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NEWS AND INFORMATION

IAOS Meeting at the SAA

Please join us for our annual meeting during the SAAs in Chicago from 12-1pm on Saturday, April 2, 2022. Please see your SAA program for location.

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 IAOS.Editor@gmail.com. Thank you for your help and support!

Call for Nominations

Please consider submitting a self-nomination for the position of IAOS President. The President oversees the annual IAOS business meeting, makes decisions in conjunction with the executive board on IAOS activities, and steers the organization in the fulfillment of its mission. Self-nominations should outline your qualifications and your vision for the future of the IAOS. Candidate statements will be sent to the membership, with elections soon to follow and the winner announced at the 2022 IAOS meeting at the SAAs. The winner will then serve as President-Elect for one year and begin the term of President in 2023. If you, or someone you know, would be interested in serving as IAOS President, please send a nomination and candidate statement to Sean Dolan, IAOS President, at sgdolan@gmail.com

NOTES FROM THE PRESIDENT

Hello IAOS members, we are finally nearing the end of 2021! There are several things to look forward to in the new year, like the return to in-person conferences. The Society for American Archaeology (SAA) meeting will be in Chicago from March 30-April 3. The IAOS business meeting will be on Saturday, April 2, from 12-1 pm, so please join us if you attend the SAA. It will be our first in-person meeting since 2019 when we met in Albuquerque. While I understand the practicality of Zoom meetings and online conferences, especially during a pandemic, I look forward to giving in-person talks again. I gave a few online talks in 2021, but they are less fun because I cannot see or engage with the audience. But as a prominent Chaco Canyon archaeologist told me this year, “at least they can’t tell what you’re drinking in your cup when it’s online!”

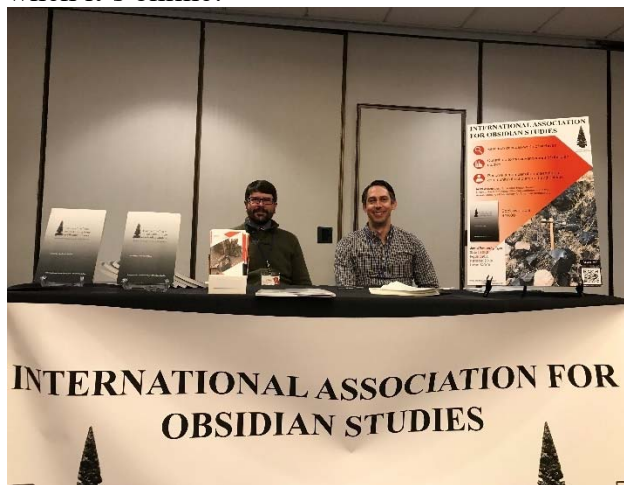


Figure 1. Lucas and Kyle at the Great Basin Anthropological Conference in Las Vegas, Nevada.

The IAOS was very active in 2021, and I thank Lucas Johnson, Carolyn Dillian, Craig Skinner, and Kyle Freund for their support. For example, the IAOS increased its membership, and Lucas and Kyle attended the Great Basin Anthropological Conference in Las Vegas, Nevada. Because of their presence, the IAOS had a booth and was a Platinum sponsor for the

conference. Also, the IAOS was one of the hosts for the International Obsidian Conference (IOC). The IOC was well-received, with many researchers presenting new and exciting work. The videos are available on YouTube, and you can find a link on the IAOS website.



Figure 2. The IAOS table at the Great Basin Anthropological Conference, Las Vegas, Nevada.

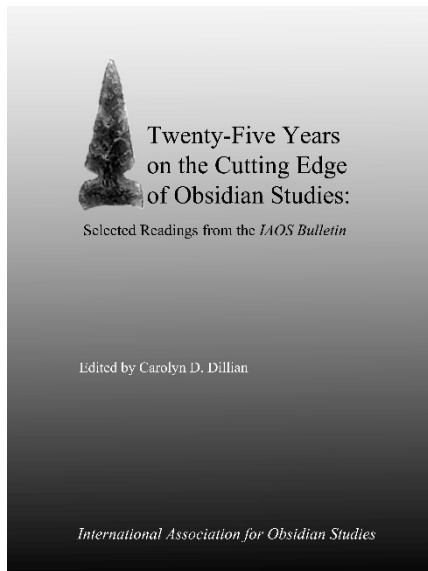
Over the years, Craig Skinner has put a lot of time and effort into making the IAOS website the best place to find obsidian-related content. However, I noticed that two of the obsidian sources that I have written about, Antelope Wells and Mule Creek, both in New Mexico, did not have bibliographic information. So, I compiled published articles, dissertations, and videos that discuss both sources. I sent the documents to Craig, and he kindly put them on the U.S. Obsidian Source Catalog page. Several other obsidian sources need bibliographic information, and I encourage IAOS members to contribute their knowledge.

This year, Steve Shackley and I published an article in *American Antiquity* on the significance of the lack of Mesoamerican obsidian in the prehispanic United States Southwest and Mexican Northwest (SW/NW) and the presence of Mesoamerican obsidian in the SW/NW after 1540 and the Coronado expedition. I started this research in 2018, and I presented an earlier draft of the paper at the 2019 SAA in the session honoring Steve. One

of the lessons I learned during this study was that there are a lot of understudied collections curated in museums and repositories. In other words, there are so many obsidian artifacts that have not been analyzed using X-ray fluorescence or neutron activation analysis. I hope to see more interest in studying obsidian procurement and lithic technology during the sixteenth century in the United States. The movement of the Spanish and their Mexican Indian allies from Central Mexico into Arizona, New Mexico, Texas, and other states is of profound interest among archaeologists and historians. There may be more Coronado-era sites that yield obsidian from sources in Mesoamerica.

Finally, please consider submitting an article, research update, or lab report to the *IAOS Bulletin*. You can submit your work to Carolyn Dillian at IAOS.Editor@gmail.com. Lastly, starting in January, please renew your IAOS membership dues. The dues help support the IAOS by supporting research through awards such as the Craig E. Skinner Poster Award given at the IOC and the SAA.

Sean Dolan, IAOS President
sgdolan@gmail.com



Twenty-Five Years on the Cutting Edge of Obsidian Studies: Selected Readings from the IAOS Bulletin

Edited volume available for purchase online!

As part of our celebration of the 25th anniversary of the IAOS, we published an edited volume highlighting important contributions from the *IAOS Bulletin*. Articles were selected that trace the history of the IAOS, present new or innovative methods of analysis, and cover a range of geographic areas and topics. The volume is now available for sale on the IAOS website for \$10 (plus \$4 shipping to U.S. addresses).

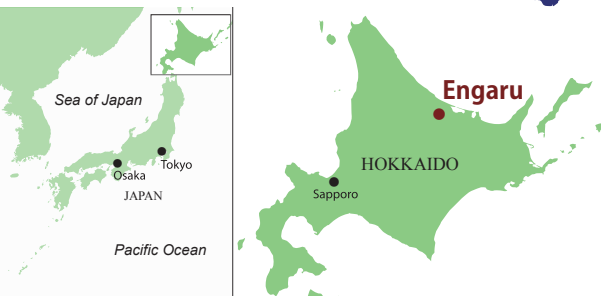
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International addresses, please contact us directly at IAOS.Editor@gmail.com for shipping information.



International Obsidian Conference 2023 Engaru

3-6 July 2023
Metroplaza (Engaru Town)



Scheduled sessions:

- Formation of obsidian from geological aspect
- Obsidian sources and their characterization
- Analytical methods and obsidian database
- Cultural aspects of obsidian by archaeological periods
- Lithic technology and traceological studies
- Geological heritage and regional development with archaeological obsidian

Conference excursion:

We are going to visit Shirataki obsidian source and Shirataki Geopark Museum.
Route of the excursion under planning can be found at the following website (link to Google Maps).
<https://www.google.com/maps/d/edit?mid=1CSJs5dN25IyZQSZcpXsnXcLNRjQvFfOb&usp=sharing>

1st Circular will be distributed in April 2022.

Local Organizing Committee,

Chair: A. Ono (ono@tmu.ac.jp),

Secretariat: Y. Matsumura (y.matsumura@engaru.jp)

Further information will be available on the Shirataki Geopark website
(<http://geopark.engaru.jp/ioc2023>)

AN EQUATION TO COMPUTE ACCURACY OF OBSIDIAN HYDRATION DATING AGES

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Abstract

Obsidian hydration dating (OHD) is based on computing the age of an obsidian artifact by measuring water absorption since the artifact was created. Unlike radiocarbon, it depends on both compositional and post-depositional processes, which affect the accuracy of the computed age. Our analysis assumes hydration measurement by optical microscopy, since it is the archaeological standard today in the western United States, and includes the effects of obsidian composition, temperature, humidity, measurement accuracy, and analytical method. We analyze the standard method for computing OHD age, and discuss the magnitudes of the resulting error sources. We conclude that the accuracy of OHD ages, computed using current methods, is unlikely to be better than $\approx 25\%$ for fast-hydrating obsidians like Coso, ranging down to $\approx 14\%$ for slow-hydrating obsidians like Bodie Hills. We propose a simple equation for archaeologists to use in estimating age uncertainty, which requires knowing only the geochemical source of a specimen, the hydration rate for the source, and the hydration rim measurement.

Introduction

Obsidian hydration dating (OHD) is based on computing the age of an obsidian artifact by measuring water absorption since the artifact was created. Thus, unlike radiocarbon, it depends on both compositional and post-depositional (environmental) processes, and these processes affect the accuracy of the computed age. This paper calculates the achievable accuracy of OHD, including the effects of obsidian composition, post-depositional temperature and humidity history, and measurement accuracy by the laboratory. The analysis expands upon previously-published accuracy studies (Rogers 2008a, 2010). Measurement of hydration by optical microscopy is assumed, since it is the industry standard today in the western United States. Most archaeological practitioners who apply OHD compute age but do not attempt to compute a standard deviation (although see Rogers and Yohe 2014 for a counter-example). We propose here a simple

method to compute the standard deviation of age.

