New Email for Bulletin Submissions

Carolyn Dillian, IAOS Bulletin editor, has a new email address. Submissions of articles, news, and notes can be emailed as a Word file to cdillian@coastal.edu

CONSIDER PUBLISHING IN THE IAOS BULLETIN

The Bulletin is a twice-yearly publication that reaches a wide audience in the obsidian community. Please review your research notes and consider submitting an article, research update, news, or lab report for publication in the IAOS Bulletin. Articles and inquiries can be sent to cdillian@coastal.edu Thank you for your help and support!

CALL FOR NOMINATIONS

We will hold elections for Secretary-Treasurer at the 2011 IAOS Annual Meeting in Sacramento, CA. The IAOS Secretary-Treasurer is responsible for a number of activities related to the organization’s business operations, including maintaining the organization’s membership list and managing membership renewals and new memberships; coordinating the planning of the IAOS Annual Meeting including meeting logistics, agenda, and notification to members; managing the organization’s bank and PayPal accounts and disbursing funds for any IAOS expenditures; and facilitating general communication with all IAOS members. The Secretary-Treasurer is elected to a two-year term and can be re-elected to serve multiple successive terms. If you are interested in running for the IAOS Secretary-Treasurer position, or would like to nominate someone, please contact IAOS President Tristan Carter at stringy@univmail.cis.mcmaster.ca
NOTES FROM THE PRESIDENT

Summer greetings to everyone and thanks once again to everyone for entrusting me with your presidency. Thanks also to outgoing president Ana Steffen for all her hard work and stable stewardship over the past two years and for helping me to pick up the reins at the SAA’s this April. Gratitude is also due to our outgoing Secretary/Treasurer Colby Phillips who has done a stellar job with the Association’s finances since 2006, not least establishing our on-line PayPal membership system. The St. Louis meetings saw yet another gathering of the clans, with a number of IAOS members using their work to engage in a variety of debates, not least one of this year’s hot topics, the role of archaeometry in North American anthropology, following Killick and Goldberg’s *Quiet crisis in American Archaeology* paper in the Jan. 2009 edition of the SAA Bulletin.

Also, congratulations are due to two of our newest members, Kyle Freund of the University of South Florida (now McMaster) and Chris M. Oswald of the University of Missouri (and member of MURR’s archaeometry lab), both of whom were awarded Student Prizes of 2 year memberships on the basis of their high quality poster presentations at the SAA’s. The posters are included on the next two pages (click to expand detail).

One of the major points of discussion in our committee meeting this year was increasing membership, not only in North America (where the bulk of our members are based), but also worldwide. To this end we shall be gathering our resources in an IAOS sponsored panel at the Sacramento meetings (March 30th-April 3rd, 2011), where we aim to present to a general SAA audience a state-of-play review of our methodological capabilities (characterization and dating), together with a series of global case studies that showcase how our work is contributing to some of the major debates in anthropological archaeology. Studies on obsidian from Anatolia, the Andes, California, the Pacific, the Rift Valley and the Southwest, will variously be employed to engage with such issues as: early hominin cognition, Neolithisation, material culture and identity, trade and power, plus communities of practice. It should be a great panel; we will make sure you all know the date, time and venue when organized and thereafter encourage you to spread the word! Nothing certain yet, but we are also exploring the possibility of a half-day trip to a northern Californian source and winery, a great way for the membership to interact in the field and hopefully meet some local experts and enjoy some local viticulture (categorically post-obsidian, says he with a nod to the health and safety executive...).

As a means of further expanding our engagement with non-US based scholars, we would ultimately aim to sponsor a similar panel at a forthcoming annual meeting of the European Association of Archaeologists.

Aside from the IAOS annual meeting at the SAA’s, a number of us also had the opportunity to reconvene at the May 2010 bi-annual symposium of the International Society of Archaeometry, a hugely successful conference hosted by our own Prof. Rob Tykot. The IAOS was a proud cosponsor of this event, an investment that also of course helped to raise our profile, leading to a number of new members joining, including scholars from Armenia, Austria and Poland. Here too obsidian studies played a major role, with oral presentations and posters documenting new geo-prospection projects and characterization studies from Armenia, Mexico, Peru, Sardinia, Turkey and the US.

I shall leave you here and wish you all well for your summer fieldwork and continuing good health and productivity. In a few days time I shall be making my annual pilgrimage to Çatalhöyük, where I shall be training two undergraduates in our lithic analysis system and involving them in our visual characterization project. After that, three weeks of visiting the major sources of Eastern and Central Anatolia, followed by those of the Aegean, collecting geological samples for my new McMaster Archaeological XRF Lab [MAX Lab] that should be operational for characterization studies this fall, but more on that next issue...

All the very best

Tristan Carter
stringy@mcmaster.ca
President IAOS
Assistant Professor, Dept. Anthropology, McMaster University / Director MAX Lab
Obsidian Source Use on the Northern Casas Grandes Frontier

Chris M. Oswald, Jeffrey R. Ferguson, Todd L. VanPool, and Christine S. VanPool

University of Missouri-Columbia

Introduction

The Draw site is located just south of Draw, New Mexico, and yet its identity by Brand (1935) as the most northerly site associated with the Casas Grandes culture. This association is based upon the numerous Casas Grandes polychrome ceramics that are gathered at this site. The site is located on the plateau of the Salinas cultural area, and Salado polychrome sherds are found throughout the site. The site has several habitation mounds, adobe circular mounds, a socket pit, and numerous obsidian artifacts that are the focus of this paper.

Research

The 76 Draw site represents the northernmost expansion of the Casas Grandes culture. This association is evidenced by the numerous Middle period (A.D. 1300-1450) ceramics that are recovered from this site. Obsidian artifacts collected from the site during the 2005 summer field season have been chemically analyzed using synchrotron X-ray fluorescence spectroscopy (SXS). This study demonstrates that obsidian procurement further confirms the relationship between the 76 Draw site and the Casas Grandes cultural region located further south in Chihuahua, Mexico.

Methods

The Middle Draw site is a large prehistoric site. The obsidian artifacts were collected from the 76 Draw site. The most significant artifacts recovered from the site were the ceramic sherd, which was approximately 15 cm in diameter. The obsidian samples were collected from each site and then analyzed using synchrotron X-ray fluorescence spectroscopy (SXS). The results were compared to the results of previous studies of the obsidian source in the American Southwest.

Conclusions

The majority of the obsidian artifacts recovered from the 76 Draw site are assigned to the Sierra Frenos source in northern Mexico. The ceramic evidence from 76 Draw, combined with the proximity of the Sierra Frenos source to the site of Paquimé suggests some form of economic interaction between the two sites. It is uncertain at this point whether this reflection direct trade with Paquimé, down the line trading, or some other form of acquisition.

Future Research

In order to further understand the variability in obsidian source usage by the site’s inhabitants, more samples will need to be analyzed from ongoing fieldwork, particularly from subsurface contexts. Furthermore, as we learn more about the stratigraphic nature of the site, future analysis might reveal the obsidian source usage may have changed through time. This analysis coupled with a more detailed focus of the lithic technology will assist in the interpretation of the role of obsidian in regards to the larger stone tool assemblage at 76 Draw. Finally, the continued search for smaller obsidian occurrences in the region may help account for the unassigned samples encountered during this study.
Lithic Technology and Obsidian Exchange Networks in Bronze Age Nuragic Sardinia (Italy)

Kyle P. Freund1 & Robert H. Tyko2, Department of Anthropology, University of South Florida

Introduction

Sardinia is located in the Mediterranean Sea off the western coast of Italy and occupies an area of approximately 24,000 square kilometers (Figure 1). The Sardinian Bronze Age (ca. 1600-850 B.C.) period is defined by the presence of nuraghi, monumental stone structures that are found throughout the island. The Sardinian Bronze Age and the factors which created and maintained an island-wide identity as seen through the presence of its distinctive nuraghi have received considerable attention; however, the amount of research directly related to the stone tools used has been relatively limited despite the wealth of knowledge it is capable of yielding. This research topic is important in Sardinia, due to the study of ancient technology, especially obsidian lithic technology, by combining typological information with source data gleaned from the examination of X-ray fluorescence spectrometry (XRF). This study specifically tests two questions: (1) how the composition of lithic assemblages was accompanied with corresponding changes in how the obsidian was used? and (2) what can we infer about the Sardinian obsidian exchange networks from those assemblages?

Methods

For this study, a Bruker Tracer III-V portable XRF machine (Figure 2) was used to analyze 346 obsidian artifacts from five Nuragic sites on the island of Sardinia. Type SB1 and SB2 were not a significant source of raw material at all, while type SA is the second most common, comprising up to 28% of one-third of the entire site's assemblages. Similar studies on obsidian at other Nuragic sites carried out by Michels et al. (1996) support these findings (Figure 3), but cannot reveal the low number of artifacts sourced at these other sites.

Results

Overview of the obsidian procurement is roughly similar to all of the other sites. Type SA obsidian is the most common, comprising up to 48% of the composition of these Nuragic assemblages. Type SB and SB2 were not significant source of raw material at all, while type SA is the second most common, comprising up to 28% of one-third of the entire site's assemblages. Similar studies on obsidian at other Nuragic sites carried out by Michels et al. (1996) support these findings (Figure 4), but cannot reveal the low number of artifacts sourced at these other sites.

Conclusions

The sourcing and typological analysis of an assembly of obsidian artifacts from five Nuragic (ca. 1600-850 B.C.) sites on the island of Sardinia. The geographical sources of these artifacts were determined using XRF technology. The results indicate that the main sources of obsidian on Sardinia. The Sardinian Bronze Age (ca. 1600-850 B.C.) period is defined by the presence of nuraghi, monumental stone structures that are found throughout the island. The presence of nuraghi, monumental stone structures that are found throughout the island.
OBITUARY: ROGER CURTIS GREEN, IAOS Board of Advisors
(March 15, 1932 - October 4, 2009)

For additional tributes, please see: http://www.nzarchaeology.org/Roger.html

The following obituary was written for the University of Auckland News website by Peter Sheppard, Associate Professor in Archaeology who came to New Zealand as a Post-doctoral Scholar to work with Roger on aspects of the archaeology of the Solomon Islands.

