydration coefficient varies with effective hydration temperature, or EHT (e.g., Hull 2001; Ridings 1996; Rogers 2007a; Stevenson et al. 1989, 1998, 2004; Onken 2006), with relative humidity (Friedman et al. 1994; Mazer et al. 1991; Onken 2006; Rogers 2008a), and with structural water concentration in the obsidian (Ambrose and Stevenson 2004; Rogers 2008b; Stevenson et al. 1998, 2000).

Rogers (2007a) developed a rigorous solution to the time-varying temperature case, and further developed an algebraic model to compute EHT from annual temperature and annual and diurnal variation. These models are the basis of the present study.

The analysis reported in Rogers (2007a) employed a simplified climatic model to represent climate over archaeological intervals. The temperature model is based on three parameters: T_a, the annual mean temperature; V_a, the annual temperature variation (July mean - January mean); and V_d, the mean diurnal temperature variation (average of January and July). These parameters are derived from measured meteorological data from the web sites of the Regional Climate Centers.

An algebraic equation was developed to fit the computer model output data to facilitate practical computations by the archaeologist (Rogers 2007a):

$$\mathrm{EHT} = T_a(1 - 3.8\times10^{-5}y)+0.0096\, y^{0.95} \qquad (2a)$$

where T_a is annual average temperature, and y is the sum of the squares of the annual and diurnal temperature variation constants, modified for depth, or

$$y = (V_a^2 + V_d^2) \qquad (2b).$$

For buried artifacts, V_a and V_d represent the temperature variations at the artifact depth, which are related to surface conditions (V_{a0} and V_{d0}) by (Carslaw and Jaeger 1959:81)

$$V_a = V_{a0}\exp(-0.44z) \qquad (2c)$$

and

$$V_d = V_{d0}\exp(-8.5z) \qquad (2d)$$

Here z is burial depth in meters. The numerical parameters in equations 2c and 2d are based on recent measurements by the author in desert conditions.

Once EHT has been computed, the measured rim thickness is multiplied by a rim correction factor (a) to adjust the rims to be comparable to conditions at a reference site:

$$R = \exp[-0.06(\mathrm{EHT}-\mathrm{EHT}_r)] \qquad (3)$$

where EHT_r is effective hydration temperature at the reference site (usually Lubkin Creek, CA-INY-30, for Coso obsidian).

Onken (2006) has suggested that the temperatures used in equations 2 and 3 ought to be surface temperatures, not the air temperatures reported by meteorological services. However, surface temperatures at brush-covered sites approximate the air temperatures, so air temperatures are used here. Furthermore, Rogers (2008c) has shown that EHT differences between sites can be computed with either air temperatures or surface temperatures, as long as they are used consistently.

It has been shown that depth correction for EHT is desirable, even in the presence of site turbation (Rogers 2007b). Burial depth of the obsidian samples in this analysis was not reported, so depth was assumed to be zero, and all the samples were assumed to have been exposed to the same relative humidity.

For this study the equation used to compute age is

$$t = 38.34(xRP)^2 \qquad (4)$$

where t is age in rcybp, x is mean rim thickness in microns, R is the rim correction factor for present temperature conditions (equation 3), and P is the paleoclimatic correction described below. Equation 4 was derived from a data set of 21 radiocarbon-obsidian correlations, in which the obsidian readings were corrected for EHT, including burial depth, local temperature conditions, and paleoclimatic shifts (Rogers 2008d).

The rate constant in equation 4 reflects a mean for obsidians of the Coso Volcanic Field at an EHT of 20.4° C. It has been shown that there are rate variations between sub-sources in the Coso field (Fredrickson et al. 2006), but they were not used here, for two reasons. First, obsidian samples in Gilreath and Hildebrandt (1997) were not identified to sub-source, and second, identifying to subsource is not, in itself, a good predictor of hydration rate. Stevenson, Mazer, and Scheetz (1998) showed that hydration rate is strongly influenced by the hydroxyl ion concentration of the obsidian, which in turn is determined by the intrinsic water content (Silver, Ihinger, and Stolper 1990). Furthermore, Stevenson et al. (1993) showed that the Coso sub-sources exhibit great internal variability in water content, such that determining a sub-source is not, in itself, sufficient to predict hydration rate for any particular specimen (Rogers 2008b; Stevenson, Gottesman, and Macko 2000). Unfortunately there is at present no cost-effective and robust method of determining structural water content in archaeological samples, and the Gilreath and Hildebrandt (1997) samples are no longer extant in any case. Since the variability imposed by hydroxyl concentration is at present uncontrollable, the approach taken here is to acknowledge the existence of variability and treat it statistically (Rogers 2008b).