Obsidian Structure and Hydration

Obsidian is an alumino-silicate, or rhyolitic, glass, formed by rapid cooling of magma under the proper geologic conditions. Like any other glass, it is not a crystal, and thus it lacks the lattice structure typical of crystals at the atomic level, but it does possess a matrix-like structure exhibiting some degree of spatial order (Doremus 1994:27, Fig. 2; 2002:59-73). Obsidians are typically about 75% SiO₂ and about 20% Al₂O₃ by weight, the remainder being matrix modifiers (mostly alkaline oxides) and trace elements (mostly rare-earth elements), some of which are source-specific (Doremus 2002:109, Table 8.1; Hughes 1988; Stevenson et al. 1998; Zhang et al. 1997). The anhydrous composition (chemical composition independent of water) of obsidians from a wide variety of sources has been shown to be remarkably consistent, within a few tenths of

a weight percent (Zhang et al. 1997). The minute interstices within the glass matrix, on the order of 0.1 - 0.2 nanometer in diameter, are where water penetration takes place.

Obsidian anhydrous chemistry has traditionally been regarded as having a major influence on hydration rate (see attempts to determine a chemical index to hydration, e.g. in Friedman and Long 1976 or Stevenson and Scheetz 1989). In archaeological analyses, anhydrous chemistry is controlled by grouping and analyzing the obsidian by geochemical source, based on trace element composition as determined by X-ray fluorescence (XRF) or neutron activation analysis. However, Stevenson et al. (1998, 2000) found no consistent influence of anhydrous chemistry on hydration rate. Zhang and Behrens (2000) and Behrens and Nowak (1997) found the effect of anhydrous chemistry to be negligibly small, although Karsten et al. (1982) reported that Ca^{2+} concentration may influence hydration rate to a very slight extent. It now appears that anhydrous chemistry has a negligible effect on hydration rate and attempts to predict hydration rate from anhydrous composition are unlikely to succeed.

All obsidians also contain small amounts of natural water, known as intrinsic water or structural water, resulting from the magma formation process; the amount is generally <2% by weight (wt%) in natural obsidians, although cases of somewhat higher concentration are occasionally encountered. Obsidian forms from a melt which is primarily silica and alumina; the melt is a liquid, with no internal order at the molecular level. As the temperature decreases the degree of order increases as the glass network starts to form. If there are no modifier ions present, the network forms with the interatomic spacing characteristic of its composition, about 0.86Å (twice the doorway radius, Doremus (2002:67)). Modifier ions present in the melt, such as water, cause the glass to form

interstices around them (Shelby 2005:145). The radius of a water molecule is in the range of 1.38 - 2.33Å (Doremus 2002:63), so the diameter is roughly 4Å. This leads to much larger interstices than for the water-free case, which represent voids in the glass matrix and hence greater openness, which leads to increased hydration rate (Garofalini 2020; Kuroda et al 2018, 2019; Kuroda and Tachibana 2019).

Thus, intrinsic water has a profound effect on hydration rate, which increases with increasing water content (Behrens and Nowak 1997; Delaney and Karsten 1981; Karsten et al. 1982; Lapham et al. 1984; Rogers 2015; Rogers and Stevenson 2017a; Stevenson et al. 1998, 2000, 2019; Zhang et al. 1991; Zhang and Behrens 2000). Four methods are currently used for measuring intrinsic water in obsidian: micro-densitometry (Ambrose and Stevenson 2004; Stevenson et al. 2019); mass loss when obsidian powder is baked (Newman et al. 1986; Steffen 2005); infrared (IR) transmission spectrometry (Newman et al. 1986); and IR photo-acoustic spectrometry (Stevenson and Novak 2011). However, micro-densitometry has proven to be unreliable, and the other three techniques are costly and, as currently practiced, are destructive to the artifact. As a result, intrinsic water measurement is not conducted for most practical archaeological investigations in the United States today.

Stevenson et al. (1993) analyzed the intrinsic water content of obsidians from the Coso source in eastern California. Coso was known to have four geochemically distinct subsources (Hughes 1988), and Stevenson demonstrated that (a) the mean intrinsic water content of the subsources varied, and (b) there was significant variation within each subsurface. The variation in intrinsic water within a geochemical source or subsurface leads to variations in hydration rate, which in turn increase the uncertainty (statistical error) in computed ages. From a practical standpoint,

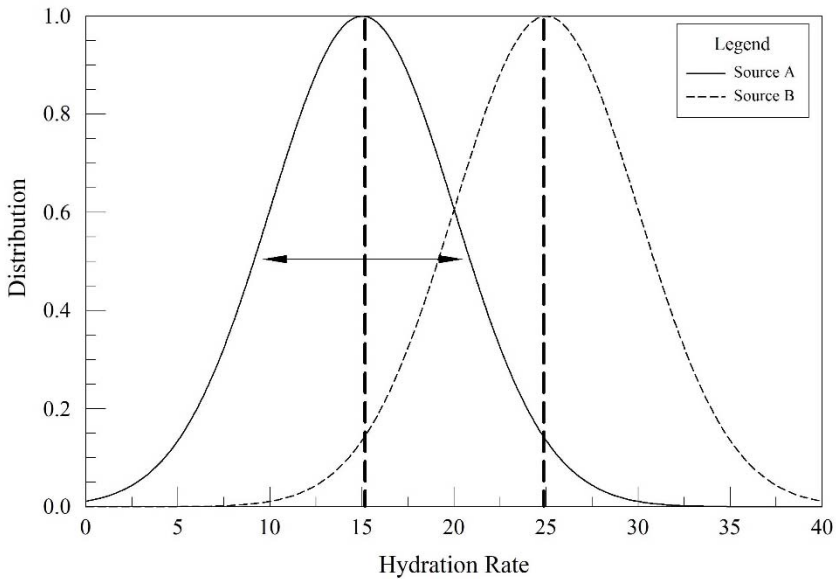


Figure 1. Hydration rate distributions for two notional obsidians. The spread is caused by intra-source variations in intrinsic water. Sourcing controls for central tendency (vertical dashed lines); intra-source variations (horizontal arrow) add to age uncertainty.

controlling for geochemical source actually functions as a proxy for controlling for intrinsic water (Stevenson et al. 2000), albeit rather poorly (Stevenson et al. 1993; Rogers 2008a). Figure 1 illustrates the process. Sourcing controls for the mean value (central tendency) of intrinsic water in the obsidian from that source; the uncontrolled intra-source variation in water content contributes to uncertainty in the age, and is reflected in the standard deviation of age.

Water in glass exists in two species, molecular water (H_2O_m), and hydroxyl (OH). The water trapped in the glass as the melt cools is H_2O_m , some of which reacts with oxygen atoms bound to the glass matrix to form OH. The molecular water is free to diffuse, while the hydroxyl is chemically bound to the glass matrix (Doremus 1994:198; 2001:129). The sum of H_2O_m and OH is total water (H_2O_t), which is the basis of this analysis.

OHD Method Overview

We term the standard method of performing an OHD analysis the Ascribed Rate method, since the hydration rate is ascribed to the geochemical source of the obsidian and is not measured for each

specimen. Hydration is measured by cutting a thin slice from the margin of an artifact with a diamond saw, mounting it on a microscope slide, polishing it to transparency, and observing it under a polarized light microscope. The thickness of the hydrated layer (the “rim” or “rind”) is on the order of microns, so typically an optical magnification of 400X or more is used. Age is computed from the equation

$$t = r^n/k \quad (1)$$

where t is age, r is the rim value, k is the hydration rate, and n is an exponent. Laboratory data (Rogers and Duke 2011; Stevenson and Scheetz 1989; Stevenson et al. 1998, 2019) indicate that the value of n is 2 within limits of experimental error (Rogers 2007, 2012). Although other equations have been proposed (e.g. Basgall 1991; Pearson 1995), 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.

Once a geochemical source and a value of hydration rim are obtained by a laboratory, two further steps are required prior to chronological analysis: obtaining a hydration

rate and controlling for the temperature history of the specimen. A mean rate for a geochemical source may be determined by any of a number of methods: obsidian-radiocarbon association, temporally sensitive artifacts, or accelerated hydration in the laboratory (summarized in Rogers and Stevenson 2020) are typical methods. Thus, as shown in Figure 1 above, the geochemical source is employed as a proxy for controlling for intrinsic water content. Any intra-source variation in water content is also ascribed to the source, based on IR measurements and the Beer-Lambert law (Newman et al. 1986), which permits computing a contribution to the age uncertainty. However, the intrinsic water content of the individual specimen is not measured.

Archaeological obsidian data must also be adjusted to control for temperature, since the rim value and rate in equation (1) must be for the same temperature. The rate k is a function of absolute temperature (T), by the Arrhenius equation

$$k = k_0 \cdot \exp[-E(w)/RT] \quad (2)$$

where k_0 is the pre-exponential and E is the activation energy. Note that k_0 is in the same units as k , and is not a function of temperature; E is in J/mol, and R is in J/(mol*K). The activation energy is a function of intrinsic water content, which causes the hydration rate to vary with water content as well. Archaeological temperatures vary in a complex manner: diurnally, monthly, and longer term and significantly affect the hydration rate. The effects of the varying temperature are summarized by the effective hydration temperature (EHT), defined as a single temperature which yields the same hydration results as the actual varying temperature over the same time. Due to the mathematical form of the dependence of hydration rate on temperature (Rogers 2007:658, equation 11 or equation 24a), EHT

is always higher than the mean temperature (except in the uninteresting case of a constant temperature, in which case they are the same). Effective hydration temperature is typically computed from meteorological records or on-site sensors; computation methods are described in Rogers (2007, 2012) and Rogers and Stevenson (2020), and are not described further here.