In 1958 archaeologist Roger Green came to the University of Auckland as a Fulbright scholar to spend 9 months in New Zealand preparing for fieldwork in French Polynesia. Although Roger’s early interest was the archaeology of the southwest USA, his exposure at Harvard to the Pacific anthropologist Douglas Oliver turned his interest to the Pacific. This shift in interest resulted in a career which spanned 50 years and field research which covered Oceania.

In 1961 Roger joined the Department of Anthropology at Auckland as the only archaeologist, replacing Professor Jack Golson, who had moved to ANU. Between 1961 and 1967 Roger conducted significant research in New Zealand, ultimately writing the important theoretical piece *A Review of the Prehistoric Sequence in the Auckland Province*, which was presented as his Harvard PhD. In keeping with his life-long pattern, however, his New Zealand research was complemented by large seminal research projects in the tropical Pacific (Moorea 1961-62; Western Samoa 1963-1967).

These projects were funded by the NSF through the Bishop Museum in Hawaii and in 1967 Roger left Auckland to take up a position at the Bishop. During this period (1967 to early 1970) Roger conducted important work on a series of Hawaiian valley systems, where he initiated research into agricultural field systems in collaboration with the New Zealand born ethnobotanist Douglas Yen.

Roger returned to Auckland in 1970 as the first James Cook Fellow, taking up a three year position at the Auckland Museum. From the Museum he initiated, with Douglas Yen, the Southeast Solomons Culture History Project (1970-72, 1976). This was the first large-scale, multi-disciplinary, multi-phase archaeological research project in the Pacific and the breadth of collaboration amongst archaeologists, social anthropologists, linguists, geologists, palynologists and other archaeological scientists reflected Roger’s enduring interest in what he termed 'holistic archaeology or anthropological history'.

During this project sites bearing Lapita pottery were found in the Reef/Santa Cruz Islands which lie 400km beyond the Main Solomons across what Roger came to call the Near/Remote Oceania boundary. This boundary marked the limits of human settlement until people bearing Lapita culture and speaking Austronesian languages moved out into the Pacific some 3,200 years ago. Although Lapita sites had been found prior to Roger’s work, his were the first systematic excavations providing detailed information on the Lapita culture and as such they have served as archetypes for subsequent work and debate. Throughout the rest of his career questions of Lapita settlement and Polynesian origins were at the core of Roger’s work and he continued to publish on his Southeast Solomons research up until his death.

In 1973 Roger was appointed to a personal Chair at Auckland which he held until his retirement in 1992, after which he was Emeritus until his death. Retirement for Roger simply meant more opportunity for publishing and his output has been prodigious. In 1995 at the time of the publication of the festschrift, *Oceanic Culture History: Essays in Honour of Roger Green*, a bibliography of 259 publications was compiled. Since 1995 publication has been steady with two new papers in the week prior to his death and more in train. Perhaps one of Roger’s proudest achievements in later years was his co-authoring with Professor Patrick Kirch (University of California, Berkeley) in 2001 of *Hawaiiki, Ancestral Polynesia: An Essay in Historical Anthropology*, which allowed him to combine his expertise in Pacific archaeology and linguistics...
and provide a theoretical and methodological basis for a holistic historical anthropology.

Roger Green has been a foundation scholar in the archaeology of the Pacific and his contribution is marked by his publication record but also by his hundreds of colleagues and students who have gone on to define the field. His contributions were recognized by memberships in the National Academy of Science (USA) and the Royal Society of New Zealand. In 2003 he was awarded the Marsden Medal by the New Zealand Association of Scientists for his work in Pacific archaeology and cultural history and in 2007 he was made an Officer of the New Zealand Order of Merit (ONZM) for 'services to New Zealand history'. Roger has been the father and grandfather of archaeology and anthropology at the University of Auckland, his academic family will miss him. Kua hinga te kauri o te wao nui a Tāne

Roger Curtis Green 1932–2009 BA BSc (New Mexico) PhD (Harvard) ONZM FRSNZ Member NatAcadSci (USA), Hon Fellow Society of Antiquaries of London Emeritus Professor of Prehistory at the University of Auckland

THE OBSIDIAN HYDRATION COOK BOOK:
AID FOR THE MATHEMATICALLY DISINCLINED

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Abstract

This paper describes a simple procedure for obsidian hydration dating. It is based on the specific case of Coso obsidian from sites with a desert temperature regime, but can be extended to other areas and to obsidian from other sources by modifying the temperature model and using the appropriate hydration rate parameters. The process corrects hydration rim values for effective hydration temperature (EHT) and computes age estimates, using a rate equation based on radiocarbon-obsidian pairings for Coso obsidian. A correction for paleoclimatic change is included. The analysis can be performed by Excel spreadsheet or scientific calculator; for larger jobs, program listings in MatLab are provided to expedite the process. References are cited which show how to compute hydration rate and site temperature parameters, in the event that the user needs to analyze other obsidians and other temperature regimes.

Introduction

This paper describes a protocol for obsidian hydration dating, using a hydration rate characteristic of Coso and temperatures typical of the northern Mojave Desert and southwestern Great Basin. The analysis corrects rim values for effective hydration temperature (EHT) and computes age estimates. A correction for paleoclimatic change is described which may be implemented if desired.

It is assumed that the reader is familiar with the techniques of optical measurement of hydration, and the analysis below starts with obsidian hydration rims from a known obsidian source (Coso). The analysis procedure is described first, for those impatient to start, and is followed by a discussion of
the theory. The references cited are not exhaustive, but will provide useful background for those interested.

**Analysis Procedure**

The recommended procedure for chronometric analysis is to proceed by the following steps. All temperatures are in °C; further, rcybp means “radiocarbon years before 1950” and cyb2k means “calibrated years before 2000”. An Excel spreadsheet is a convenient way to implement the process.

1. Using the altitude of the site, compute $T_a$, $V_a$, and $V_d$ from the equations

   $$T_a = 22.25 - 1.8h,$$

   $$V_{a0} = 1.65 + 0.94T_a,$$

   $$V_{d0} = 15.8$$

   If any specimen is from a rock shelter or cave, multiply $V_a$ by 75% and use $V_d = 5\, ^\circ C$.

2. Make sure all the specimens are Coso obsidian.

3. Using the temperature parameters from step 1 and the burial depth $z$ in meters, compute the EHT for each specimen:

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

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

   $$Y = V_a^2 + V_d^2$$

   $$EHT = T_a \times (1-Y \times 3.8 \times 10^{-5}) + 0.0096 \times Y^{0.95}$$

   Note that the last term in the EHT equation involves raising $Y$ to the 0.95 power. This is easily performed in MS Excel by entering $[Y]^{0.95}$, where $[Y]$ is the cell reference to the cell containing the $Y$ variable.

4. Compute the EHT-corrected rim thickness for each specimen, using a value of $EHT_r = 20.4\, ^\circ C$.

   $$RCF = \exp[-0.06(EHT-EHT_r)]$$

   $$r_c = RCF \times r$$

5. Group the EHT-corrected rim data as may be appropriate archaeologically; exclude outliers by Chauvenet’s theorem (Taylor 1982).

6. Compute ages based on current conditions ($k$ is hydration coefficient):

   $$t = k \times r^2$$

   $$k = 38.87 \text{ rcybp/µ}^2$$

   $$k = 43.72 \text{ cyb2k/µ}^2$$

   As an example, consider the case of a Coso obsidian specimen with a 5.0µ rim, retrieved from a surface site at an altitude of 2,440 ft amsl in the northern Mojave Desert. Substituting $h = 2.44$ in step 1 above gives $T_a = 17.86\, ^\circ C$, $V_a = 18.44\, ^\circ C$, and $V_d = 15.80\, ^\circ C$. Entering these into step 3, with a burial depth $z = 0$, gives an EHT of $21.57\, ^\circ C$. With an $EHT_r$ of $20.4\, ^\circ C$, step 4 gives an $RCF$ of 0.9321, so the corrected rim value is $0.9321 \times 5\, µ = 4.66\, µ$. Finally, using this rim value in step 6 gives ages of 844 rcybp or 950 cyb2k.

7. Consult Figure 1 below to decide whether to make a correction for paleotemperature changes. The figure shows the change in hydration coefficient $k$ due to paleotemperature change as a function of artifact age.
The effect of paleotemperature change is especially significant during certain periods: Holocene Maximum around 6,000 years ago, Medieval Climatic Anomaly and Little Ice Age. Use of the present-day hydration rate is not appropriate in these age ranges, whereas for ages about 4,000 years ago the effect is negligible. To apply the correction, compute the age as in step 6. In Fig 1, read off the change in $k$ for that age; multiply $k$ by this value to give $38.87 \times 0.95 = 36.93$. Now recompute the age as $36.93 \times 15^2 = 8309$ rcybp.

8. Once you have the ages, compute the accuracy of the age estimates. First compute the sample standard deviation for each estimate as

$$\sigma_r = 2t \times (\sigma_r/r)$$

where $t$ is the age estimate, $r$ is the mean EHT-corrected rim value, and $\sigma_r$ is the standard deviation of the rim values for that estimate. Next compute

$$\sigma_{tFlow} = CV_{Flow} \times t$$

where $CV_{Flow}$ is the coefficient of variation of the hydration rate for the particular obsidian flow of interest and $t$ is the age estimate. The values of $CV_{Flow}$ for Coso are in Table 1.

### Table 1. Values of $CV_{Flow}$ for Coso Obsidian Sources

<table>
<thead>
<tr>
<th>Flow Source</th>
<th>$CV_{Flow}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarloaf Mountain</td>
<td>0.07</td>
</tr>
<tr>
<td>West Sugarloaf</td>
<td>0.20</td>
</tr>
<tr>
<td>West Cactus Peak</td>
<td>0.25</td>
</tr>
<tr>
<td>Joshua Ridge</td>
<td>0.20</td>
</tr>
</tbody>
</table>

If the source is not specified, use $CV_{Flow} = 0.21$ for the Coso Volcanic Field.