Site Formation

It is known that the EHT to which an artifact was exposed is a function of the burial depth of the artifact, and ideally it should be corrected to surface conditions prior to analysis. Rogers (2006a, 2007a, 2007b) proposed a mathematical technique for performing these calculations. However, vertical mixing of artifacts during site formation is a fact of life; it can often be severe, and would be expected to perturb any depth correction. This raises the question of how site turbation affects obsidian hydration dating.

The effects of site formation processes have been estimated by a simulation-based study of obsidian hydration dating, for cases on no mixing, moderate mixing, and complete mixing (Rogers 2007b). The data showed that long-term stability of a site, followed by rapid mixing, is the worst case for obsidian hydration dating. Frequent mixing of a site had little effect on hydration rate, probably because the positive and negative perturbations approximately compensate for one another. Further analysis of the simulation data showed that applying a rim correction to each artifact based on its depth of recovery is, on the average, the best chronological analysis strategy, even in cases of extreme mixing. For cases where data are to be aggregated, this strategy will lead to improvement in the mean of the rim data relative to use of uncorrected rim data; for individual artifacts it will lead to better rim estimates on the average (Rogers 2007b), although the benefits for any specific artifact are indeterminate.

In the case of the present study, no data on burial depth were available for the sample set, so surface conditions were assumed. Furthermore, the Coso Volcanic Field is geothermally active, which can perturb the depth correction for EHT. Both of these considerations constitute a limit to the absolute accuracy of the present analysis; however, the analysis of Gilreath and Hildebrandt (1997) is subject to the same limitations, so any overall shift in ages demonstrated in the present analysis probably represents a real phenomenon.

Temperature Analysis

Current Temperatures

Computation of EHT by the method described above requires the three temperature parameters for the site, annual average temperature (T_a), annual temperature variation (V_a), and mean diurnal variation (V_d) (Rogers 2007a). Frequently there are no long-term meteorological records for the immediate area of an archaeological site, so the parameters must be scaled from surrogate sites which lie in a similar weather pattern and do have records. This is the case for the Coso Volcanic Field.

Table 1. Sites used in temperature analysis.

Station	Alt, ft	Ave Max, deg F	Ave Min, deg F	Annual Ave, deg F	Jul Max, deg F	Jul Min, deg F	Jan Max, deg F	Jan Min, deg F	Ta, deg C
Baker	940	86.2	54.0	70.1	110.0	74.9	63.4	34.9	21.17
Trona	1700	80.1	54.0	67.1	102.0	73.6	59.0	36.1	19.47
Daggett Airport	1930	81.7	54.4	68.1	104.2	73.4	61.3	37.5	20.03
Cantil	1960	80.1	47.5	63.8	104.3	69.2	58.9	28.9	17.67
Barstow	2140	79.8	47.1	63.5	101.9	66.0	60.2	31.7	17.47
China Lake Airfield	2240	80.5	47.0	63.8	100.6	67.2	59.9	32.3	17.64
Inyokern	2440	80.9	47.4	64.2	102.4	65.9	60.5	31.1	17.86
Mojave	2740	75.9	49.5	62.7	96.6	68.3	57.7	33.6	17.06
Haiwee	3282	73.6	45.1	59.4	95.7	63.8	52.7	29.1	15.19
Randsburg	3570	74.7	50.5	62.6	97.4	67.6	54.3	36.4	17.00
Wildrose	4100	72.3	45.2	58.8	95.0	63.4	51.6	30.1	14.86
Mtn Pass	4740	70.7	45.0	57.9	92.3	65.3	51.1	29.4	14.36
WhiteMtn	11811	46.7	20.4	33.6	66.6	37.0	33.5	8.6	0.86

For sites in the same circulation patterns, altitude is the dominant parameter affecting temperature, so scaling was done by altitude. The parameters must be computed from a sufficiently long run of data to be representative of long-term climate. Sensors emplaced at a site do not provide this, so all of the computations discussed here are based on data covering a period of 30 years, in accordance with standard meteorological practice (Cole 1970). All the temperatures used in this study are air temperatures, measured five feet above the ground in an enclosure which shelters the sensor from direct sunlight, again normal meteorological practice.

Rather than scaling from a single site, this analysis is based on data from 13 sites in similar weather patterns in the northern Mojave Desert and Southwestern Great Basin (Table 1). Monthly temperature data were obtained from the Western Regional Climate Center (WRCC), using the data base from 1971 – 2000. (The temperatures presented in Table 1 are in degrees Fahrenheit, as they reflect the meteorological data.)