Sources of Age Error

The sources of error in the age computation have been analyzed in detail (Rogers 2008a, 2010), and the primary contributors to age uncertainty have been found to be intra-source variations in intrinsic water and uncertainties in temperature history, as discussed above. Other sources include errors in measurement of the optical hydration rim and variations in humidity history. Measurement of the hydration rim by optical microscopy typically yields a rim value in the range of 0 – 20 μ . Larger values may occur but are infrequent, because the creation of the hydrated layer leads to stress build-up, and larger rims typically spall off as perlite (Friedman et al. 1966). The laboratories making the readings report both a mean and standard deviation, which are based on six repetitions of the measurement. The standard deviation is typically in the region of 0.06 – 0.1 μ , so $\sigma_r = 0.08\mu$ is used here as a nominal value. It will be shown below that the uncertainty in hydration rim measurement has only a small effect on age accuracy.

Uncertainties in EHT are due to uncertainties in modeling the temperature history and are typically on the order of 1°C (Rogers 2007, 2008b). However, it should be noted that other sources of EHT error exist in some cases, due to site formation processes. Significant turbation of the stratigraphy of a site can alter the temperature history experienced by an artifact, which adds another error term. This additional term can be evaluated numerically, but since it has been

analyzed in detail in Rogers and Stevenson 2020, and is not always present, we do not treat it further here.

Humidity effects on hydration have been examined by Ebert et al. (1991), Friedman et al. (1994), and Mazer et al. (1991). Mazer et al. (1991) reported that the hydration rate was relatively unaffected by humidity, as long as humidity was under about 80%. Above that level, the hydration rate increased by a factor of approximately 1.2 between 90% and 100% relative humidity, so clearly there is an effect. Humidity trends, unlike temperature trends, are highly random and are virtually impossible to model deterministically, so are most conveniently incorporated statistically, as will be described below. Finally, current practice in evaluating the uncertainty in hydration rate partitions the uncertainty between uncertainty in the rate ascribed to the source and uncertainty due to intra-source variations in water content (i.e. specimen-to-specimen variation).

Error/Uncertainty Quantification

The computation of age based on obsidian hydration employs the model of equation (1). The preferred value of n , based on both physics and experimental data, is $n = 2$. Analysis of uncertainties is based on propagation-of-error theory (Cvetanovic et al. 1979:51ff., Taylor 1982:173-175). If a dependent variable y is a function of a number of independent variables x_1, x_2, \dots, x_n , and the errors are independent, the standard deviation of y , σ_y , is given by

$$\sigma_y^2 = \sum (\partial y / \partial x_i)^2 * \sigma_{x_i}^2 \quad (3)$$

where the sum is taken over all n variables. In this case the dependent variable is t in equation (1), so

$$\sigma_t^2 = (\partial t / \partial n)^2 * \sigma_n^2 + (\partial t / \partial r)^2 * \sigma_r^2 + (\partial t / \partial k)^2 * \sigma_k^2 \quad (4)$$

After some algebra this reduces to

$$CV_t^2 = (2 * CV_r)^2 + CV_k^2 \quad (5)$$

where CV = coefficient of variation (standard deviation divided by mean value) and the subscripts refer to the specific variable; thus, CV_t is the coefficient of variation of the computed OHD age.

Determining the uncertainty in hydration rate (CV_k) follows the same logic. The rate k is a function of intrinsic water content (w) and absolute temperature ($T = EHT$), by the Arrhenius equation (equation (2), above), so any uncertainties in EHT will be reflected in the computed age. Again, by equation (4) above, the uncertainty in rate is

$$\sigma_k^2 = (\partial k / \partial T)^2 * \sigma_T^2 + (\partial k / \partial w)^2 * \sigma_w^2 \quad (6)$$

The uncertainty in rate due to uncertainty in EHT , expressed as the CV , is the first term of equation (6)

$$CV_{EHT} = [E / (R * T^2)] * \sigma_{EHT} \quad (7)$$

where σ_{EHT} is the standard deviation of the computed EHT . If EHT is computed carefully, $\sigma_{EHT} \approx 1.0^\circ C$, but current methods are unlikely to get much better (Rogers 2007, 2012); also, $[E / (R * T^2)] \approx 0.11$ for typical archaeological conditions, so

$$CV_{EHT} = 0.11 * \sigma_{EHT} \quad (8)$$

This is the value used in the analysis.

Determining the uncertainty due to water content (second term of equation (6)) involves partitioning the uncertainty between a mean rate, which is ascribed to the geochemical source (CV_{ks}), the rate variations due to intra-source variations in intrinsic water (CV_{ke}), and rate variations due to humidity (CV_{hum}); all three components are subject to uncertainty. Typical values of CV_{ks} range from 5 – 15% (Rogers and Stevenson 2017b). The value of CV_{ke} depends on the intra-source variation in water content, and can be estimated from the

equation relating hydration rate, water content, and temperature:

$$k = \exp(37.76 - 2.289 * w - 10433/T + 1023 * w/T) \quad (9)$$

where k is hydration rate in $\mu^2/1000$ years, w is total intrinsic water content in wt%, and T is temperature in K (Rogers 2015; Rogers and Stevenson 2017a). If the method of equation (3) is applied to equation (9), the result is

$$CV_{ke} = (1023/T - 2.289) * \sigma_w \quad (10)$$

where σ_w is the standard deviation of intrinsic water content in wt%. For typical archaeological conditions the quantity in parentheses ≈ 1.2 .

The uncertainty contribution due to humidity variations is estimated from the reported factor of 1.2 in rate (Mazer et al. 1991) and corresponds to a coefficient of variation of about 6% in rate ($= 0.20/\sqrt{[12]}$), so

$$CV_{hum} = 0.06 \quad (11)$$

Thus, the uncertainty in OHD age is

$$CV_t^2 = (2 * CV_r)^2 + CV_{ks}^2 + CV_{hum}^2 + CV_{EHT}^2 + CV_{ke}^2 \quad (12)$$

The uncertainties are treated as independent, since there is no reason to expect mutual dependence.

A Practical Equation for Archaeologists

The analysis to this point has included a number of parameters which are not accessible to the practicing archaeologist, who usually knows the geochemical source for the specimens, the appropriate hydration rate for that source, and the measured hydration rim, but is not in a position to estimate the error terms. Here we derive a simple equation to satisfy the needs of archaeological analysis. We start with equation (12), in which the coefficient of variation of the computed age (CV_t) is composed of the square root of the sum of the squares of five terms: a term quantifying uncertainty due to hydration rim measurement, which varies with the rim value; three terms including uncertainty in EHT, humidity, and ascribed rate, all of which are constant; and a term defining the uncertainty due to intra-source variations in water content, which varies with water content. Rate variations due to intrinsic water variation are described by equation (10), and, for typical archaeological temperatures, is

$$CV_{ke} = 1.2 * w * CV_w \quad (13)$$

Source	Hydration rate, $\mu^2/1000$ yrs. at 20°C	Total water, wt%	Std. dev. total water, wt%	CV_w	N	Reference
Bodie Hills Group 2	10.03	0.113	0.035	0.311	86	(1)
Bodie Hills Group 1	11.25	0.208	0.062	0.298	27	(1)
Coso West Sugarloaf	18.14	0.620	0.160	0.258	22	(2), (3)
Coso Joshua Ridge	22.27	0.810	0.300	0.370	63	(2), (3)
Coso Sugarloaf Mountain	29.87	1.020	0.180	0.176	21	(2), (3)

* Data for Coso West Cactus Peak are not shown, since they appear to be bimodal and may represent an unresolved subsurface. (1) Stevenson et al. n.d.; (2) Rogers 2008a, 2011; (3) Stevenson et al. 1993

Table 1. Bodie Hills and Coso* obsidian source data.

The coefficient of variation of intrinsic water (CV_w) can be estimated from the data in Table 1.

Per Table 1, the CV_w is in the range of 20 – 35%; if 30% can be chosen as a nominal value, $CV_{ke} = 0.36 * w$.

The water content w in turn is related to hydration rate and temperature by equation (9). Figure 2 shows a plot of $(CV_{ke})^2$ as a function of source hydration rate k ; a linear best fit equation is

$$(CV_{ke})^2 = 0.007 * k - 0.0763 \quad (14)$$

where k is the source hydration rate in $\mu^2/1000$ years at EHT = 20°C. For the constant term, typical values are $CV_{EHT} = 0.11$, $CV_{hum} = 0.06$, and $CV_{ks} = 0.05$; the constant term is the sum of the squares, or 0.0182. Then the uncertainty in age, CV_t is

$$CV_t = \text{sqrt}[(0.16/r)^2 + 0.007 * k - 0.0581] \quad (15)$$

Thus, knowing source and source rate k , and the hydration rim r for each specimen, the archaeologist can perform EHT adjustments and then compute age by equation (1) and age

uncertainty by equation (15). Age standard deviation is then $\sigma_t = t * CV_t$. Of course, if measurements of intrinsic water are available, it is preferable to compute CV_t by equation (12). Equation (15) agrees with equation (12) to within ± 0.015 rms.

Conclusions

Equation (16) enables the archaeologist to obtain a quantitative estimate of accuracy of the age determined by OHD, using only those parameters readily at hand – source, source rate, and hydration rim. The accuracy of OHD ages, computed using current methods, is unlikely to be better than $\approx 25\%$ for fast-hydrating obsidians like Coso, ranging down to $\approx 14\%$ for slow-hydrating obsidians like Bodie Hills. For context, a radiocarbon age of 10,000 years with a standard deviation of 100 years corresponds to a $CV_t = 1\%$.