Finally, compute the point accuracy of the age estimate by

$$\sigma_a = \sigma_r /\sqrt{N}$$

where $\sigma_a$ is either $\sigma_r$ or $\sigma_{tFlow}$, whichever is greater. This is the best estimate of accuracy.

9. Finally, the span of time represented by the rim data is either $\sigma_r$ or $\sigma_{tFlow}$, whichever is greater.

You are now ready to do archaeological assessments based on the obsidian data.
Theory
1. Obsidian Hydration

Hydration of obsidian is known as a diffusion-reaction process (Doremus 2002). The basis of chronometric analysis using obsidian hydration is the equation

\[ t = k r^2 \]  (1)

where \( t \) is age in calendar years, \( r \) is rim thickness in microns, and \( k \) is a constant, the hydration coefficient. Here \( k \) is the reciprocal of the hydration rate. Although other equations have been proposed (e.g. Basgall 1991; Pearson 1994), equation 1 is the only form with both theoretical (Ebert et al. 1991; Doremus 2002) and laboratory (Doremus 1994; Stevenson et al. 1998, 2000) support.

The age parameter in equation 1 is in calibrated years before the hydration measurement was made; for analysis purposes this can be taken as the year 2000, so the measurement is in calibrated years before 2000, or cyb2k. 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 with a different rate constant.

The hydration coefficients for Coso obsidian used herein are

\[ k = 38.87 \text{rcybp}/\mu^2 \]  (2a)

\[ k = 43.72 \text{cyb2k}/\mu^2 \]  (2b)

for rim values

\[ 0 < r < 12\mu \]

(Rogers 2009).

The hydration coefficient is affected by five parameters: ground-water chemistry (Morgenstein et al. 1999); obsidian anhydrous chemistry (Friedman et al. 1966); obsidian intrinsic water content (Zhang and Behrens 2000); humidity (Mazer et al. 1991); and temperature (Rogers 2007a). Ground-water chemistry is only a problem in cases where potassium content is very high, as in some desert playas; otherwise it can be ignored. Obsidian anhydrous chemistry is controlled by sourcing the obsidian. Intrinsic water concentration can vary within an obsidian source (Stevenson et al. 1993), and can affect hydration rate significantly (Zhang and Behrens 2000); there are no archaeologically appropriate techniques for measuring intrinsic water at present, so its effects must be controlled statistically, by sample size. Humidity is a small effect which can generally be ignored.

Temperature is the major effect which needs to be controlled in performing an obsidian analysis. Archaeological temperatures vary both annually and diurnally, and the hydration rate is a strong function of temperature. The key concept is “effective hydration temperature” (EHT), which is defined as a constant temperature which yields the same hydration results as the actual time-varying temperature over the same period of time. Due to the mathematical form of the dependence of hydration rate on temperature, EHT is always higher than the mean temperature. The mathematical derivation is given in Rogers 2007a.

The equation for EHT, which specifically accounts for average annual temperature, mean annual temperature variation, mean diurnal temperature variation, and burial depth, is

\[ \text{EHT} = T_a \times (1-Y \times 3.8 \times 10^{-5}) + 0.0096 \times Y^{0.95} \]  (3)

where \( T_a \) is annual average temperature, and the variation factor \( Y \) for surface artifacts is defined by

\[ Y = V_a^2 + V_d^2 \]  (4a)

in which \( V_a \) is annual temperature variation (July mean minus January mean) and \( V_d \) is mean diurnal temperature variation. All temperatures are in degrees C.

For buried artifacts, \( V_a \) and \( V_d \) represent the temperature variations at the artifact burial depth, which are related to surface conditions by

\[ V_a = V_{a0} \exp(-0.44z) \]  (4b)

and

\[ V_d = V_{d0} \exp(-8.5z) \]  (4c)

where \( V_{a0} \) and \( V_{d0} \) represent nominal surface conditions and \( z \) is burial depth in meters (Carslaw and Jaeger 1959:81). Depth correction for EHT is desirable, even in the presence of site turbation,
because the depth correction, on the average, gives a better age estimate.

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

\[
\text{RCF} = \exp[-0.06(\text{EHT} - \text{EHT}_r)] \tag{5}
\]

where EHT\(_r\) is effective hydration temperature at the reference site. The EHT-corrected rim value \(r_c\) is then

\[
r_c = \text{RCF} \times r \tag{6}
\]

The value of EHT\(_r\) for Coso obsidian is conventionally taken to be that of Lubkin Creek, or CA-INY-30, which is 20.4ºC by this technique. Since most Coso work uses CA-INY-30 as a reference, correcting the rim to these conditions allows direct comparison of EHT-corrected rim data with other published data.

Temperatures have varied slightly over archaeological time scales, which can introduce a small error (<7%) into age estimates made based on current conditions. A technique to correct for this has been described (Rogers 2010), but is generally needed only in Paleoindian studies. A procedure for implementing this calculation is given in Rogers 2010.

2. Temperature Estimation

Most archaeological sites are not collocated with meteorological stations but temperature parameters for them can be estimated by regional temperature scaling (Rogers 2008a). It is important to use long-term data in these computations, and 30 years is the standard for determining climatological norms (Cole 1970). Such data can be down-loaded from the web site of the Western Regional Climate Center. The scaling principle is that desert temperature parameters are a strong function of altitude above mean sea level, and the best estimates of temperature are determined by scaling from 30-year data from large a number of meteorological stations.

With this technique, in the northern Mojave Desert, annual average temperature can be predicted by the equation

\[
T_a = 22.25 - 1.8h, \quad 0.94 \leq h \leq 11.8, \tag{7}
\]

where \(h\) is altitude in thousands of feet. The accuracy of this model is 0.98ºC, 1-sigma.

The annual temperature variation can be predicted by

\[
V_a = 1.65 + 0.94T_a, \tag{8}
\]

with \(T_a\) defined as above. The accuracy of the prediction is 0.27ºC, 1-sigma.

The best fit between \(V_d\) and altitude is relatively poor, and, in the absence of other data about a site, the optimal estimate is

\[
V_d = 15.8ºC \tag{9}
\]

for locations in the western Great Basin and deserts, irrespective of altitude. The accuracy of this estimate is 1.67ºC, 1-sigma.

These equations are for air temperatures. Obsidian on the surface is exposed to surface temperatures, which can be significantly higher than air temperatures in areas devoid of vegetation (Johnson et al. 2002; Rogers 2008b). However, a detailed analysis based on data from Rose Spring (CA-INY-372) has been shown that meteorological air temperature gives a good estimate of surface ground temperature in situations in which even intermittent shade is present (Rogers 2008c).

3. Paleotemperature Effects

Since climate has not been stable over periods of archaeological interest, the effects of resulting temperature changes must be included in some cases. Figure 2 shows a reconstruction of the variation of regional-scale mean temperature since

![Figure 2. Changes in regional-scale mean temperatures since the late Pleistocene, based on multi-proxy data (West et al. 2007:17, Fig. 2.2)](image-url)

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the late Pleistocene, based on multi-proxy data (West et al. 2007).

Computation of the effective hydration coefficient for ancient artifacts, including the temperature variations in Figure 2, results in the relative hydration coefficient curve of Figure 1.

Figure 1 shows that temperature changes probably did affect the hydration rate of obsidian throughout the Holocene to a noticeable degree. The effect is especially significant for the Holocene Maximum around 6,000 years ago, and more recently during the Medieval Climatic Anomaly and the Little Ice Age. Use of the present-day hydration rate is not appropriate in these age ranges.

4. Accuracy and Resolution

Age is computed from equation 1, after appropriate temperature corrections. However, in actuality experimental errors occur in both r and k. Errors occur in r because of material inhomogeneities and due to the finite accuracy of laboratory procedures. Errors arise in k due primarily to unpredictable variations in water content in the obsidian (Ambrose and Stevenson 2004; Rogers 2008d; Stevenson et al. 1993, 2000; Zhang et al. 1991; Zhang and Behrens 2000). Since these effects are independent, but cannot be easily separated in practice, it is useful to examine two limiting cases.

The simplest case is to assume that the hydration coefficient k is known and error-free, and all errors are in the measurement of the rim r. For this case it can be shown that the standard deviation in the age estimates due to the standard deviation of errors in r ($\sigma_r$) is

$$\sigma_\text{r} = 2 \times t \times (\sigma_r/r)$$

(10)

This is the familiar sample standard deviation.

For the second case we assume that all error is arising from uncorrected variations in k, which is a function of the individual obsidian flow and has been published for Coso (Stevenson et al. 1993; Rogers 2008d). The standard deviation in age due to such flow-related uncertainties is

$$\sigma_{\text{Flow}} = CV_{\text{Flow}} \times t$$

(12)

where $CV_{\text{Flow}}$ is the measured uncertainty in hydration rate specific to the flow. Values of $CV_{\text{Flow}}$ were presented in Table 1; for the Coso volcanic field as a whole, $CV_{\text{Flow}} = 0.21$ (Rogers 2008d).

Finally, the point accuracy $\sigma_a$ is given by

$$\sigma_a = \sigma_t / \sqrt{N}$$

(13)

where $\sigma_t$ is either $\sigma_{\text{r}}$ or $\sigma_{\text{Flow}}$, whichever is greater.

Extension of the Method

To apply this method to other obsidian sources, an appropriate hydration coefficient is needed, for known EHT conditions. Obsidian-radiocarbon association is the best method of developing a hydration coefficient; an example of the process can be found in Rogers 2009. Extension to other geographic areas requires a temperature analysis as in Rogers 2008a. The analysis method is the same with these numerical modifications.

Implementation of the Process

The analysis procedure described above can be carried out with a scientific calculator or an Excel spreadsheet. Making the correction for paleotemperature changes requires an iterative process, as described above.