The values of T_a, V_a, and V_d were computed for each site, and a least-squares fit made against altitude (Analytical details are in Rogers 2007c). The annual average temperature was shown to decrease by 1.8° C per 1,000 feet altitude increase, which is within the limits of measurement error for the mean adiabatic lapse rate. It was also shown to be predicted by the equation

$$T_a = 22.25 - 1.80x \tag{5}$$

where x is altitude in thousands of feet. The accuracy of this model is 0.79° C, 1-sigma, for the data set of Table 1.

The annual temperature variation was found to decrease by 1.7° C per 1,000 feet altitude increase, and to be predicted by

$$V_a = 22.63 - 1.70x \tag{6}$$

Table 2. Coso Volcanic Field hydration rim statistics.

Type	N	Uncorrected, u		EHT-corrected, u		
		Mean	St Dev	Mean	St Dev	CV
Desert Series	12	3.0	1.2	3.7	1.5	0.41
Saratoga Spring	6	4.8	0.8	5.8	1.0	0.17
Rose Spring	20	5.2	0.8	6.3	1.0	0.15
HBN	8	6.3	1.0	7.7	1.2	0.16
Elko Series	22	7.5	3.1	9.2	3.8	0.41
Gypsum	4	10.1	2.2	12.1	2.6	0.22
Leaf	6	11.1	4.0	13.1	4.7	0.36
GBS	21	12.9	2.7	15.4	3.2	0.21
Little Lake/Pinto	12	14.2	4.3	17.2	5.2	0.30
GBCB	2	17.3	5.4	20.9	5.4	0.26

with x defined as above. The accuracy of the prediction is 0.76° C for the data set of Table 2. Furthermore, if T_a is known for a site, V_a is predicted by

$$V_a = 1.65 + 0.94T_a \tag{7}$$

The accuracy of this predictor is 0.27° C, for the data set of Table 1.

The best fit between V_d and altitude is poor, and, in the absence of other data about a site, the best estimate is 15.8° C for locations encompassed by the area of the data set of Table 1 (i.e., the western Great Basin and deserts). The accuracy of this estimate is 1.79° C, 1-sigma.

The reference site for Coso obsidian is conventionally taken to be that of Lubkin Creek, or INY-30; correcting the rim to INY-30 allows direct comparison of EHT-corrected rim data with other published data. The altitude of Lubkin Creek is approximately 3000 feet amsl. Equations 5 and 6 (or 7) then yield an annual mean temperature of 16.9° C, an annual variation of 17.5° C. Using a mean diurnal variation of 15.8° C, equations 2a and 2b give an EHT of 20.4° C.

The altitude at the Coso Volcanic Field is approximately 4500 feet amsl. Using these same equations yields an EHT of 17.2° C. Thus, since the Coso Volcanic Field is higher than the Lubkin Creek site, the EHT is less; the resulting rim correction factor, per equation 3, is 1.21. This contrasts with the value of 0.8723 used by Gilreath and Hildebrandt (1997:16).

Paleotemperature

It is known that mean temperature has varied over archaeological time scales (Fig. 1), which would affect the hydration rate of obsidian. The analysis leading to equations 2a – 2d assumes T_a, V_a, and V_d are stable; however, if the parameters change slowly over time, the effect can be approximated as a series of stepwise changes and equation 2a – 2d can still be employed to compute EHT. Mathematical details of the analytical technique are developed in Rogers 2007d.