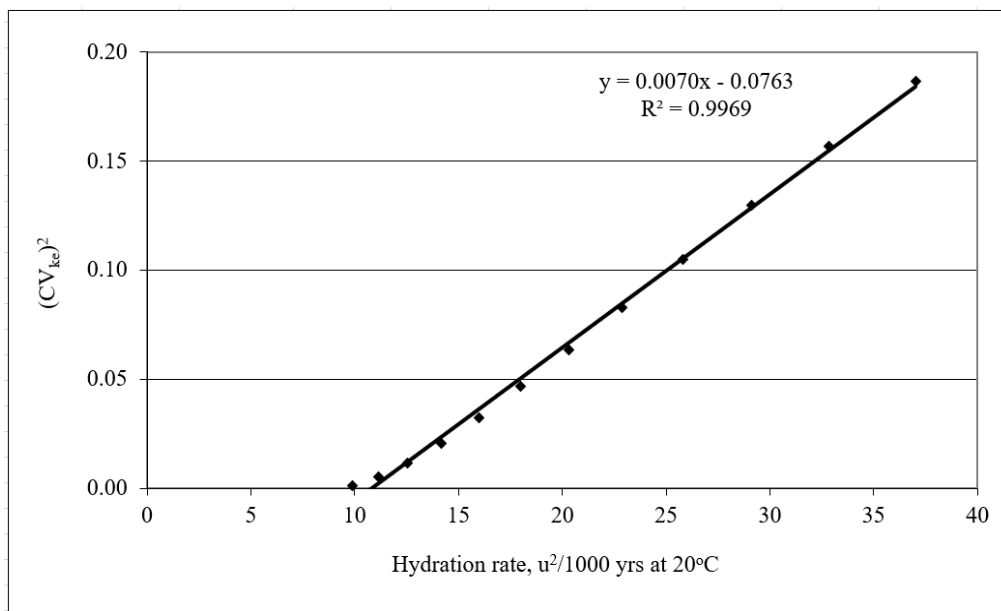


Figure 2. Linear least squares best fit to CV_{ke} vs hydration rate k . Hydration rate is in $\mu^2/1000$ years at an EHT of 20°C.

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FORMATIVE OBSIDIAN PROCUREMENT AND PRODUCTION IN SALINAS LA BLANCA, GUATEMALA

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Abstract

Museum collections of archaeological objects are a valuable source of data about past societies. This paper presents a new technical and geochemical analysis of obsidian excavated by Michael Coe and Kent Flannery in the 1960s from the archaeological site of Salinas La Blanca, Guatemala, housed at the Yale Peabody Museum of Natural History. The analyses demonstrate the changing patterns of obsidian use and procurement practices of the people of Salinas La Blanca over a one thousand year period.

Introduction

The Pacific Coast and highlands of Guatemala were an early nexus of cultural interaction and innovation throughout the Formative period, demonstrating early evidence of social complexity, urbanism, and monumental sculpture (Love 2007). The first settled villages in this region appeared around 1500 BCE, with urbanism spreading across the coast and highlands as the Formative period progressed (Chinchilla 2021; Love 2016). Regional powers waxed and waned throughout the Formative, while smaller settlements' populations remained relatively stable throughout these sociopolitical transitions. Archaeological investigation of these communities has the potential to shift focus from elites and luxury resources to common people and utilitarian goods.

Obsidian, a material with both economic and social significance, was used to produce stone tools across Mesoamerica. Long distance networks of obsidian exchange existed by the Early Formative period, connecting communities of people across the region (i.e., De Leon et al. 2009; Ebert et al. 2015; Golitko et al. 2015; Hirth et al. 2013; Stark et al. 2016). One of these networks connected the Soconusco and Guatemalan highlands to the Gulf Coast through the Isthmus of Tehuantepec (Golitko et al. 2015;

Fig.4; Hirth et al. 2013; Stark et al. 2016). Another connected the Central Mexican highlands to Guerrero and Oaxaca (Golitko et al. 2015; Joyce et al. 1995). Both exchange networks relied on the Pacific Coast as a corridor for the movement of obsidian (Ebert et al. 2015; Stark et al. 2016). As the Pacific Coast was such a significant landscape for facilitating trade, it follows that it was also a region where economic interactions strengthened social ties between peoples. Because obsidian sources are chemically distinct, it is possible to trace the movement of obsidian artifacts across the ancient Mesoamerican landscape.

The Yale Peabody Museum of Natural History (hereafter YPM) is home to a collection of artifacts from the archaeological site of Salinas La Blanca, excavated by Michael Coe and Kent Flannery under the auspices of the Smithsonian Institution in the 1960s. Salinas La Blanca, located in the Pacific Coastal estuary of the Chiapas/Guatemala border, was inhabited throughout the Formative period. Hundreds of artifacts from this excavation remain curated by the YPM Division of Anthropology, including pottery, figurines, stone tools, and shell jewelry. Revisiting the obsidian artifacts excavated from Salinas La Blanca presents a village-based perspective on lithic

procurement and production during this transformative period in Mesoamerican history.

Salinas La Blanca

Salinas La Blanca is located on the Western Guatemalan Coast, in the eastern extreme of Soconusco region, only a few kilometers from the Mexican border in the Pacific coastal plain. Occupation at Salinas La Blanca spans the entirety of the Formative period, roughly 1300 BCE – 100 CE. The Western Guatemalan Coast was first studied by Shook (1948), who noted many sites from the Formative and Late Classic. North of Salinas La Blanca is El Sitio, a ceremonial site occupied in the Formative and Late Classic periods (Coe and Flannery 1967:5). El Jobo, a Late Formative archaeological site, is located to the east and is home to a stela in the Izapan style (Coe and Flannery 1967:5). This stela demonstrates ties to the piedmont site of Izapa, a major regional power and religious center located in Chiapas whose sculptural style is found throughout the Pacific Coast and Highland regions during the Late Formative (Love 2011; Rosenswig 2019). Closer to Salinas La Blanca is Bocana, to the north, and La Victoria, between the Naranjo and Suchiate Rivers to the west (Coe 1961). Further up the Naranjo River is La Blanca, a larger regional center prominent in the Middle Formative (Love 2016). Home to the earliest pyramids on the Pacific coast of Guatemala, La Blanca exerted significant influence over the surrounding area before it was eclipsed by El Ujuxte in the Late Formative period. More broadly, the region is bordered to the north by the volcanic highlands and to the south by the Pacific Ocean.

Salinas La Blanca itself is located on the eastern bank of the Naranjo River, only a few kilometers from the Pacific Ocean. On the alluvial plain of the coast, teeming with tropical vegetation and animals, the site is approximately 5m above sea level. This

proximity to the water is reflected in an abundance of marine resources in the assemblage. It is surrounded by mangrove swamps, salt playas, and tropical savannah (Coe and Flannery 1967:17). The primary extant features are two mounds, the product of household middens which demonstrate the extensive use of marine resources like shellfish. While only two mounds are described by Coe and Flannery, they note the numerous other mounds around the salt playas, which suggests the site was more expansive (ibid:17). Salinas La Blanca was excavated by Coe and Flannery in 1962. Obsidian from these excavations includes specimens from Salinas La Blanca proper (SM-1) and a surface collection at Mound 2 (SM-42), which is 2km north. Subsistence at Salinas La Blanca contained both domesticated and wild foodstuffs, suggesting that the site was not merely a location of resource extraction but a sedentary settlement.

Salinas La Blanca was first occupied in the Early Formative Cuadros phase, now believed to begin around 1300 BCE (Bryant et al. 2005). The earliest occupants of Salinas La Blanca were full-time farmers who also exploited local natural resources. These coastal farmers cultivated crops including maize and avocados, hunted game, and collected marine fauna within the estuaries. These practices continue into the Jocotal phase, a short transitional period in the ceramic assemblage. Ceramics from Jocotal phase Salinas La Blanca are very similar to contemporary ceramics at Kaminaljuyu, suggesting ties between the Western Guatemala Coast and the Eastern Guatemalan Highlands (Coe and Flannery 1967:69). While a Conchas ceramic phase, dating from 800 BCE - 300 BCE, was identified at nearby La Victoria, there is no Conchas phase material at Salinas La Blanca (Coe 1961; Coe and Flannery 1967:67). Instead, the ceramics at Salinas La Blanca transition directly from the Jocotal to Crucero ceramic phases, with no

Conchas materials present. Salinas La Blanca remained inhabited until CE 50/100 (Nance 1992:39).

Regionally, the Pacific Coast and Highlands of Guatemala experienced significant changes in systems of social power during the Late Formative period (300 BC – 100 CE). The expansion of monumental construction and the carving of iconographically complex stelae reflected the consolidation of political power into the institution of divine kingship (Fields 1989; Love 2011). The final occupation of Salinas La Blanca coincided with a period of political instability and economic disruption during the end of the Late Formative. As a region the Soconusco suffered a demographic collapse around 100 CE, when many sites such as El Ujuxte suffered a similar fate and were abandoned (Love 1998, 2002, 2007). At Izapa, Takalik Abaj, and Kaminaljuyu, occupation

continued but their monumental art programs cease or decline significantly (Love 2007:298). Izapa-style art production ceased throughout the region, never to return, and Izapa-style monuments at the latter two sites were mutilated (see Love 2007). Amidst these major cultural transformations, the village at Salinas La Blanca was abandoned permanently.

Like all sites in the region, Salinas La Blanca had no local source of stone suitable for making chipped-stone tools and relied on long-distance exchange to obtain it (Stark et al. 2016). Obsidian artifacts represent the only material class with cutting-edges recovered at the site and were undoubtedly critical to daily life. The need for this critical commodity maintained ties between this coastal community and the highlands for over a millennium.