For analysis requiring large numbers of computations, however, even the spreadsheet becomes cumbersome. For such cases it is convenient to use a computer program to perform the repetitive calculations. Two such programs have been developed, written in MatLab. Program OHAStandard is a demand-response program, suitable for individual data points. Program OHAMatrix is designed for large data sets; it reads input from an Excel-generated comma-separated variable (.csv) input file, and outputs to a similar file. In either case the paleoclimatic correction is made by an iterative fit to the Holocene curve of Fig. 2. Point accuracy and sample standard deviations are computed, and a warning is provided if the calculation is outside the valid range of the equations. These programs may be obtained by contacting the author at matmus1@maturango.org
References Cited
Note: References from the International Association for Obsidian Studies are available to download from their web site, http://members.peak.org/~obsidian/

Basgall, Mark E.

Carslaw, H. S., and J. C. Jaeger

Cole, F. W.

Doremus, R. H.


Ebert, W. L., R. F. Hoburg, and J. K. Bates

Friedman, Irving, Robert I. Smith, and William D. Long

Hull, Kathleen L.

Johnson, Michael J., Charles J. Mayers, and Brian J. Andraski

Mazer, J. J., C. M. Stevenson, W. L. Ebert, and J. K. Bates

Morgenstein, M. E, C. L. Wickett, and A. Barkett

Pearson, James L.

Rogers, Alexander K.


Stevenson, Christopher M., E. Knauss, J. J. Mazer, and J. K. Bates
Stevenson, Christopher M., J. J. Mazer, and B. E. Scheetz
Stevenson, Christopher M., Mike Gottesman, and Michael Macko

Taylor, J. R.
Zhang, Y., E. M. Stolper, and G. J. Wasserburg
Zhang, Y, and H. Behrens
PROVENANCE OF OBSIDIAN TOOLS FROM NORTHWESTERN IRAN USING X-RAY FLUORESCENCE ANALYSIS AND NEUTRON ACTIVATION ANALYSIS

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Abstract

In this paper 212 obsidian tools from archaeological sites in northwestern Iran, including the Tabriz: Khodafarin cemeteries, Ardebil: Ghosha Tepe-Shahryi, and Urmia: Dem-i-suliman were analyzed by X-ray Fluorescence Analysis and Neutron Activation Analysis. The aim of the analysis was to determine the provenance of these samples. These sites were chosen for study because of the abundance of obsidian samples on archaeological sites in northwest Iran and their proximity to obsidian sources in Armenia, Azerbaijan, and Turkey. A comparison of the results shows that obsidian trade and exchange between the archaeological sites and sources was quite extensive.

Key words:
Obsidian, northwest Iran, provenance, XRF, NAA

Introduction

Obsidian, with a composition similar to rhyolite, is formed when highly viscous molten lava cools rapidly such that the process of crystallization is precluded. The chemical composition of obsidian at any particular source or flows is, with few exceptions, homogeneous. Different sources or flows are also compositionally different from one another (Glascock et al. 1998).

Research on the obsidian provenance which started almost five decades ago has employed a number of chemical methods of analysis, including: (1) PIXE to study obsidian from New Zealand (Duerden et al. 1984); (2) XRF to characterize obsidian from northern California (Hughes 1982); and (3) NAA to analyze obsidian from the highlands of Guatemala (Asaro et al. 1978).

Renfrew and colleagues, in the mid-1960s, were the first to demonstrate that the chemical compositions of obsidian artifacts could be used to reconstruct obsidian exchange networks involving the Anatolian sources. In 2009, 212 obsidian samples were analyzed by X-ray fluorescence (XRF) and neutron activation analysis (NAA) at the Archaeometry Lab at MURR. The artifacts came from archaeological sites in northwestern Iran, including Tabriz: Khodafarin cemeteries, Ardebil: Ghosha Tepe-Shahryi, and Urmia: Dem-i-suliman. The objective of the analysis was to determine the compositions of the obsidian artifacts. By comparing the artifact compositional data to compositional data for obsidian sources, it will be possible to study prehistoric trade and exchange of obsidian. The sources most likely to be responsible for obsidian artifacts found in northwestern Iran are located in Armenia, Azerbaijan, Turkey, and Iran.
Archaeological Sites of Tabriz, Ardebil, and Urmia

The Khodafarin cemeteries are located near Tabriz in the East Azerbaijan province of Iran in Kaleybar township, including Larijan cemetery is located in 9 km Khomarlu city with 39° 9’ 39” longitude and 47° 0’ 12” latitude (296 m above sea level) and Toali cemetery is located in 25 km northwest Khomarlu city with 39° 5’ 40” longitude and 46° 49’ 5” latitude (330 m above sea level). These cemeteries are located inside Khodafarin and GizGalasi Dams.

Abbreviation codes for these cemeteries are shown in tables including: (1) KH for Khodafarin dam; (2) C for cemetery; (3) LA or TA for Larijan or Toali cemeteries; and (4) K is the cemetery number. For example: KH.C.LA.K4 (Hejabari Noubari, 2007).

The dimensions of these cemeteries are different because people with different social positions were treated differently. Objects that were found in the cemeteries included grey wares, stones, and bronze objects. The cemeteries were used continuously from the late Bronze to Iron I Age.

Ghosha Tepe is located in Ardebil province a distance of 31 km from Meshginshahr in northwest Iran. The Shahryi site is approximate 1.5km from Pierazemyan village with coordinates of 47° 55’ 07” longitude and 38° 33’ 53” latitude (1057 m above sea level). The Ghosha tepe site covers an area roughly 80
meters x 114 meters with mounds up to 5 meters tall. This tepe is related to Chalcolithic period. In this tepe 220 pottery sherds (plain and painted) and 1089 stone artifacts were found.

The Khodafarin cemeteries (Hejabari Noubari, 2007) and Ghosha tepe sites were excavated (Hejabari Noubari, 2004) by Alireza Hejabari Noubari of Tarbiat Modares University in Tehran, Iran.

Dem-e-suliman tepe is located about 35 km west of Urmia city next to Moana village. This tepe is at the foot of a mountain area according to surface documentation of ceramics the tepe is related to Neolithic age (Khanmohamady, 2008).

During geological survey, a sample of mother stone (i.e., source sample) with a 10 kg core was found in the east Azerbaijan province of Lilan next to Malkan Township to the SW of Sahand Mountain. A part of this core was removed for analysis. This mother stone is currently in the Tabriz museum. In geology survey, Mansoor Ghorbane of Shahid Beheshti University obtained samples of obsidian from Armenia.

Analytical Methodology

A variety of physical, chemical, and isotopic methods have been employed for obsidian provenance research. However, the three analytical methods most often used today are neutron activation analysis (NAA), X-ray fluorescence (XRF), and laser ablation-inductively coupled plasma-mass spectrometry (LA-ICP-MS). Each of the methods has specific advantages and disadvantages with respect to the analysis of obsidian (Glascock et al. 1998). For example, NAA offers excellent sensitivity, precision and accuracy for a large number of elements, and it can be used to analyze the very smallest of samples (e.g., 5 mg). Although NAA is the most reliable and accurate method for most elements, it requires that a portion of the artifact to be destroyed and thereby making the irradiated sample radioactive. NAA is also more expensive and time-consuming than the other analytical methods. XRF offers good sensitivity and accuracy for several of the incompatible trace elements (i.e., Rb, Sr, Y, Zr, and Nb) frequently important for discriminating between obsidian sources (Shackley 1998, 2007). XRF can be performed non-destructively, and it is both a rapid and inexpensive method. However, XRF has limitations when the samples are small, thin, and/or irregularly-shaped. These types of samples may require corrections. Most XRF labs in the world will not attempt to source artifacts smaller than 8mm in diameter and 2 mm thick. The third method of LA-ICP-MS is capable of measuring a large number of elements on very small samples in a relatively short period of time. However, LA-ICP-MS has limitations regarding standardization and instrument stability. XRF was the primary method of choice for this study. To supplement the XRF, some of the samples were also analyzed by NAA.

The obsidian artifacts submitted for analysis ranged in size from less than 5 mm diameter and 1 mm thick up to about 2 cm diameter and 4 mm thick. A majority of the samples were smaller than 1 cm in diameter. Although many of the artifacts were less than ideal, the Archaeometry Lab at MURR has been working on techniques for smaller artifacts (Eerkens et al. 2008). Thus far, the techniques have been successfully tested on obsidian from western North America. However, the rate of success for any region is dependent upon the number of possible sources and the similarity of sources to one another. Since the Archaeometry Lab has only recently started to analyze obsidian from the ancient Near East, the sourcing results reported here may have some limitations.

Characterization of Obsidian Sources in the Region

A small number of obsidian from sources in Turkey had been analyzed by the Archaeometry Lab prior to October 2007, but the number of sources in the region is quite large as shown in Figure 1 and the MURR obsidian database for this region was very sparse. As a result, several colleagues were contacted to request the loan of obsidian source materials for compositional analysis at MURR. Jim Blackman (Smithsonian Institution), Bastien Varoutsikos (graduate student from France), Bernard Gratuz (CNRS-France) and Ellery Frahm (graduate student from the University of Minnesota) were extremely helpful in providing a total of 215 obsidian source samples from sources in eastern Turkey, Armenia, Georgia, and Azerbaijan. All of the source samples were analyzed by XRF.
Fig. 2. Log-log bivariate plot of Rb versus Sr measured by XRF for obsidian sources from the ancient Near East relevant to this study. Ellipses at the 90% confidence level surround the source groups.

Fig. 3. Log-log bivariate plot of Rb versus Zr measured by XRF for obsidian sources in the ancient Near East relevant to this study. Ellipses at the 90% confidence level surround the source groups.
Fig. 4. Log-log bivariate plot of Cs versus Th measured by NAA for obsidian sources in the ancient Near East relevant to this study. Ellipses at the 90% confidence level surround the source groups.

Fig. 5. Log-log bivariate plot of Rb versus Zr measured by XRF for obsidian artifacts from northwestern Iran. Ellipses at the 90% confidence level surround the source groups.
and a smaller subgroup were analyzed by NAA to enhance the Laboratory’s ability to differentiate between chemically similar sources.