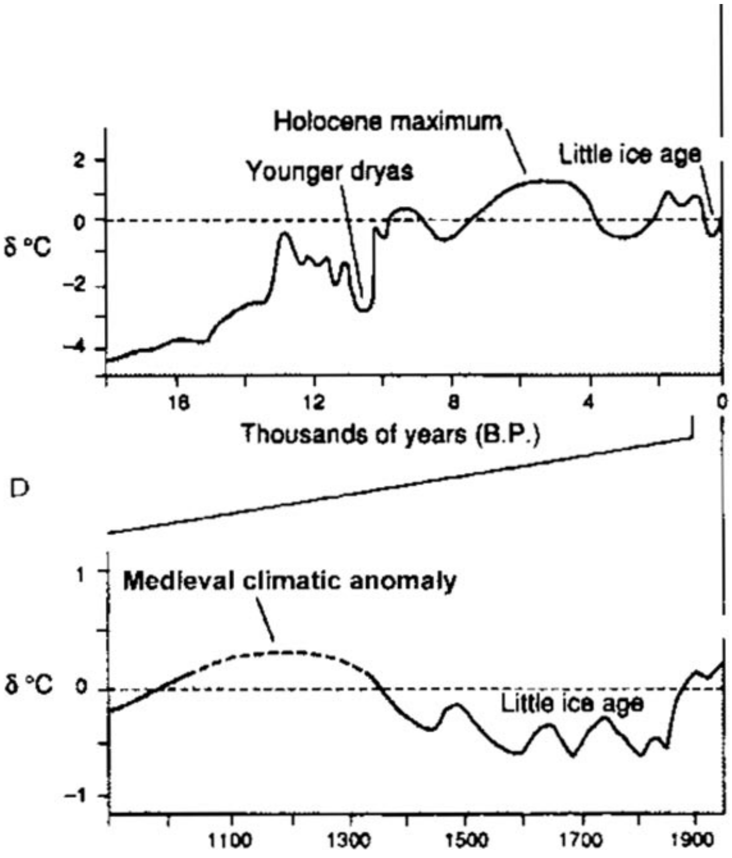

Fig. 1. Generalized global temperature profile (West et al. 2007:17, Fig 2.2).

A temperature history is the critical input needed for calculation of EHT and of effective hydration rate. Numerical estimates of mean temperatures for past 18,000 years were derived from those presented in West et al (2007:17, Fig. 2.2), which are based on landscape-level multiproxy data. Variations in mean annual temperature were read from Figure 1 at 500-year intervals (50-year intervals for ages less than 1000 years) to create the numerical temperature model. Annual variation was computed from equation 7, and mean diurnal variation was set equal to 15.8°C. The computations of hydration rate and rim correction factor as a function of time were implemented in MatLab 5.3; note that in this case the rim correction factor is a paleoclimatic adjustment to the rim correction factor computed for present conditions from equation 3.

Computations for the EHT adjusted rims and ages for this study include both the present-day EHT and the paleoclimatic adjustment. The paleoclimatic adjustment factor is relative small, generally under 3% in hydration rate, which corresponds to 6% in age.

Obsidian Analysis

Mean and Accuracy

The obsidian data reanalyzed here are those of Gilreath and Hildebrandt (1997:73, Table 16), which summarize the hydration data for 12 point types, spanning Paleoindian times (Great Basin Concave Base) to late prehistoric (Desert Series). The total set includes 113 valid data points. The data as reported are rims without EHT correction. Sources, provenience, and burial depth were not reported, so for analysis purposes the artifacts are assumed to be surface finds, with hydroxyl chemistry characteristic of the volcanic field as a whole.

Table 3 presents the statistics for the original rim data, comparing the uncorrected rim readings with EHT-corrected readings (based on a rim correction factor of 1.21 and a paleoclimatic adjustment). The significance of this comparison is that the EHT-corrected rims are what would be expected had the specimens been found at Lubkin Creek. Note the significant shift to larger rims.

Table 3. Hydration rim values in microns corresponding to period boundaries. Rim values uncorrected, Coso conditions.

Age, RCYBP	G&H	This Study
650	4.2	3.3
1350	5.8	4.9
3300	8.5	7.8
600	11.0	10.5

Gilreath and Hildebrandt (1997:83, Fig. 19) also presented a plot of the uncorrected rim data, with chronological boundaries superimposed. The boundaries were computed from Basgall's equation (Gilreath and Hildebrandt 1997:16)

$$t = 31.62(xR)^{2.32} \qquad (8)$$

where t is in rcybp, R is the rim correction factor (0.8723), and x is the uncorrected rim in microns. However, as discussed above, the rim correction factor employed by Gilreath and Hildebrandt is incorrect, which leads to incorrect placement of the chronological boundaries. When the correct rim correction factor is employed, the effect is to shift the boundaries downward, so that a given age corresponds to a smaller rim value. Figures 2 and 3 show this effect graphically. In this case the chronological boundaries are computed by the equation 4 above with R = 1.21 and a paleoclimatic adjustment. Table 3 summarizes the boundary point shifts numerically; the rim values represent uncorrected rims under Coso climatic conditions.

These changes in rim correction factor also affect ages assigned to the hinge points, the rim values that characterize the various point types. Table 4 gives the mean and standard deviations (sd) for the Coso Volcanic Field sample; the ± 1-sd deviation ages are the ages corresponding to the ± 1-sd rim values, and hence are not symmetric about the mean. The columns labeled "G&H" are computed by equation 7 and the R value of 0.8723, while those of "This Study" are computed by equation 4, a present rim correction factor of 1.21 with a paleoclimatic adjustment.

Again, the shift of point types to earlier ages is observable. Although most ages are reasonable, it is notable that neither method gives reasonable values for the oldest points, the Little Lake/Pinto and the GBCB types, for reasons which are not clear. The GBCB sample size is very small (N = 2), and the standard deviation is very large, so little credence should be attached to the GBCB data. The Little Lake/Pinto sample, however, is large enough (N = 12) to dispel sample-size concerns. The few points of this type illustrated in Gilreath and Hildebrandt (1997:79, Plate 6, g – m) suggest very crude workmanship and primarily percussion flaking, and appear to be more "Pinto" than "Little Lake" in morphology, which may indicate very old points.