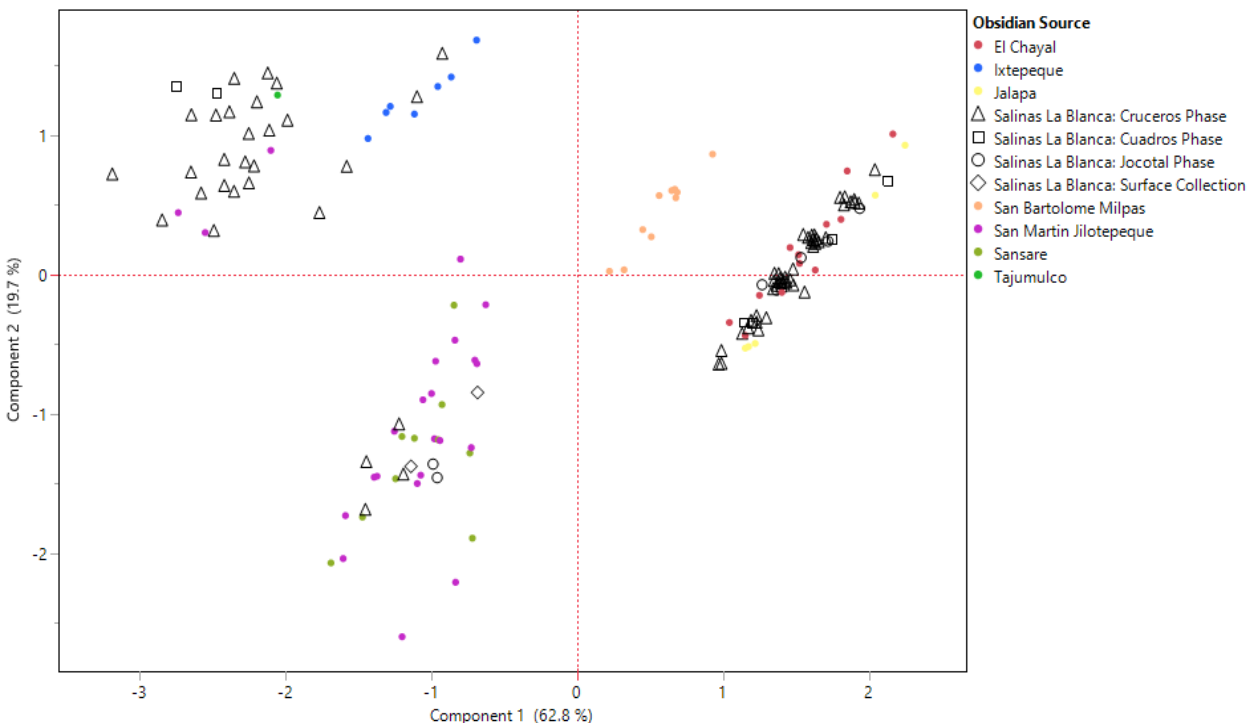


Figure 1. Principal component analysis of Rb, Sr, Y, and Zr in Salinas La Blanca artifacts and MURR reference collection

Methods

The identification of obsidian sources based on their chemical composition has a long history in Mesoamerican archaeology, providing valuable information on trade and interaction networks. Geochemical obsidian sourcing in Mesoamerica began with instrumental neutron activation analysis (INAA), a significant improvement from macroscopic sourcing techniques that rely on interpreting the physical attributes of obsidian (i.e., luster, granularity, color, opacity) and comparing it to material gathered from an obsidian source. While INAA is a powerful analytical tool, new instruments like portable X-ray fluorescence (pXRF) have been increasingly used to characterize large samples of obsidian assemblages (Ebert et al. 2015; Moholy-Nagy et al. 2013). As pXRF becomes more readily available as an

analytical tool, some have raised concerns about the validity of pXRF-obtained chemical data compared to traditional benchtop XRF or INAA (Liritzis and Zacharias 2011). These concerns are primarily focused on perceived unreliability of the pXRF or reproducibility of pXRF data. However, numerous studies have demonstrated pXRF is a powerful instrument capable of distinguishing between obsidian sources (i.e., Frahm 2014).

The Salinas La Blanca obsidian data was gathered using the Yale Archaeological XRF ExoLab's Olympus Vanta handheld X-ray fluorescence spectrometer (XRF). The instrument consists of a Rh anode in 4-W x-ray tube. The instrument exposes the sample to a small dose of radiation, which causes the sample to emit an energy signature, indicative of elemental concentrations (Tykot 2015:43). This device emitted two beams for each

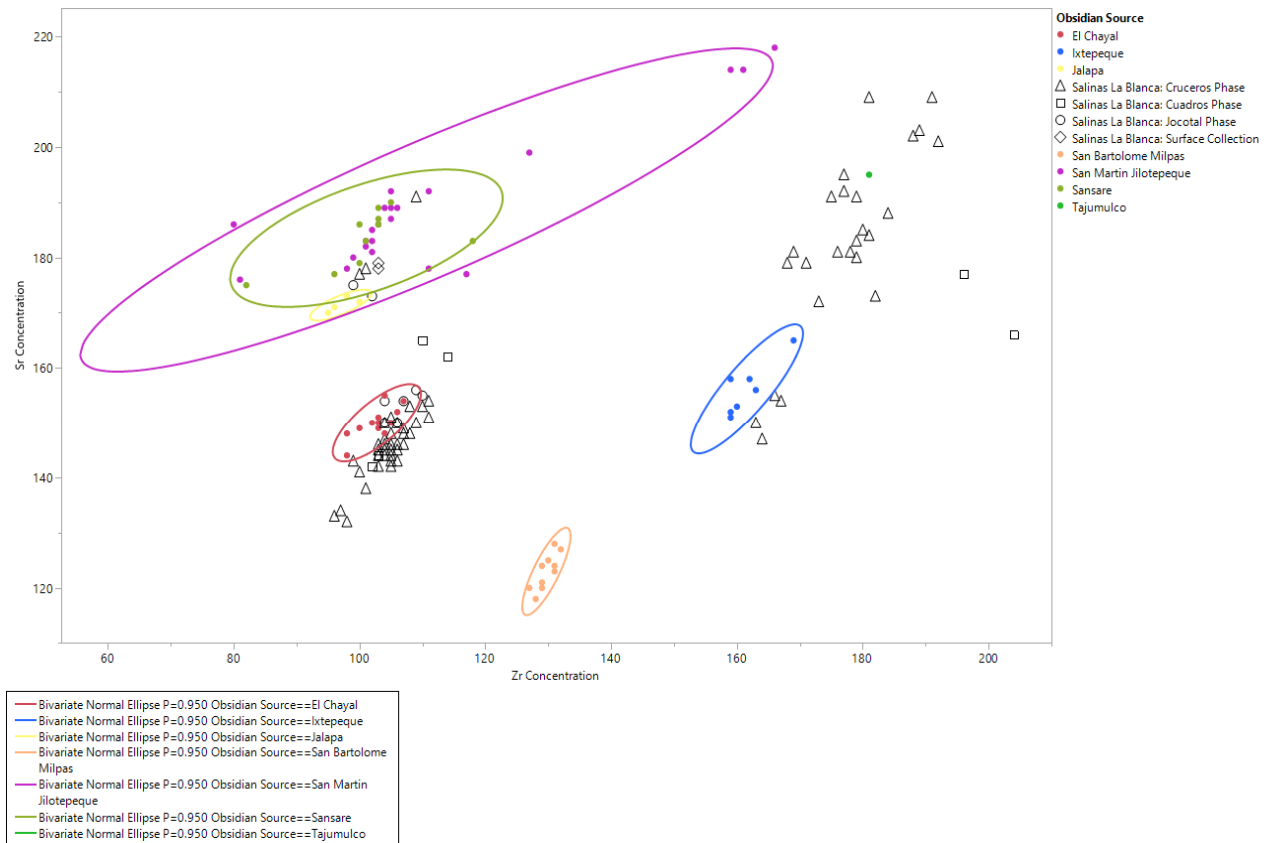


Figure 2. Bivariate fit of Sr by Zr concentration in ppm with 95% confidence ellipses for obsidian sources.

measurement, the first for a 30 second interval and the second a 10 second interval. The resulting elemental data, reported in parts per million (ppm) was then analyzed statistically to separate obsidian into chemical groups and match these groups to an obsidian source. Comparative compositional data on obsidian sources was acquired from the Missouri University Research Reactor (MURR) databases. The full chemical data may be found in Appendix 1.