Examination of the XRF data shows that most, but not all, of the obsidian sources in the region could be differentiated from one another. A few of the neighboring sources in Armenia were found to be chemically similar on most of the measured elements, and a source sample from the Sahand Mountain source was found to be chemically similar to samples from the Geghasar source on many of the elements. These sources were analyzed by both XRF and NAA. The best bivariate plots from the XRF measurements are shown in Figures 2 and 3 where Rb versus Sr and Rb versus Zr, respectively, have been plotted. Figure 4 shows the results possible with NAA when using the high-precision elements Cs and Th.

By XRF, the similarity of source samples lead to the necessity of combining Metz Arteni and Pokr Arteni samples into a single group referred to as the Arteni compositional group; sources at Geghasar and Spitaksar were combined to create the Gegham compositional group; and source samples from Sevkar, Metz Sevkar, Satanakar, Metz Satanakar, Pokr Satanakar, and Bazenk were combined to create the Syunik compositional group. By NAA, it was still very difficult to separate the sources in the Syunik region of Armenia; and the results for the Sahand Mountain sample and samples from the Geghasar source were also found to overlap. In order to differentiate, Sahand Mountain from Geghasar the best available plot is that shown in Figure 3 using the elements Rb and Zr.

**Analysis of the Artifacts from Northwestern Iran**

All 212 obsidian artifacts and 3 source samples were analyzed by XRF on the Elva-X instrument in the same manner as the source samples. Sample descriptions are listed in Table 1 and the XRF compositional and source assignment data are presented in Table 2. Results for the artifacts analyzed by NAA are listed in Table 3. As shown in Figure 3, the Sahand Mountain sample was found to be unique on a single element with a Zr concentration of about 60 ppm, whereas the most similar source to it is the Geghasar source which has Zr concentrations above 80 ppm. Unfortunately, there was only a single sample from Sahand Mountain available for testing which somewhat limits confidence in assigning artifacts.

Due to the small dimensions for many of the artifacts and the similarity of source compositions it was necessary to combine some of the similar source groups when assigning artifacts from the XRF data. The final XRF results indicated in Table 4 show that 191 artifacts came from the Syunik-Gegham sources, 29 artifacts came from Meydan, 13 artifacts came from Sahand Mountain, 10 artifacts came from Nemrut, 4 artifacts came from Arteni sources, 2 artifacts came from Gutansar, 1 artifact came from Damlik, 11 artifacts were chert, 3 artifacts were basalt, and 2 artifacts could not be assigned. Figure 5 summarizes the obsidian in a plot of Rb versus Zr from XRF data showing these results (without the chert and basalt samples).

**Results and Conclusions**

With a combination of XRF and NAA measurements on obsidian artifacts from Northwestern Iran, it appears that obsidian trade and exchange between the archaeological sites and sources was quite extensive. Sources in Armenia and Turkey were extremely important and supplied more than 95% of the raw materials found on archaeological sites in northwestern Iran. A single source in Iran at Sahand Mountain provided a small amount of obsidian for local use.

**Acknowledgements**

We acknowledge the help of James Blackman, Bastien Varoutsikos, Bernard Gratuz and Ellery Frahm for providing source samples from Turkey, Armenia, Georgia, and Azerbaijan and I thank Hossein Esmaeli who is Manager of Tabriz Museum to enable an obsidian source database for the ancient Near East to be established in the Archaeometry Lab at MURR.
References
Eerkens, J.W., J.R. Ferguson, M.D. Glascock, C.E. Skinner and S.A Waechter

Ghorabi, Sohila, Michael D. Glascock, Farhang Khademi, Abdulhamid Rezaie & Mohammad Feizkhah

Glascock, M.D., G.E. Brawell and R.H. Cobean

Hejabari, Noubari Alireza


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BODIE HILLS OBSIDIAN FROM MONO COUNTY, EASTERN CALIFORNIA: A HYDRATION RATE AND AN ISSUE

Alexander K. Rogers, MA, MS
Archaeology Curator and Staff Archaeologist
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Abstract

This paper reports a hydration rate for Bodie Hills obsidian from Mono County in Eastern California USA, based on obsidian – radiocarbon pairing data from the western slope of the Sierra Nevada. The analysis employs regional temperature scaling to determine site temperature parameters, and temperature-dependent hydration theory to compute hydration rim corrections for effective hydration temperature (EHT), including the effects of paleoclimatic change and artifact burial depth. The rate is based on a linear least-squares best fit employing the Total Least Squares algorithm, which takes into account uncertainties in both variables and employs both error-based and judgmental weighting. The resulting hydration age coefficient is $103 \pm 25$ radiocarbon yrs/$\mu^2$, which is reasonably consistent with prior studies. However, this result is not consistent with rates developed for the eastern slope of the Sierra Nevada when temperature differences are taken into account. This discrepancy cannot be resolved until better data on the chemistry, chemical variability, and rate variability of Bodie Hills obsidian are available.

Introduction

This paper proposes a tentative hydration rate for Bodie Hills obsidian, whose source is in Mono County in eastern California, USA. The calculations are based on obsidian-radiocarbon pairing data from the western slope of the Sierra Nevada, kindly provided by Jay Rosenthal of Far Western Anthropological Research Group. The calculation explicitly takes effective hydration temperature (EHT) into account in computing the rate, using temperature parameters computed from 30-year weather data by regional temperature scaling (Rogers 2007b). All EHT values are corrected for burial depth of the artifact. The output is a hydration age coefficient (reciprocal of the rate) applicable to the western slope of the Sierra Nevada. The tentative nature of this rate must be emphasized. The data set employed is relatively error-prone, and an attitude of skepticism is appropriate in applying the rate in chronological analyses, especially since the age coefficient is not consistent with the value for the eastern slope.

I recognize the viewpoint of those who argue that laboratory hydration techniques are the best way to measure rates (e.g. Stevenson et al. 1998). However, most practical rate determinations are still based on obsidian – radiocarbon pairing, and this paper is a modest attempt to optimize this technique by advanced numerical analysis.

Obsidian Hydration

Hydration of obsidian has both a physical and a chemical aspect, and is known as a diffusion-reaction process (Doremus 1994, 2000, 2002). The process is described by a second order partial differential equation, which predicts the concentration of diffusing molecules (i.e. water) as a function of time and depth within the obsidian (Crank 1975:4, eq. 1.6; Doremus 2002:9ff.). The equation has a closed-form solution in only a few cases; however, all these solutions have the property that the concentration of diffusing molecules can be written as a function of a single
parameter, $z = \sqrt{(r^2/Dt)}$, where $r$ is rim depth, $t$ is time, and $D$ is the diffusion coefficient. This equation also holds if $D$ is a function of time, in which case $D$ is replaced by its time average (Crank 1975:104-105). Although the equation was first derived for the case of $D$ being constant in $x$ and $t$ (Crank 1975:4ff), it also holds if $D$ is a function of concentration (Crank 1975:119-121; Rogers 2007a; Wagner:1950), which seems to be the case in hydration (Anovitz et al. 1999; Doremus 2002).

The rim thickness is defined physically by the optical hydration front, which is a region of mechanical stress between the hydrated and unhydrated volumes of the glass, and is defined mathematically by a specific point on the concentration-vs.-depth curve for the diffusing water. The point is often assumed for convenience to be the 50% point on the curve, but is more likely to be the inflection point, since that is the point of maximum mechanical stress (Rogers 2008a); the two points are close enough together that the difference is not significant experimentally, although it can be observed by SIMS (Stevenson et al. 2004). The point on the concentration curve defining the rim thickness thus progresses by the equation

$$r^2 = Dt.$$  \hspace{1cm} (1)

All that is known of the physics and chemistry of the process suggests the validity of equation 1, and no other form of functional dependence is currently suggested by theory (see e.g. Doremus 2000, 2002; Ebert et al. 1991; Stevenson et al. 1989, 1998; Zhang et al. 1991). In fact, Haller argued, based on the physical chemistry of diffusion, 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). Use of another mathematical form, such as a power law or a polynomial, may give a better fit to a particular data set (as is the case here), but has no foundation in diffusion mechanics. Furthermore, the accuracy of an alternative fit is spurious, since it is simply fitting the experimental errors in the data set, and there is no guarantee that any new data points will fit. The analysis here uses the quadratic form only.

For the case of obsidian, the “hydration rate” is equivalent to the diffusion coefficient $D$ in equation 1. Also, the hydration rate varies with EHT (e.g. Hull 2001; Onken 2006; Ridings 1996; Rogers 2007a; Stevenson et al. 1989, 1998, 2004), with relative humidity (Friedman et al. 1994; Maier et al. 1991; Onken 2006; Rogers 2008a), and with structural water concentration in the obsidian (Ambrose and Stevenson 2004; Friedman et al. 1966; Rogers 2008c; Stevenson et al. 1998, 2000). The analysis below explicitly treats EHT, while humidity effects are typically small and are ignored. Structural water concentration has never been measured for Bodie Hills obsidian; however, since it is a “slow” obsidian, it is likely that structural water concentration is very low. Its chemical variability has not been characterized.

The analysis here controls for EHT by the temperature-dependent diffusion technique (Rogers 2007a, 2008c), which explicitly accounts for average annual temperature, mean annual temperature variation, mean diurnal temperature variation, and burial depth. It has been further shown that, although EHT exhibits a small dependence on the activation energy of the obsidian, the effect is second-order and can be ignored in practical analyses (Rogers 2007a).

The equation for EHT is

$$EHT = T_a \times (1-Y \times 3.8 \times 10^{-5}) + 0.0096 \times Y^{0.95}$$  \hspace{1cm} (2)

where $T_a$ is annual average temperature, and the variation factor $Y$ for surface artifacts is defined by

$$Y = V_a^2 + V_d^2,$$  \hspace{1cm} (3a)

in which $V_a$ is annual temperature variation (July mean minus January mean) and $V_d$ is mean diurnal temperature variation (Rogers 2007a).