As a further complicating factor, Gilreath and Hildebrandt did not specify the provenience of the individual points. It is known that geothermal activity at Coso causes elevated ground

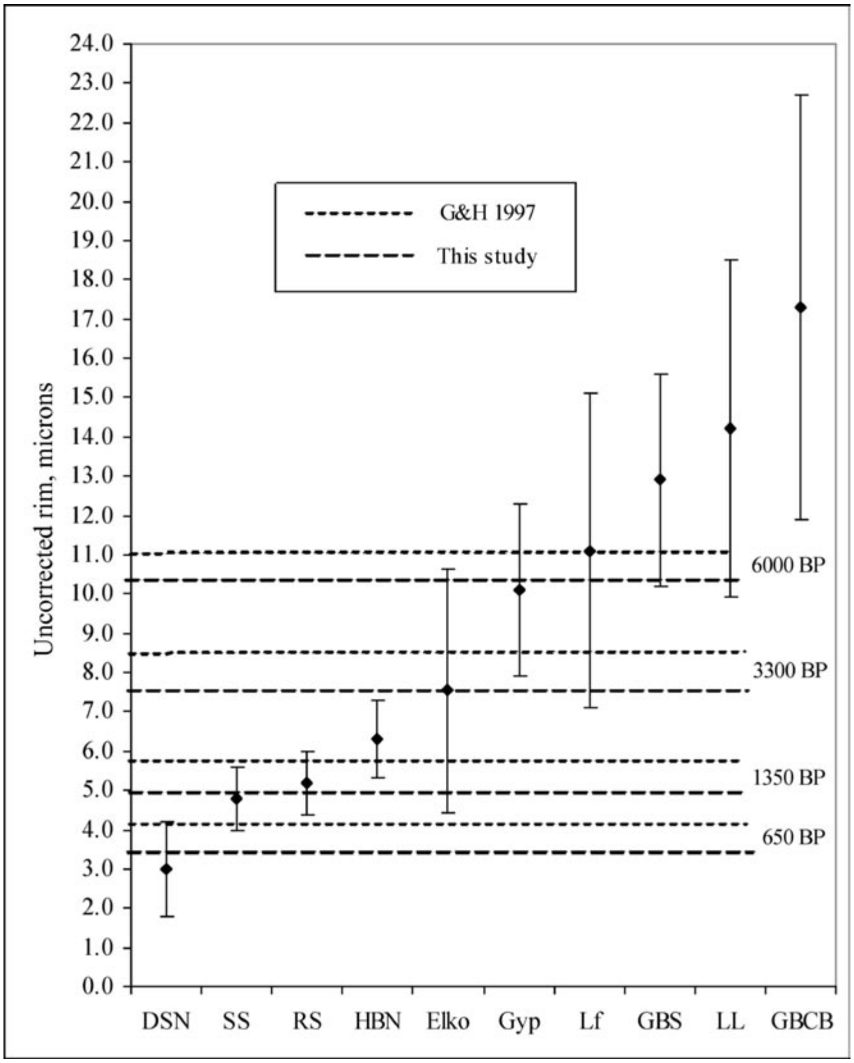

Fig. 2. Coso Volcanic Field hydration rim data and chronological boundaries. Boundaries labeled "G&H" were computed from equation 8 with rim correction factor R = 0.8723. Boundaries labeled "This Study" were computed from equation 4 with the correct rim correction factor (1.21) and paleoclimatic correction.

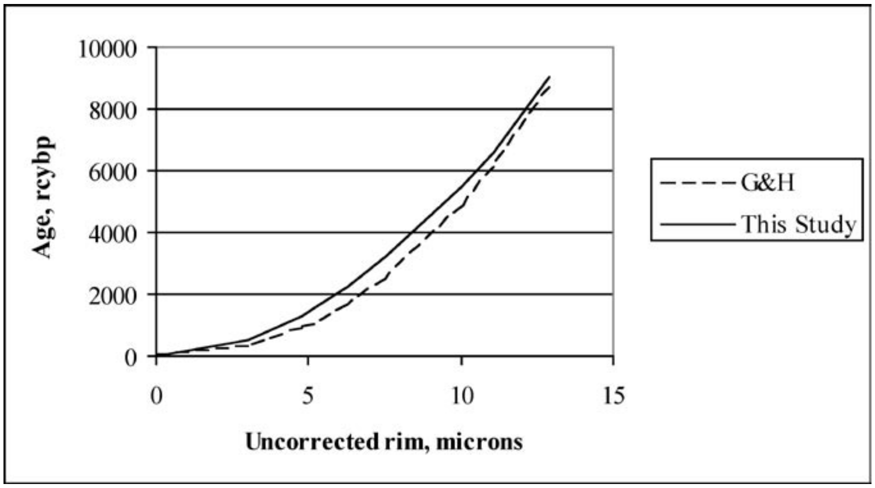

Fig. 3. Comparison of ages inferred from rim readings, "G&H" data employ a rim correction factor of 0.8723 and equation 8; "This Study" data employ a rim correction factor of 1.21 and equation 4.