Obsidian sources were assigned based on the chemical composition of Salinas La Blanca obsidian artifacts in comparison to the MURR reference samples, with an emphasis on the ratio of mid-Z elements including Rb, Sr, Y, Zr, and Nb to each other (Glascock 2020:39). The principal component analysis of these elements was a preliminary method by which the Salinas La Blanca obsidian was compared to the reference groups and

demonstrates the variability within the Salinas La Blanca assemblage (Figure 1). The bivariate plotting of the noted elements provides an avenue by which the chemical differences between groups may be explored more deeply. The bivariate plot of Sr by Zr concentrations (Figure 2) demonstrates how the Salinas La Blanca artifacts relate to prominent obsidian sources in highland Guatemala. A large quantity of Salinas La Blanca artifacts cluster tightly together around the El Chayal reference group, presenting strong evidence for their association with this source. Another large group clusters around the sample point from Tajumulco. Within the confidence ellipse of the San Martin Jilotepeque source is a smaller ellipse for the Sansare source, reflecting the strong chemical similarities between these obsidian sources. Because of the chemical similarities between Sansare and multiple other obsidian sources,

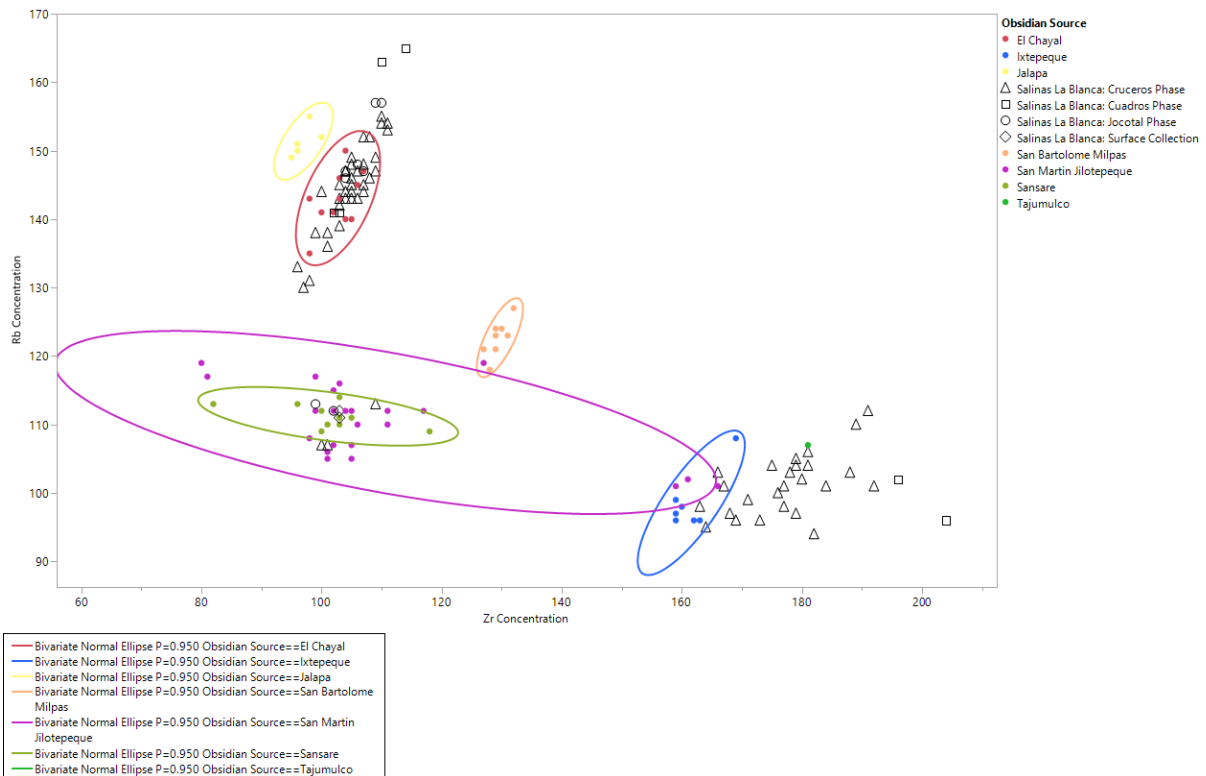


Figure 3. Bivariate fit of Rb by Zr concentration in ppm with 95% confidence ellipses for obsidian sources.

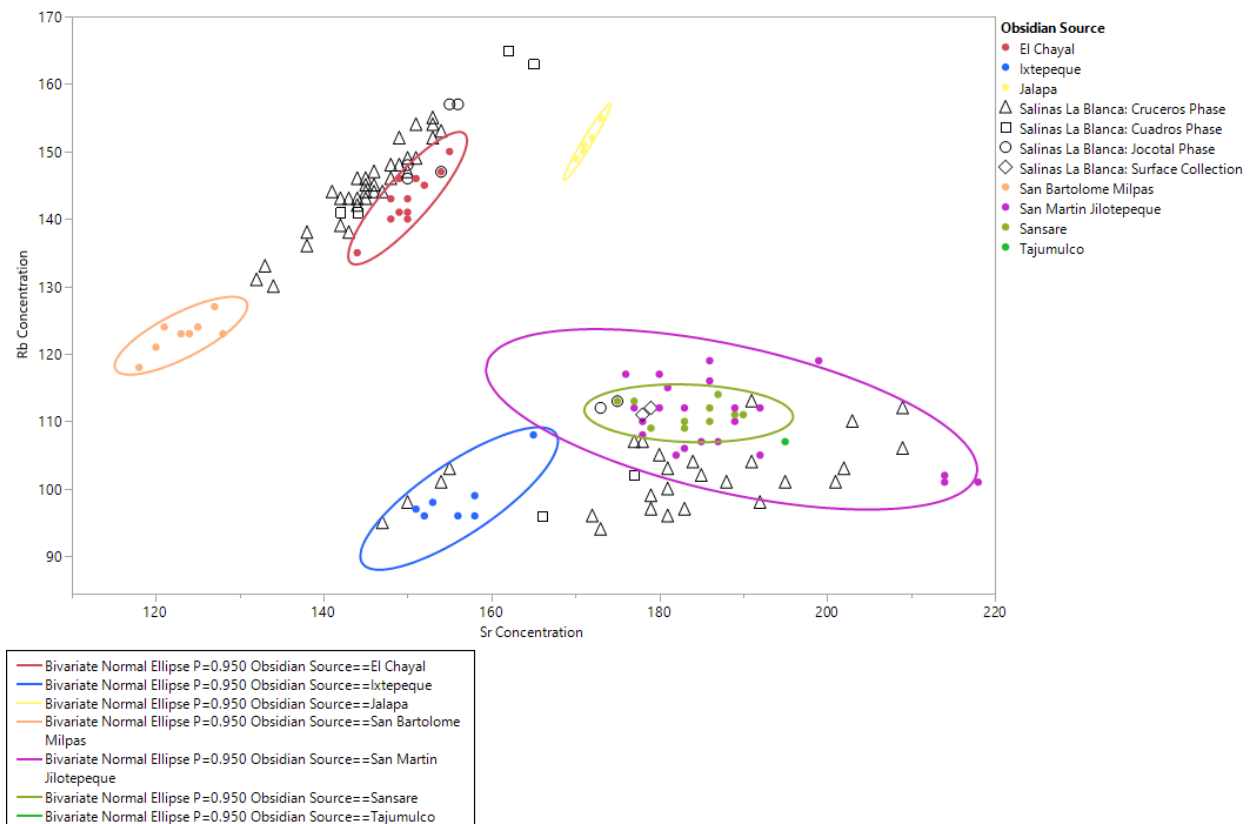


Figure 4. Bivariate fit of Rb by Sr concentrations in ppm with 95% confidence ellipses for obsidian sources.

the Sansare outcrop should not be considered a separate obsidian source but rather part of the larger El Chayal flow system (Braswell and Glascock 1992:48). Thus, materials which fall within both the San Martin Jilotepeque and Sansare groups were assigned as San Martin Jilotepeque. Finally, a small group of data points cluster near the Ixtepeque reference group. Examining the bivariate plotting of other elemental concentrations, such as Rb by Zr (Figure 3) and Rb by Sr (Figure 4) reinforces these groupings. While bivariate plotting of elemental concentrations provides valuable information about potential chemical groupings, the bivariate plotting of elemental ratios provides further insight into these groups (Bishop 1984:106). The ratio of Rb/Zr v. Sr/Zr (Figure 5) supports the obsidian source assignments already suggested in the bivariate plots of elemental concentrations,

providing another line of evidence to support the identification of obsidian sources. The full numerical values for the ratios of Rb/Zr, Sr/Zr, Y/Zr, and Nb/Zr may also be found in Appendix 1.

Obsidian artifacts

Cuadros

The Cuadros ceramic phase is dated by the excavators from 1000 - 850 BCE (Coe and Flannery 1967:70). This chronology has been revised, moving the Cuadros phase back to 1300 - 1100 BCE (Bryant et al. 2005). Three obsidian artifacts were recovered from this period: one uniface and two flakes (Figure 6). Regionally, obsidian production in this period was largely focused on percussion flakes (Stark et al. 2016). Coe and Flannery (1967:63) refer to the obsidian from the Cuadros period as “barely meriting the term