For buried artifacts, $V_a$ and $V_d$ represent the temperature variations at the artifact burial depth, which are related to surface conditions by

$$V_a = V_{a0} \exp(-K_a z)$$  \hspace{1cm} (3b)

and

$$V_d = V_{d0} \exp(-K_d z)$$  \hspace{1cm} (3c)

where $V_{a0}$ and $V_{d0}$ represent nominal surface conditions and $z$ is burial depth (Carslaw and Chapman 1944; Rogers 2007a).
Jaeger 1959:81). Here $K_a$ and $K_d$ are the attenuation coefficients for the annual and diurnal temperature variations, respectively; they are related to the thermal diffusivity of the soil by the equation

$$K_{a,d} = \left( \frac{\pi}{dP_{a,d}} \right)^{\frac{1}{2}}$$  (4)

where $d$ is thermal diffusivity and $P_{a,d}$ is the period of the annual or diurnal temperature variation (1 day for diurnal, 365.25 days for annual). The value of $d$ varies between 0.0046 cm$^2$/sec for normal soil and 0.0020 cm$^2$/sec for dry sand (Carslaw and Jaeger 1959; App. 4). For this analysis a mean value of 0.0033 cm$^2$/sec was used. This dependence of temperature variation on depth is well attested in physics, geology, and soil science.

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

$$RCF = \exp[-0.06(EHT-EHT_r)]$$  (5)

where $EHT_r$ is effective hydration temperature at the reference site. The EHT-corrected rim value $r_c$ is then

$$r_c = RCF \times r$$  (6)

The rim value $r_c$ is used in the rate analysis.

**Temperature Scaling**

Computation of EHT by the method above requires three temperature parameters for the site, as shown in equations 2 and 3a: annual average temperature ($T_a$); annual temperature variation ($V_a$), defined as difference between the July average temperature and the January average temperature; and mean diurnal variation ($V_d$), defined as the average of the daily temperature ranges for July and January. In meteorological terms, $V_a$ is the annual range and $V_d$ is mean diurnal range.

Frequently there are no long-term meteorological records for the area of an archaeological site, so the parameters must either be scaled from a surrogate site or measured. Regional scaling is the method employed here (Rogers 2007b), which ensures that the parameters are 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).

The analysis which developed the scaling equations was based on monthly temperature data from the Western Regional Climate Center (WRCC), using the data base from 1971 – 2000. Since the obsidian-radiocarbon pairing data are from the western slope of the Sierra Nevada, the temperature analysis drew from sites in the same region. Eleven sites are represented, varying in altitude from sea level to 3700 feet above mean sea level (amsl), and in similar weather patterns. Details of the analysis may be found in Rogers 2008b.

The analysis showed the effects of a complicating factor not present east of the Sierra Nevada: the Central Valley temperature inversion layer at about 1500 feet, a well-known meteorological phenomenon. Below this altitude, all three temperature parameters are essentially independent of altitude, while above it they scale with altitude.

Annual average temperature, $T_a$, has an average value of 15.85°C below 1500 ft. Above 1500 ft the value of $T_a$ is given by

$$T_a = 19.44 - .0027x, \quad 1500 < x < 4000$$  (7)

where $x$ is altitude in feet. The 1-sigma accuracy is 0.42°C below 1500 feet and 0.14°C above.

Annual variation, $V_a$, again exhibited a break at about 1500 ft. The average value of $V_a$ below 1500 ft is 16.02°C, while above 1500 ft the value is

$$V_a = 20.75 - .0029x, \quad 1500 < x < 4000$$  (8)

The 1-sigma accuracy of this fit is 0.34°C below 1500 feet and 0.23°C above.

The scaling for diurnal variation, $V_d$, shows a poorer correlation with altitude. Since $V_d$ represents a difference of measured quantities, the instability is not unexpected. In addition, the data represent short-term phenomena and microclimates, which tend to be less stable than long-term parameters. For sites below 1500 ft, the best fit is the mean value of $V_d$ of 14.77°C; above
that altitude, the best fit is

\[ V_d = 18.57 - 0.0015x, \quad 1500 < x < 4000 \quad (9) \]

One sigma accuracy is 1.67°C below 1500 feet and 0.95°C above that level.

Finally, equations 7 – 9 can be combined with equations 2 and 3 to yield an approximate relationship between EHT and site altitude for the western slope of the Sierra Nevada. The equation is

\[ \text{EHT} = 18.91°C, \quad 0 \leq x \leq 1500 \text{ feet} \quad (10a) \]

\[ \text{EHT} = 23.89 - 0.0034x, \quad 1500 < x < 4000 \text{ feet}. \quad (10b) \]

When EHT is computed from equation 2 using parameters of the stated accuracies, the overall accuracy of EHT is 0.40°C below 1500 feet and 0.06°C at higher altitudes.

**Data Sets**

Three data sets are used in this analysis: radiocarbon data, obsidian data, and site temperature data. Obsidian-radiocarbon pairs used in this analysis are summarized in Table 1; all are from the western slope of the Sierra Nevada.

The first data set is the radiocarbon data, shown in Table 1. The time parameter in equation 1 must be measured from the date the rim was measured, which is closer to 2000 than to the 1950 “present” in the radiocarbon terms. Thus, in performing the analysis, 50 years was added to the radiocarbon age; the age equation must subsequently subtract 50 years to be in rcybp. Ideally the time should be in actual calendar, or clock, time, not radiocarbon years; However, an analysis showed that converting ages to calendar years did not improve the fit (probably due to the poor quality of the data), so the analysis was carried out in radiocarbon years.

The second data set is the obsidian data, also shown in Table 1. Since the hydration rims are expected to conform to a model of the form of equation 1, they should be approximately linear in a plot of rim-squared \((r^2)\) vs. time \((t)\). Figure 1 shows that the basic fit is rather poor. Not only is there scatter in the data, but the rim values are systematically too high for ages below 2500 rcy, and too low for ages above 2500 rcy.

The source of these errors could be one or more of three factors: laboratory errors in rim measurement, errors due to rate variations caused by chemical (especially intrinsic water) variations in the obsidian, or obsidian-radiocarbon association errors due to site formation processes. Rim measurement errors reported by laboratories are typically of the order of 0.01 - 0.05 μ, and may be expected to be consistent from one sample to the next. Figure 2 shows the observed error standard deviations for those samples with sample size \(N > 1\); it is clear that the errors are not consistent, and exceed the expected magnitude for laboratory errors. Further, it can be shown that the coefficient of variation (CV) for errors arising from rate variations should be independent of the age of the sample; Figure 3 shows this not to be the case. It is therefore likely that the errors are arising in the obsidian-radiocarbon association process due primarily to site formation processes, although the presence of multiple obsidian subsources in the data set, with slightly different hydration rates, cannot be entirely ruled out.

The third data set is comprised of the temperature parameters for the archaeological sites of Table 1. These parameters were computed from the site elevation data by equations 7 – 9, and are summarized in Table 2. Figure 4 shows the resulting surface EHT values.
Table 1. Obsidian-radiocarbon pair data from western Sierran slope sites. From Rosenthal and Waechter (2002).

<table>
<thead>
<tr>
<th>Seq. No</th>
<th>Site</th>
<th>Context</th>
<th>Elevation meters amsl</th>
<th>^14C BP</th>
<th>^14C BP +/− median intercept (cal BP) (µ)</th>
<th>Bodie Hills Rim Values (µ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CAL-991</td>
<td>Component 991A1, 0-20 cm Unit 4/5, Feature 3, 30-35</td>
<td>1005 250 60</td>
<td>300 1.3¹</td>
<td>1.2 1.2 1.3 1.4 1.4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>TUO-2197</td>
<td>cm</td>
<td>870 270 70</td>
<td>330 2.2</td>
<td>1.5 2.0 2.2 2.3 2.4 2.6</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Same as #2</td>
<td></td>
<td>870 270 50</td>
<td>340</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>TUO-407</td>
<td>Unit N104/E97: Feat 6 fill, 20 cm</td>
<td>610 320 110</td>
<td>363 1.9</td>
<td>1.8 1.9</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>CAL-114/H</td>
<td>Unit 7; Feature 2, 38-73 cm</td>
<td>1050 360 70</td>
<td>400 1.9²</td>
<td>1.3 1.6 1.7 1.7 1.8 2.4 3.1</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>AMA-56</td>
<td>Feature 1B: 60-76 cm</td>
<td>65 1160 60</td>
<td>1080 3.1</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>CAL-789</td>
<td>Unit S44/W30: 20-50 cm</td>
<td>450 1220 40</td>
<td>1160 3.6</td>
<td>3.3 3.6 3.6 3.7</td>
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</tr>
<tr>
<td>8</td>
<td>CAL-789</td>
<td>Unit S10/E20: 30-40 cm</td>
<td>450 1270 40</td>
<td>1210 3.4</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>PLA-695/H</td>
<td>Unit 95Q: 130-140 cm</td>
<td>670 1340 60</td>
<td>1255 3.8</td>
<td>3.5 3.8 4.0</td>
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<tr>
<td>10</td>
<td>SAC-60</td>
<td>Burial 38-11, 122 cm</td>
<td>2 1550 150</td>
<td>1465 4.0</td>
<td>3.8 4.1</td>
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</tr>
<tr>
<td>11</td>
<td>PLA-695/H</td>
<td>Unit 95F: 70-90 cm</td>
<td>670 2170 70</td>
<td>2175 4.5</td>
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<tr>
<td>12</td>
<td>SJO-142</td>
<td>Burial 18, 71 cm</td>
<td>0 2495 120</td>
<td>2560 4.8</td>
<td>-</td>
<td></td>
</tr>
<tr>
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<td>2580 3.9</td>
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<tr>
<td>14</td>
<td>SJO-68</td>
<td>Burial 23, 120 cm</td>
<td>0 3775 160</td>
<td>4155 4.9</td>
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<td></td>
</tr>
<tr>
<td>15</td>
<td>SJO-68</td>
<td>Cremation 1, 119 cm 90N/26E, Feat. 232, Black</td>
<td>0 4350 250</td>
<td>4950 5.5</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>CAL-629/630</td>
<td>Clay: 203-212 cm</td>
<td>305 8510 150</td>
<td>9050 7.3³</td>
<td>6.5 6.9 7.0 7.4 7.4 7.4</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Same as # 16</td>
<td>96N/25E, Green Clay, : 225-93E/26E, Feat. 232, Black</td>
<td>8630 145</td>
<td>9370</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>CAL-629/630</td>
<td>235 cm</td>
<td>305 9040 90</td>
<td>9990 7.3</td>
<td>6.4 6.6 6.8 7.4 7.5 7.5</td>
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</tr>
<tr>
<td>19</td>
<td>CAL-629/630</td>
<td>Clay: 170-200 cm 86N/23E, Black Clay: 190-93N/24E, Feat 212, Black</td>
<td>305 9230 100</td>
<td>10195 7.4</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>CAL-629/630</td>
<td>200 cm</td>
<td>305 9240 150</td>
<td>10200 8.2</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

¹ excludes outlier of 3.0; ² excludes outlier of 4.4µ; ³ excludes one outlier of 10.4µ; outliers removed using Chauvenet's Criterion

Fig. 1. Uncorrected rim data from the western Sierran slope.
Fig. 2. Sample standard deviation for hydration rims from western Sierran slope sites. Only samples with N>1 are included.