Table 4. Age means and standard deviations for Coso Volcanic Field.

Type	N	Ages, rcybp, G&H			Ages, rcybp, This Study		
		Mean-1sd	Mean	Mean+1sd	Mean-1sd	Mean	Mean+1sd
Desert Series	12	90	295	643	105	526	947
Saratoga Spring	6	574	877	1253	869	1304	1739
Rose Spring	20	716	1055	1471	1061	1532	2003
HBN	8	1103	1647	2319	1543	2261	2979
Elko Series	22	713	2469	5520	562	3242	5922
Gypsum	4	2785	4924	7778	3145	5573	8001
Leaf	6	2174	6130	12518	1846	6610	11374
GBS	21	5038	8687	13501	5267	9060	12853
Little Lake/Pinto	12	4701	10855	20051	4472	11341	18210
GBCB	2	7204	17162	32232	8050	16778	25506

temperatures in some areas, including a few where temperature increases with depth. If some of the point specimens were recovered from such areas, the anomalously large rims might be explained.

For comparison, the ages computed for Little Lake points from a nearby site (Ayers Rock, CA-INY-134) exhibit a mean age of 6944 rcybp, with a point estimate accuracy of ±800 rcy, and a sample standard deviation of 2500 rcy, based on a sample size of 17. The Ayers Rock ages are in the expected range, while the ages from the Coso Volcanic Field are not.

The case of the arrow-size points (Desert Series, Saratoga Spring, and Rose Spring) is especially interesting, since the age of the Rose Spring points may shed light on the time of introduction of the bow and arrow. The new rim correction factors developed in this study shift the estimated ages to earlier times, as shown in Figure 4. The mean age of the Rose Spring points was computed to be 1055

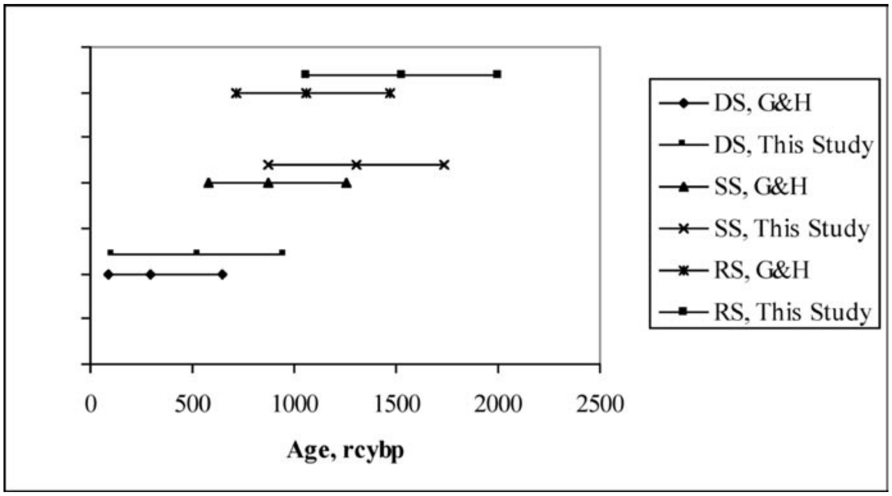

Fig. 4. Ages computed for arrow-size points from the Coso Volcanic Field, showing effect of correcting the temperature assumptions.

rcybp by the method of Gilreath and Hildebrandt (1997), with a standard deviation of 378 rcy. By the corrected method of this study the mean age is 1532 rcybp, with a point-estimate accuracy of approximately ± 155 rcy. The standard deviation of the Rose Spring sample is approximately 471 rcy, with a sample size of 20. If we assume that the age of the mean plus one standard deviation is representative of the age of initial use, this implies a time of introduction of 2003 rcybp (as opposed to 1471 rcybp by the method of Gilreath and Hildebrandt). In contrast, the Rose Spring/Eastgate points from Ayers rock are somewhat later, with a mean age of 1072 rcybp, a point estimate accuracy of ±176 rcy, and a sample standard deviation of 495 rcy, based on a sample size of 8.