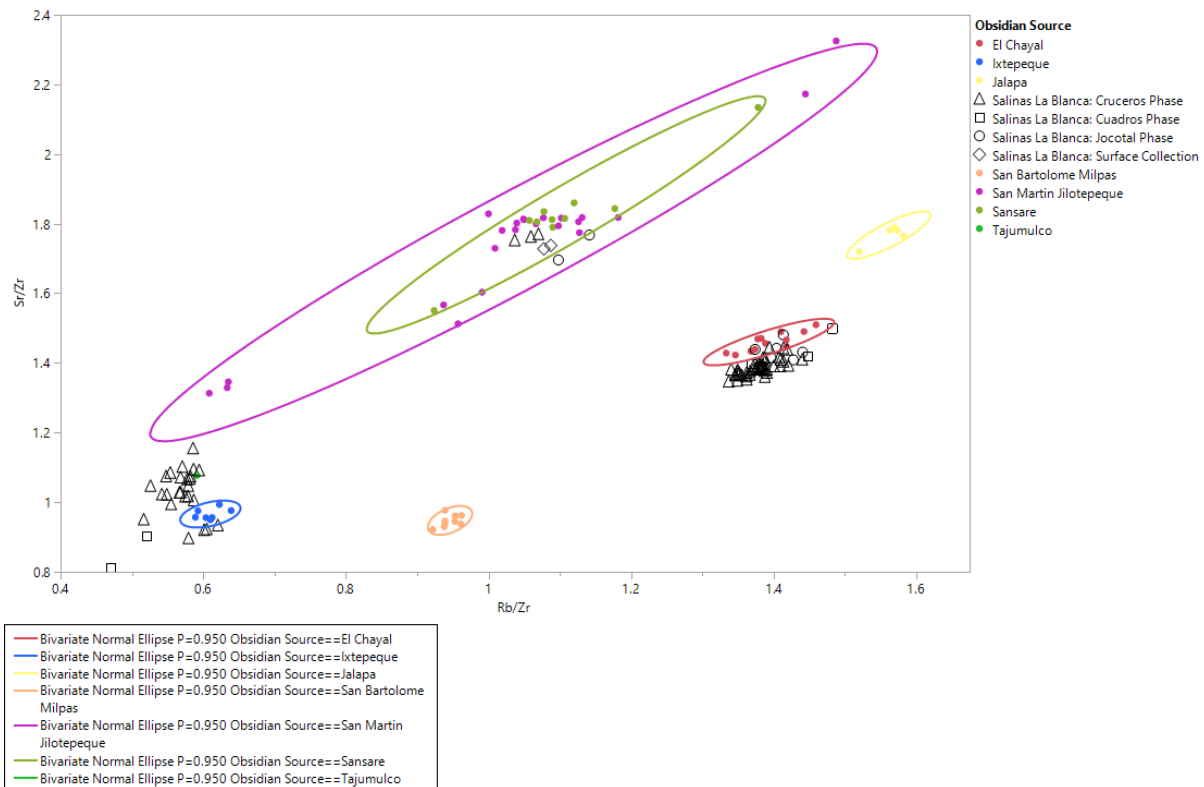


Figure 5. Bivariate fit of Sr/Zr by Rb/Zr in ppm with 95% confidence ellipses for obsidian sources.

‘artifacts.’” However, they describe the obsidian artifacts from the Cuadros phase as being of good quality, identifying some signs of unifacial retouching and suggesting that they were used as scrapers. Otherwise, they identify obsidian of this phase as waste flakes (ibid:64). Other stone tools from this phase include a metate, a mano, hammerstones, river pebbles, and a pumice abradar (Coe and Flannery 1967:64). Of the three obsidian pieces in the YPM from this period, one matches the chemical signature of the Tajumulco Volcano and two match the chemical signature of El Chayal. The Tajumulco example is in the form of a unifacial tool with evidence of pressure flaking in the form of four dorsal flake scars. The tool is partially retouched on one side and exhibits a crushed platform. This artifact was found in the same archaeological unit (sm-1/1m) as one El Chayal flake. Both examples

from El Chayal are flakes with no evidence of use.



Figure 6. Obsidian artifacts from the Cuadros phase at Salinas La Blanca.



Figure 7. Obsidian artifacts from the Jocotal phase at Salinas La Blanca

Jocotal

The Jocotal phase, originally placed at 850 - 800 BCE (Coe and Flannery 1967:70), was also modified and pushed back to 1100 - 1000 BCE (Bryant et al. 2005). Inhabitants during the Jocotal phase largely produced material culture similar to that of the Cuadros phase, demonstrating cultural continuity. Four pieces of obsidian in the YPM collection were recovered from the Jocotal phase of excavations (Figure 7). Three of these pieces were assigned to El Chayal, with the fourth falling within the range of San Martin Jilotepeque. Coe and Flannery (1967:64) describe the Jocotal material as “good quality, gray, banded obsidian, in small waste flakes or fractured chunks.” They identify signs of retouching on one flake, and two chips produced by bipolar percussion. We concur with Coe and Flannery’s assessment for the presence of production, albeit small-scale, using bipolar percussion. Other stone tools excavated from the Jocotal phase include hammerstones, and a pumice abrader (Coe and Flannery 1967:64).

Crucero

The Crucero ceramic phase refers to the period from 300 BCE - CE 100 (Coe and

Flannery 1967:70). In the Crucero phase, the people of Salinas La Blanca continued procuring obsidian from sources established in earlier periods. The thirty-nine total obsidian pieces demonstrate a significant increase in volume, and more variety in form, now including blades, drills, and scrapers (Figure 8). Coe and Flannery (1967:67) suggested that the Late Formative obsidian at Salinas La Blanca was traded in from an obsidian source near Kaminaljuyu. Geochemical data confirms their inclination, twenty-four obsidian artifacts of the Crucero sample were assigned to El Chayal. Furthermore, most blades found in the Crucero phase were from El Chayal. Eleven specimens were assigned to Tajumulco; two were assigned to San Martin Jilotepeque; and two to Ixtepeque. In the Crucero phase the variety of obsidian forms increases, with the assemblage including retouched flakes, prismatic blades, and blades with “burinlike” blows (Coe and Flannery 1967:65). The flakes are described as generally being of poor quality, while the prismatic blades are of good quality but fragmentary. Other stone tools found in the Crucero phase include metates, manos, hammerstones, river pebbles, and a pumice abrader (Coe and Flannery 1967:64).



Figure 8. Obsidian artifacts from the Crucero phase at Salinas La Blanca.

Source	Total	Cuadros	Jocotal	Crucero	Surface Collection
El Chayal	29	2	3	24	0
Ixtepeque	2	0	0	2	0
San Martin Jilotepeque	4	0	1	2	1
Tajumulco	12	1	0	11	0

Table 1. Obsidian sources assigned to Salinas La Blanca obsidian based on concentrations of Nb, Rb, Sr, Y, and Zr.

Discussion

Obsidian from the earliest layers at Salinas La Blanca identifies two distinct volcanoes as sources, indicating that the people of Salinas La Blanca were participating in the economic networks circulating obsidian from throughout the Guatemalan Highlands. From the earliest occupation layers the nearest source, Tajumulco, and the much more distant El Chayal source both contribute to the assemblage. The El Chayal obsidian industry has been argued to date as far back as 5000 BCE, and by the Middle and Late Formative periods must have been well established (Coe and Flannery 1964:48). Workshops at El Chayal were identified by Coe and Flannery (1964), who proposed an Archaic date for the workshop, although this dating is disputed by others (i.e., Michels 1975). This geochemical evidence demonstrates Salinas La Blanca's connection to the broad community of people in which El Chayal obsidian was being circulated in the Early Formative.

By the Jocotal period, an additional source, San Martin Jilotepeque appeared in the assemblage alongside El Chayal, whereas Tajumulco was not identified. However, due the small sample size we should not assume the absence of Tajumulco obsidian in the YPM collection indicates the cessation of procurement of obsidian from this source by Salinas La Blanca. It is likely that obsidian and other artifacts from this period were washed away by the periodic flooding of the estuary

system or that they were not gathered in the limited excavations. Nonetheless, the addition of the San Martin Jilotepeque source may be interpreted as an expansion of the exchange networks at Salinas La Blanca, which now connected them to new populations in the highlands and/or piedmont zones.

As the Formative period progressed, dramatic changes occurred at a regional level in terms of the organization and scale of economy. Prismatic blades first appeared across the region in the Middle Formative, reflecting new lithic production technologies and an increasingly complex obsidian industry (Jackson and Love 1991). The Crucero phase of Salinas La Blanca featured a new suite of ceramic and lithic artifacts. While the material culture of the Crucero phase is easily differentiated from its Cuadros and Jocotal predecessors, there are some continuities. The obsidian sources represented in the data set indicate that the inhabitants of Salinas La Blanca maintained highland connections throughout their history, even as the habitation of the site experienced a hiatus. The presence of grey obsidian from Ixtepeque volcano, in Jutiapa, Guatemala, expands the Salinas La Blanca economic network to include regional centers cities further southeast. The importation of obsidian from distant sources, instead of simply increasing their reliance on the more local Tajumulco, may be related to the poor quality of the Tajumulco obsidian for prismatic blade production. At Salinas La

Blanca, prismatic blades first appear in the Late Formative and were usually made from El Chayal obsidian. Prismatic blades were likely adopted for technical purposes, rather than functioning as status goods (Jackson and Love 1991). These blades are an important component of the lithic assemblage as they represent specialists exchanging both finished tools and raw materials to households, with the potential for social power emerging from craft specialization related to prismatic blade production (Jackson and Love 1991).

Economic relationships often involve bidirectional exchange which encourages interdependence in trade (Cropanzano and Mitchell 2005:876). Salt production was important in the region during the colonial period (Coe and Flannery 1967:92), a practice evidenced at nearby Guzman Mound to have begun in the Formative period (Nance 1992). Considering the demand for salt from expanding piedmont and highland centers, the inhabitants of Salinas La Blanca may have exported salt in exchange for highland products. The marine fauna so common in the house middens may have provided another source of economic capital. Shells from the coast have been found in Guatemalan highland sites near obsidian sources, such as Kaminaljuyu, indicating the existence of shell-based trade (Kidder 1945:74). Additionally, the Soconusco in which Salinas La Blanca is located was later known by the Aztecs as an important source of cacao (Gasco 1996). Ultimately, there were likely many resources available to the Salinas La Blanca community which they may have exploited in exchange for highland obsidian.

Conclusions

This paper demonstrates the importance of revisiting legacy collections through a re-analysis of obsidian excavated from Salinas La Blanca in the 1960s. Revisiting this site using geochemical analyses unavailable at the time of the original publication better informs

academic understanding of Formative period Soconusco. As the people of Salinas La Blanca settled into their village by the sea, they maintained connections with highland peoples for generations. Over the course of a thousand years, their ability to acquire obsidian increased as they participated in an expanding regional exchange network that brought novel trends related to tool production. The tools they used also changed, as they adopted the prismatic blade technology as it spread across Mesoamerica and incorporated it as they resettled the site. Importantly, obsidian exchange networks never closed at Salinas La Blanca. Despite not being suitable for blade production, Tajumulco obsidian continued to flow into the site. Prismatic blade production is not evidenced here, suggesting blades of San Martin Jilotepeque, El Chayal, and Ixtepeque obsidian were imported as finished products. The entire site assemblage consists largely of flakes indicating the presence of both pressure flake retouching and bipolar percussion throughout the site's occupation. Beyond informing reconstructions of Pacific coastal peoples, this project also provides another case study in the usefulness of pXRF as an effective and powerful archaeometric tool.