Fig. 3. Coefficient of variation (CV) for hydration rims from western Sierran slope sites. If they were due to rate variability, such as from obsidian chemistry variations, the values would be approximately equal.

Fig. 4. Surface EHT data for western Sierran slope sites. In performing the age coefficient analysis, EHT is corrected for depth for buried artifacts.
Table 2. Temperature data for western Sierra slope sites, based on temperature scaling derived from 30-year meteorological records.

<table>
<thead>
<tr>
<th>Seq. No.</th>
<th>Site</th>
<th>Context</th>
<th>Elevation meters asml</th>
<th>Elevation kft asml</th>
<th>Ta</th>
<th>Va</th>
<th>Yd</th>
<th>Y</th>
<th>EHTz</th>
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<tr>
<td>1</td>
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<td>Component 991A1, 0-20 cm</td>
<td>1005</td>
<td>3296</td>
<td>10.54</td>
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<td>TUS-2197</td>
<td>Unit 4/5, Feature 3, 30-35 cm</td>
<td>870</td>
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<td>14.29</td>
<td>359.71</td>
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<tr>
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<td>Unit N401/E97: Feat 6 fill, 20 cm</td>
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<td>2001</td>
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<td>14.94</td>
<td>15.57</td>
<td>465.70</td>
<td>17.08</td>
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<tr>
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<td>CAL-114/H</td>
<td>Unit 7; Feature 2, 38-73 cm</td>
<td>1050</td>
<td>3444</td>
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<td>10.76</td>
<td>13.40</td>
<td>295.41</td>
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<td>AMA-56</td>
<td>Feature 1B: 60-76 cm</td>
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<td>213</td>
<td>15.85</td>
<td>16.02</td>
<td>14.77</td>
<td>474.79</td>
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</tr>
<tr>
<td>7</td>
<td>CAL-789</td>
<td>Unit S44/W30: 20-50 cm</td>
<td>450</td>
<td>1476</td>
<td>15.85</td>
<td>16.02</td>
<td>14.77</td>
<td>474.79</td>
<td>18.91</td>
</tr>
<tr>
<td>8</td>
<td>CAL-789</td>
<td>Unit S10/E20: 30-40 cm</td>
<td>450</td>
<td>1476</td>
<td>15.85</td>
<td>16.02</td>
<td>14.77</td>
<td>474.79</td>
<td>18.91</td>
</tr>
<tr>
<td>9</td>
<td>695/H</td>
<td>Unit 95Q: 130-140 cm</td>
<td>670</td>
<td>2198</td>
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<td>439.86</td>
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<td>15.85</td>
<td>16.02</td>
<td>14.77</td>
<td>474.79</td>
<td>18.91</td>
</tr>
<tr>
<td>11</td>
<td>695/H</td>
<td>Unit 95F: 70-90 cm</td>
<td>670</td>
<td>2198</td>
<td>13.51</td>
<td>14.37</td>
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<td>439.86</td>
<td>16.40</td>
</tr>
<tr>
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<td>SJ0-142</td>
<td>Burial 18, 71 cm</td>
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<td>0</td>
<td>15.85</td>
<td>16.02</td>
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<td>18.91</td>
</tr>
<tr>
<td>13</td>
<td>CAL-789</td>
<td>Feature 1, 60-80 cm</td>
<td>450</td>
<td>1476</td>
<td>15.45</td>
<td>16.47</td>
<td>16.36</td>
<td>538.63</td>
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<tr>
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<td>SJ0-68</td>
<td>Burial 23, 120 cm</td>
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<td>0</td>
<td>15.85</td>
<td>16.02</td>
<td>14.77</td>
<td>474.79</td>
<td>18.91</td>
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<tr>
<td>15</td>
<td>SJ0-68</td>
<td>Cremation 1, 119 cm</td>
<td>0</td>
<td>0</td>
<td>15.85</td>
<td>16.02</td>
<td>14.77</td>
<td>474.79</td>
<td>18.91</td>
</tr>
<tr>
<td>16, 17</td>
<td>CAL-629/630</td>
<td>90N/26E, Feat. 232, Black Clay: 203-212 cm</td>
<td>305</td>
<td>1000</td>
<td>15.85</td>
<td>16.02</td>
<td>14.77</td>
<td>474.79</td>
<td>18.91</td>
</tr>
<tr>
<td>18</td>
<td>CAL-629/630</td>
<td>96N/25E, Green Clay, 225-235 cm</td>
<td>305</td>
<td>1000</td>
<td>15.85</td>
<td>16.02</td>
<td>14.77</td>
<td>474.79</td>
<td>18.91</td>
</tr>
<tr>
<td>19</td>
<td>CAL-629/630</td>
<td>93N/24E, Feat 212, Black Clay: 170-200 cm</td>
<td>305</td>
<td>1000</td>
<td>15.85</td>
<td>16.02</td>
<td>14.77</td>
<td>474.79</td>
<td>18.91</td>
</tr>
<tr>
<td>20</td>
<td>CAL-629/630</td>
<td>86N/23E, Black Clay: 190-200 cm</td>
<td>305</td>
<td>1000</td>
<td>15.85</td>
<td>16.02</td>
<td>14.77</td>
<td>474.79</td>
<td>18.91</td>
</tr>
</tbody>
</table>

Table 2. Temperature data for western Sierra slope sites, based on temperature scaling derived from 30-year meteorological records.

### Analytical Process

Since equation 1 is quadratic, the analysis process is to compute a linear least-squares best fit between $r^2$ and $t$, with the resulting slope being the rate. A simple form of the best fit slope for an equation constrained to pass through the origin can be found in many references (e.g. Meyer 1975:71ff., Cvetanovic et al. 1979). However, a critical assumption in using such an equation is that the independent variable be error-free, and all error be confined to the dependent variable. This is clearly not the case for obsidian, since significant experimental error exists in both variables; in fact, for the present data set the error CVs for both $t$ and $r^2$ are of the order of 30%, so use of the simple fit equations is inappropriate for this case. (This includes the built-in SLOPE and INTERCEPT functions in MS Excel – use of these functions can lead to incorrect answers.)

The error-in-both-variables problem can be avoided by using a best-fit algorithm which weights the data points by the sum-squared deviation from the best fit line, measured perpendicular to the line (Meyer 1975; called the Total Least Squares – TLS - algorithm by Van Huffel and Vandewalle 1991). This is the algorithm applied here.

Any least-squares best fit algorithm includes provision for weighting of individual data points, such that more confidence is placed on high-quality data points and less on lower-quality data (Cvetanovic et al. 1979). The TLS algorithm, as developed here, applies two types of weighting to the variables: error weighting, or weighting by the inverse of the error variance characteristic each data point; and judgmental weighting, a factor which assigns higher confidence to certain data points; the details of this procedure are discussed below.

For this analysis, age, $t$, is chosen as the independent variable, in accordance with the physical process, and the square of the hydration rim, $r^2$, is the dependent variable; change of variable weighting is applied to optimize errors in $r$ (Cvetanovic et al. 1979). With change of variable, the TLS algorithm for the slope (or hydration rate) is

$$m = \frac{-B + \sqrt{(B^2 + 4AC)}}{2A} \quad (11a)$$
where

\[ A = \sum w_i t_i r_i (\sigma_{t_i})^2 / \sigma_{m_i}^4 \]  
\[ B = \sum w_i [t_i^2 (\sigma_{r_i})^2 - r_i^2 (\sigma_{t_i})^2] / \sigma_{m_i}^4 \]  
\[ C = \sum 4 w_i t_i r_i (\sigma_{r_i})^2 / \sigma_{m_i}^4 \]  
\[ \sigma_{m_i}^2 = 4 r_i^2 (\sigma_{r_i})^2 + m_i^2 (\sigma_{t_i})^2 \]  

Here \( t_i \) is the age of the \( i \)th point, \( r_i \) is the EHT-corrected rim value, \( w_i \) is the judgmental weight, \((\sigma_{t_i})^2\) is expected error variance of the \( i \)th data point in the \( t \) dimension, \((\sigma_{r_i})^2\) is the corresponding error variance in the \( r \) dimension, and \( \sigma_{m_i}^2 \) is the error variance perpendicular to the best-fit line. Note that \((\sigma_{t_i})^2\) and \((\sigma_{r_i})^2\) refer to error statistics, not the instantaneous deviation of each point from the best-fit line. The implementation of this algorithm is iterative, because the unknown \( m \) occurs on both sides of equations 11.

For the first step, corrections for EHT were computed for each hydration rim value in Table 1. This entailed drawing the temperature parameters for each site from Table 2, and applying depth corrections per equations 3b and 3c. Using the depth-corrected parameters, EHT was then computed by equations 2 and 3, and the rim correction factor computed from equations 5 and 6. A reference EHT of 18.91°C was chosen, characteristic of the Central Valley below 1500 ft altitude.

Judgmental weights were chosen based on examination of the data of Table 1 and the plot in Figure 1. The baseline chosen was \( w_i = 1 \) for all data points. However, a greater weight \( w_i = 2 \) was assigned to the four data points which derived from burial contexts; this was because association in burials is usually better than in non-burial contexts, and also because burials tend to be excavated more carefully. Finally, a lesser weight \( w_i = 0.5 \) was assigned to the data points from CAL-629/630, due to the very large scatter in the data evident in Figure 1.