Variability

The process of analyzing the obsidian specimens has controlled for four sources of variability. First, the source has been determined to be Coso, although the specific flows are not matched with the specimens. Second, the process of assembling the data in Gilreath and Hildebrandt has eliminated data points which are obvious outliers, and, third, those which were questionable due to poor readability (such as diffuse rims). Finally, EHT and paleoclimate have been controlled by computation.

The remaining variability within the sample set arises from one or more of four causes. First, the published report by Gilreath and Hildebrandt did not identify specimens by flow; significant chemistry variations (hydroxyl ion) exist between flows, and these variations cause variations in hydration rate (Rogers 2008d). The coefficient of variation (CV, standard deviation normalized to the mean) expected in rim thickness due to hydroxyl variability ranges between 0.07 for the Sugarloaf Mountain flows to 0.25 for West Cactus Peak; the composite for the field is 0.21 (Rogers 2008d). Thus, even if all the material used for a specific point type originated from the same flow, we do not know which flow it was. Second, and related to this, the material used for a specific point type was possibly mixed, from different flows, thus introducing further variability. Since the specimens were not matched with flows, the relative proportions of the mix are not known. Third, and of obvious archaeological interest, some of the variability may not be due to chemistry at all but to tool manufacture over an extended period of time. Finally, and an issue which cannot be controlled, some unexpected phenomenon may have occurred, such as a fire or a geothermal event; this possibility is not considered further here.

When the CV of the hydration rim data is sorted by age, no obvious trends result (Fig. 5), and analysis shows that there is no regular variation of CV with sample size. However, in Figure 6 the point types have been arranged in order of increasing CV, which does reveal two patterns. First, the point types on the left (Elko Thin, Elko Side-Notched, Rose Spring, Humboldt Basal-Notched, and Saratoga Spring) are all relatively young. They exhibit CVs which are smaller than the field as a whole, suggesting a preference for Sugarloaf Mountain tool stone and possibly shorter occupation spans. The other points on the right, except the Desert Series, are considerably older point types. Since there is no reason to expect the rim CV due to chemistry to increase with age, the larger CVs for these points may indicate manufacture over extended periods of time.

The Desert Series data are anomalous, having the largest CV in the data set as well as the youngest age. The cause is not clear, but it cannot be entirely accounted for by chemistry. If the original provenience data were available it might be possible to identify whether geothermal activity was responsible, but such is not the case. A histogram

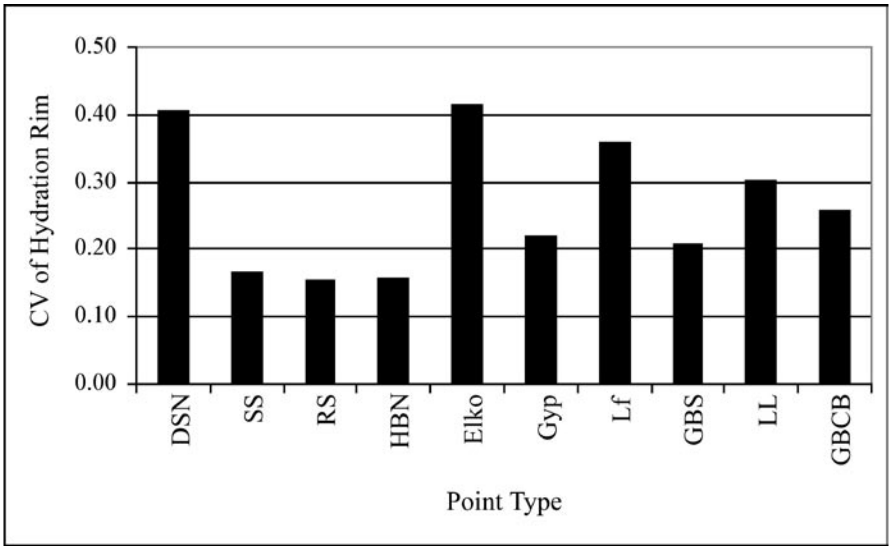

Fig. 5. Hydration rim CV by point type. CV due to obsidian chemistry ranges from 0.07 to 0.25, with a composite value for the Coso Volcanic Field of 0.21.

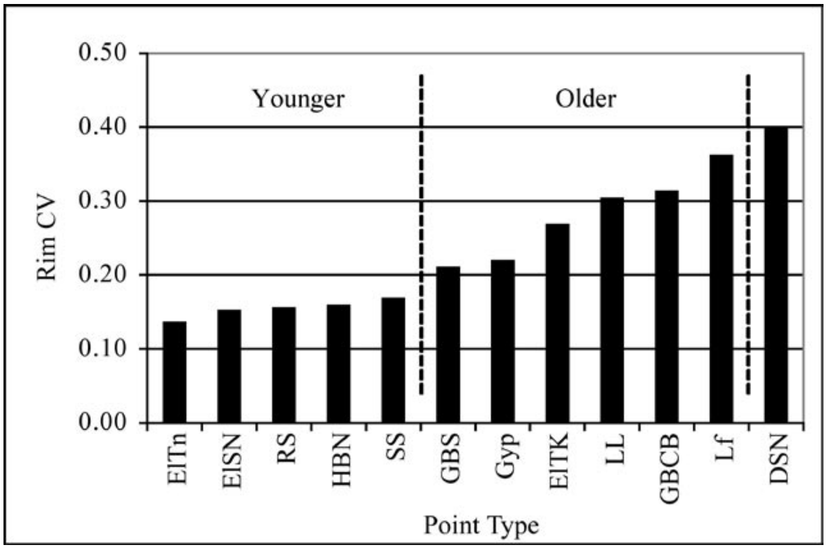

Fig. 6. Hydration rim CV arranged in ascending order. Note older points fall on the right, except Desert Series, which is anomalous.The Elko series is broken down as follows: ElTN = Elko thin; ElSN = Elko side notched; ElTK = Elko thick, as defined by Gilreath and Hildebrandt 1997.

of the Desert Series rims gives the appearance of two superimposed data sets with a gap between; statistically, the distribution has a long "tail" on the positive side of the mean.

The same phenomenon was found with the Desert Side-Notched and Cottonwood Triangular data sets at Ayers Rock (CA-INY-134). In this case the two point types were statistically indistinguishable at the 95% confidence level, and both exhibited outlier points on the high side. This high-side outlier phenomenon is partly explained by physics: the distribution can never be more than approximately normal, because it is cut off at zero on the low side while it is unconstrained on the high side. Put another way, no rim can ever be less than zero, but there is no statistical limit to how large it can be. This effect would be expected to appear more prominently with small rim values, because the mean is close to zero and there is less room on the low side of the mean, so it may be an expected phenomenon for late-period points.

The tail on the high side of the mean may also be at least partly cultural in origin. The Desert Side-Notched and Cottonwood Triangular points at Ayers Rock were manufactured from obsidian from three sources: West Sugarloaf (N = 8), West Cactus Peak (N = 6), and Joshua Ridge (N = 1). All these sources exhibit high variability in intrinsic water content (Stevenson et al. 1993), which in turn is reflected in high variability in hydration rate and hence in rim thickness (Rogers 2008b). The Sugarloaf Mountain source, which has much lower variability, was not represented in the late series points at Ayers Rock. If a similar trend in source utilization occurred at the Coso Volcanic Field sites, then roughly half the variation observed for Desert Series points is explained by the water variability. The remaining variation would suggest the points were manufactured over a period beginning approximately 735 rcybp and continuing until the historic period.

Conclusions

The corrected values computed here have significant implications for assigning ages to point types, as well as for the time of introduction of the bow and arrow. The basic problem is that Gilreath and Hildebrandt made an incorrect assumption regarding the temperature regime at the Coso Volcanic Field, which led to the assignment of ages which are too young. The present study corrects this issue, and adds the refinement of an adjustment for paleoclimatic conditions and an improved age equation. The result of these corrections is a change in the hydration rim ages assigned to period boundaries in the Coso region, plus an attribution of older ages to point types.

The question of when the bow and arrow was introduced to the southwestern Great Basin was analyzed in detail by Yohe (1992, 1998), who concluded that bow and arrow technology were firmly established at Rose Spring (CA-INY-372) by 1600 rcybp (Yohe 1998:31). This would imply that introduction of the new technology occurred somewhat earlier. Recently he has suggested a date of introduction of 2000 rcybp (R. Yohe, personal communication).

Gardner (2006), in a study of sites across the western Mojave Desert, concluded that the bow and arrow was introduced closer to 2000 rcybp, and recommended an earlier chronology for the region. She suggested 2000 to 900 rcybp for the Rose Spring (or Haiwee) period, and 900 to Contact for the Late Prehistoric (or Marana) period (Gardner 2006:365).

The recalibration of obsidian hydration dates for the Coso Volcanic Field suggests these earlier chronologies have merit. Although the shift in mean ages shown by this analysis is not statistically significant, it may be archaeologically significant for corroborating other investigators and as an indicator suggesting further research. In particular, the obsidian data now yield a probable age of introduction of the bow and arrow of approximately 2000 rcybp, instead of the 1500 years usually cited. Analysis of the hydration rim variability data, quantified by the CV of the hydration rims, suggests extended use of the Coso Volcanic Field at all periods, with increasing time spans in the Early Holocene. The corrections still leave issues regarding the ages of very old point types, which require further research.

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