The values of \((\sigma_{t_i})^2\) and \((\sigma_{r_i})^2\) were developed iteratively by computing an initial best fit, observing data points for logical groupings, computing the variances for these groupings, and recomputing the best fit using the new variances. The process was repeated until the value of the age coefficient converged to a stable value, typically after four or five iterations.

This process led to computation of the age coefficient \( h \), the reciprocal of rate, which permits convenient computation of age by equation 12:

\[ t = hx^2 - 50 \]  

The results for an EHT of 18.91°C are:

\[ t_{rcybp} = 103.09r^2 - 50, \] for \( 0 \leq r \leq 8 \mu \)  

Potential errors in the age coefficient are, however, significant. If the same analysis is run with the data set excluding CAL-629/630, the age coefficient \( h \) is approximately 10% smaller than in equations 12 and 13; if the analysis is run on CAL-629/630 data alone the value of \( h \) is about 10% greater. Computing the slope based on burials alone results in an \( h \) value about 5% smaller. This confirms the marginal quality of the data set, because excluding parts of a data set should not lead to such large changes; there is no way to resolve these error sources once the input data are specified (Gerald and Wheatley 1984; Johnson and Riess 1982).

Although derived by the best numerical analysis techniques available, these age coefficients do not yield a particularly good fit archaeologically. In Table 3 the computed ages in rcybp are compared to the radiocarbon ages; the errors are summarized in Figure 5. Mean error is 107 years, which is reasonably good, but standard deviation is 796 years, which is not. Examination of Figure 6 shows there is also a systematic error present, with ages below 2500 rcybp consistently underestimated and ages over that age overestimated. Use of a power law with exponent greater that 2 will yield a closer fit; however, it represents a fit to the effects of site formation processes, and there is no reason to expect it to be significant. The error standard deviation of 796 yrs corresponds to an overall error margin in hydration age coefficient of about \( \pm 25\% \).
Table 3. Estimation errors from equations 12-13.

These values apply only to the reference temperature of 18.91°C, and the value of $h$ is very sensitive to EHT (which is why references to rates for “eastern slope” or “western slope” are overly simplistic and should be avoided). In fact the value of $h$ varies with EHT by the equation

$$h_s = h_r \times \exp[-.12(EHT_s - EHT_r)]$$  \hspace{1cm} (14)$$

where $h_s$ is the value of $h$ at a site being analyzed, $EHT_s$ is the surface EHT at that site, and $h_r$ is the value of $h$ at the reference EHTr. Combining the

![Graph showing estimation error in age. Error standard deviation is 796 years.](image-url)
value of $h$ from equation 13 with the EHT expression of equation 10, the suggested equations for the western slope of the Sierra Nevada are (with $z$ being altitude above mean sea level in feet)

$$t_{rcybp} = 103.09 r^2 - 50, \quad z \leq 1500 \text{ ft} \quad (15a)$$

$$t_{rcybp} = 56.71 \times \exp(0.00041z) \times r^2 - 50, \quad 1500 \text{ ft} < z < 4000 \text{ ft} \quad (15b)$$

Figure 6 presents these data graphically.

The value of age coefficient $h$ for the eastern slope of the Sierra, which scales from equation 13 by means of equation 14, presents an additional problem. Prior studies have shown that the EHT for the Bridgeport area is approximately $10^\circ C$ (Rogers 2008b). Since equations 12 and 13 are for an EHT of $18.91^\circ C$, the temperature difference is $8.91^\circ C$; the exponential factor in equation 14 then has a value of 2.91, so the age equation for the eastern Sierra becomes

$$t_{rcybp} = 300.31 r^2 - 50, \quad \text{for } 0 \leq r \leq 8 \mu. \quad (16)$$

The implications of this conclusion, in which the age coefficient seems much too large, are discussed below.

**Discussion**

The age equation for the western slope of the Sierra Nevada has been derived here to be

$$t_{rcybp} = 103.09 r^2 - 50, \quad z \leq 1500 \text{ ft} \quad (15a)$$

$$t_{rcybp} = 56.71 \times \exp(0.00041z) \times r^2 - 50, \quad 1500 \text{ ft} < z < 4000 \text{ ft} \quad (15b)$$

where $z$ is site altitude above mean sea level in feet. Rosenthal and Waechter (2002), based on a similar data set, proposed the equation

$$t_{rcybp} = 149.05 r^2 - 50, \quad \text{“below 914 m”} \quad (17)$$

This analysis predates temperature-dependent diffusion theory (Rogers 2007a), and the EHT analysis method was not described, nor is there any mention of depth correction. Furthermore, the altitude limit of 914 m corresponds to 3000 ft above mean sea level, not to the height of the meteorological inversion layer. As the hydration age coefficient is very sensitive to EHT, which in turn is very sensitive to meteorological conditions and to burial depth, the age coefficient in equation 17 must be treated with caution.

For eastern slope rates Rosenthal and Waechter proposed

$$t_{rcybp} = 169.39 r^2 - 50, \quad \text{“1820 to 2734 m”} \quad (18)$$

based on an analysis of time-sensitive projectile points. An alternative analysis of eastern slope rates by Rogers (2008d) yielded for an EHT of $9.83^\circ C$
\[ t_{\text{cybp}} = 177.59 r^2 - 50, \quad \text{for } 0 \leq r \leq 7\mu. \quad (19) \]

which is comparable in magnitude to equation 18. The problem is that neither equation 18 nor 19 agrees with equation 16, where the age coefficient is 300.31 rcy/\(\mu^2\). There is no question that the age coefficient scales with EHT by equation 14; there is also no question that the EHT on the eastern slope is at least 6 - 9°C lower than on the western slope. Then by equation 14 the age coefficient on the eastern slope must be greater than on the west by a factor of 2 – 3, which is certainly not the case in comparing equations 18 and 19 with equation 16. This is a fundamental problem.

One way to assess realism of the age coefficients is to use Halford’s 2002 data from the eastern slope (Halford 2002) and focus on Rose Spring projectile points. The advantage of Rose Spring points is that they were constrained to a fairly tight time interval, the Haiwee period. Yohe concluded that bow and arrow technology (including Rose Spring points) was well established at Rose Spring by 1600 BP (Yohe 1992, 1998). Similarly, it is generally agreed that Rose Spring point types were superseded by Desert and Cottonwood series by about 650 BP. The median for this interval is 1125 rcybp, or 1175 radiocarbon years corrected to 2000. Halford reported a sample of 11 Rose Spring points made of Bodie Hills obsidian, from known proveniences whose EHT could be assessed. The mean is 2.3 \(\pm\) 0.73\(\mu\). Computing the age coefficient from these data alone yields a value of 222.12 \(\pm\) 84.36 yrs/\(\mu^2\), which is closer to the value in equation 16 than are the values in equation 18 or 19; if the point sample happened to be derived from a time earlier than the mid-point of the Haiwee period, the agreement is closer yet. However, if the age coefficient of equation 16 (300.31 rcy/\(\mu^2\)) is used to compute the ages corresponding to Halford’s projectile point hydration rim data, the ages are far too large, falling outside the expected age bands; even the Rose Spring rate of 222.12 yrs/\(\mu^2\) gives ages which are generally too large.

**Conclusions**

The errors inherent in the data set of Table 1 are evident, and are probably due to site formation processes which have introduced errors in the obsidian – radiocarbon associations. Equation 15 is usable, but the hydration age coefficients are probably no more accurate than \(\pm 25\%\), and chronometric analyses more fine-grained than this should not be attempted. For the eastern side of the Sierra Nevada, equation 19 is probably preferable, although again with the caveat that accuracy is no better than \(\pm 25\%\).

The data for each side of the Sierra Nevada yield internally-consistent rates and age coefficients. However, the age coefficients for eastern and western slopes are not consistent with each other when temperature scaling is taken into account. The western slope data reported in this paper, although fraught with problems arising from site formation processes, give an age coefficient which agrees to some degree with radiocarbon data. The eastern slope data reported elsewhere (Halford 2002; Rosenthal and Waechter 2002; Rogers 2008d) yield age coefficients which give consistent, although again equivocal, agreement with ages for temporally-sensitive projectile points in that area. However, the age coefficients on the two sides of the Sierra Nevada are not consistent with known temperature differences between the two regions. This issue cannot be resolved until better data on the chemistry, potential chemical variability, and possible rate variability of Bodie Hills obsidian are available.

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References Cited
Ambrose, W. R., and C. M Stevenson
Anovitz, Lawrence M., J. Michael Elam, Lee R. Riciputi, and David R. Cole
Carslaw, H. S., and J. C. Jaeger
Cole, F. W.
Crank, J.
Cvetanovic, R. J., D. L. Singleton, and G. Paraskevopoulos
Doremus, R. H.
Ebert, W. L., R. F. Hoburg, and J. K. Bates
Friedman, Irving, Robert I. Smith, and William D. Long
Gerald, C. F., and P. O. Wheatley.
Halford, F. K.
Haller, W.
Hull, Kathleen L.
Johnson, L. W., and R. D. Riess
Mazer, J. J., C. M. Stevenson, W. L. Ebert, and J. K. Bates
Meyer, S.
Onken, Jill
Ridings, Rosanna
Rogers, Alexander K.


Rosenthal, Jeffrey S. and Sharon A. Waechter
2002 *Results of Phase-II Test Excavations at CA-ELD-616/H near Cool, Western El Dorado County*. Report prepared for CalTrans District 03, Marysville, California.

Stevenson, Christopher M., J. Carpenter, and B. E. Scheetz

Stevenson, Christopher M., J. J. Mazer, and B. E. Scheetz

Stevenson, Christopher M., Mike Gottesman, and Michael Macko

Stevenson, Christopher M., Ihhab M. Abdelrehim, and Steven W. Novak

Van Huffel, S., and J. Vandewalle

Wagner, Carl

Yohe, R. M. II


Zhang, Youxue, E. M. Stolper, and G. J. Wasserburg
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