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Obsidian

Sample ID	Context	Source	Rb/Zr	Sr/Zr	Y/Zr	Nb/Zr	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)
cruceros_01a	Salinas La Blanca: Cruceros Phase	TAJ	0.548913	1.021739	0.086957	0.054348	101	188	16	184	10
cruceros_01b	Salinas La Blanca: Cruceros Phase	TAJ	0.541899	1.022346	0.089385	0.055866	97	183	16	179	10
cruceros_02a	Salinas La Blanca: Cruceros Phase	TAJ	0.554913	0.99422	0.080925	0.052023	96	172	14	173	9
cruceros_02b	Salinas La Blanca: Cruceros Phase	TAJ	0.568182	1.028409	0.085227	0.051136	100	181	15	176	9
cruceros_03a	Salinas La Blanca: Cruceros Phase	TAJ	0.568047	1.071006	0.08284	0.035503	96	181	14	169	6
cruceros_03b	Salinas La Blanca: Cruceros Phase	TAJ	0.585635	1.154696	0.088398	0.044199	106	209	16	181	8
cruceros_04a	Salinas La Blanca: Cruceros Phase	TAJ	0.553672	1.084746	0.090395	0.050847	98	192	16	177	9
cruceros_04b	Salinas La Blanca: Cruceros Phase	TAJ	0.547872	1.074468	0.079787	0.037234	103	202	15	188	7
cruceros_05a	Salinas La Blanca: Cruceros Phase	TAJ	0.570621	1.101695	0.073446	0.045198	101	195	13	177	8
cruceros_05b	Salinas La Blanca: Cruceros Phase	TAJ	0.526042	1.046875	0.067708	0.036458	101	201	13	192	7
cruceros_06a	Salinas La Blanca: Cruceros Phase	SMJ	1.07	1.77	0.13	0.06	107	177	13	100	6
cruceros_06b	Salinas La Blanca: Cruceros Phase	SMJ	1.059406	1.762376	0.118812	0.059406	107	178	12	101	6
cruceros_07a	Salinas La Blanca: Cruceros Phase	TAJ	0.578947	1.046784	0.081871	0.035088	99	179	14	171	6
cruceros_07b	Salinas La Blanca: Cruceros Phase	TAJ	0.516484	0.950549	0.071429	0.032967	94	173	13	182	6
cruceros_08a	Salinas La Blanca: Cruceros Phase	TAJ	0.586592	1.005587	0.083799	0.03352	105	180	15	179	6
cruceros_08b	Salinas La Blanca: Cruceros Phase	TAJ	0.578652	1.016854	0.078652	0.039326	103	181	14	178	7
cruceros_09a	Salinas La Blanca: Cruceros Phase	CHA	1.419048	1.438095	0.142857	0.066667	149	151	15	105	7
cruceros_09b	Salinas La Blanca: Cruceros Phase	CHA	1.413462	1.442308	0.153846	0.057692	147	150	16	104	6
cruceros_10a	Salinas La Blanca: Cruceros Phase	TAJ	0.586387	1.094241	0.08377	0.04712	112	209	16	191	9
cruceros_10b	Salinas La Blanca: Cruceros Phase	TAJ	0.582011	1.074074	0.079365	0.047619	110	203	15	189	9
cruceros_11a	Salinas La Blanca: Cruceros Phase	CHA	1.361905	1.352381	0.142857	0.07619	143	142	15	105	8
cruceros_11b	Salinas La Blanca: Cruceros Phase	CHA	1.349515	1.378641	0.165049	0.087379	139	142	17	103	9
cruceros_12a	Salinas La Blanca: Cruceros Phase	TAJ	0.577381	1.065476	0.077381	0.029762	97	179	13	168	5
cruceros_12b	Salinas La Blanca: Cruceros Phase	TAJ	0.536424	2.02649	0.07947	0.02649	81	306	12	151	4
cruceros_13a	Salinas La Blanca: Cruceros Phase	TAJ	0.594286	1.091429	0.08	0.04	104	191	14	175	7
cruceros_13b	Salinas La Blanca: Cruceros Phase	TAJ	0.581006	1.067039	0.083799	0.027933	104	191	15	179	5
cruceros_14a	Salinas La Blanca: Cruceros Phase	CHA	1.387387	1.36036	0.153153	0.099099	154	151	17	111	11
cruceros_14b	Salinas La Blanca: Cruceros Phase	CHA	1.407407	1.416667	0.157407	0.083333	152	153	17	108	9
cruceros_15a	Salinas La Blanca: Cruceros Phase	CHA	1.409091	1.390909	0.163636	0.109091	155	153	18	110	12
cruceros_15b	Salinas La Blanca: Cruceros Phase	CHA	1.4	1.390909	0.172727	0.109091	154	153	19	110	12
cruceros_16a	Salinas La Blanca: Cruceros Phase	TAJ	0.566667	1.027778	0.077778	0.044444	102	185	14	180	8
cruceros_16b	Salinas La Blanca: Cruceros Phase	TAJ	0.574586	1.016575	0.071823	0.049724	104	184	13	181	9

Obsidian

Sample ID	Context	Source	Rb/Zr	Sr/Zr	Y/Zr	Nb/Zr	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)
cruceros_17a	Salinas La Blanca: Cruceros Phase	CHA	1.44	1.41	0.17	0.12	144	141	17	100	12
cruceros_17b	Salinas La Blanca: Cruceros Phase	CHA	1.386792	1.415094	0.188679	0.113208	147	150	20	106	12
cruceros_18a	Salinas La Blanca: Cruceros Phase	CHA	1.336735	1.346939	0.173469	0.122449	131	132	17	98	12
cruceros_18b	Salinas La Blanca: Cruceros Phase	CHA	1.385417	1.385417	0.166667	0.104167	133	133	16	96	10
cruceros_19a	Salinas La Blanca: Cruceros Phase	IXT	0.60479	0.922156	0.101796	0.071856	101	154	17	167	12
cruceros_19b	Salinas La Blanca: Cruceros Phase	IXT	0.620482	0.933735	0.096386	0.066265	103	155	16	166	11
cruceros_20a	Salinas La Blanca: Cruceros Phase	CHA	1.393939	1.444444	0.161616	0.080808	138	143	16	99	8
cruceros_20b	Salinas La Blanca: Cruceros Phase	CHA	1.340206	1.381443	0.175258	0.103093	130	134	17	97	10
cruceros_21a	Salinas La Blanca: Cruceros Phase	CHA	1.409524	1.409524	0.152381	0.133333	148	148	16	105	14
cruceros_21b	Salinas La Blanca: Cruceros Phase	CHA	1.349057	1.349057	0.169811	0.113208	143	143	18	106	12
cruceros_22a	Salinas La Blanca: Cruceros Phase	CHA	1.384615	1.413462	0.163462	0.086538	144	147	17	104	9
cruceros_22b	Salinas La Blanca: Cruceros Phase	CHA	1.383178	1.383178	0.158879	0.093458	148	148	17	107	10
cruceros_23a	Salinas La Blanca: Cruceros Phase	CHA	1.371429	1.380952	0.161905	0.114286	144	145	17	105	12
cruceros_23b	Salinas La Blanca: Cruceros Phase	CHA	1.345794	1.364486	0.158879	0.11215	144	146	17	107	12
cruceros_24a	Salinas La Blanca: Cruceros Phase	CHA	1.420561	1.392523	0.149533	0.093458	152	149	16	107	10
cruceros_24b	Salinas La Blanca: Cruceros Phase	CHA	1.366972	1.376147	0.165138	0.082569	149	150	18	109	9
cruceros_25a	Salinas La Blanca: Cruceros Phase	CHA	1.351852	1.37037	0.175926	0.12963	146	148	19	108	14
cruceros_25b	Salinas La Blanca: Cruceros Phase	CHA	1.383178	1.383178	0.17757	0.130841	148	148	19	107	14
cruceros_26a	Salinas La Blanca: Cruceros Phase	SMJ	1.036697	1.752294	0.119266	0.091743	113	191	13	109	10
cruceros_26b	Salinas La Blanca: Cruceros Phase	SMJ	1.036697	1.752294	0.12844	0.091743	113	191	14	109	10
cruceros_27a	Salinas La Blanca: Cruceros Phase	CHA	1.413462	1.403846	0.163462	0.115385	147	146	17	104	12
cruceros_27b	Salinas La Blanca: Cruceros Phase	CHA	1.378641	1.398058	0.174757	0.097087	142	144	18	103	10
cruceros_28a	Salinas La Blanca: Cruceros Phase	IXT	0.601227	0.920245	0.079755	0.04908	98	150	13	163	8
cruceros_28b	Salinas La Blanca: Cruceros Phase	IXT	0.579268	0.896341	0.085366	0.04878	95	147	14	164	8
cruceros_29a	Salinas La Blanca: Cruceros Phase	CHA	1.386792	1.377358	0.150943	0.084906	147	146	16	106	9
cruceros_29b	Salinas La Blanca: Cruceros Phase	CHA	1.390476	1.380952	0.161905	0.07619	146	145	17	105	8
cruceros_30a	Salinas La Blanca: Cruceros Phase	CHA	1.383178	1.392523	0.168224	0.140187	148	149	18	107	15
cruceros_30b	Salinas La Blanca: Cruceros Phase	CHA	1.348624	1.376147	0.165138	0.12844	147	150	18	109	14
cruceros_31a	Salinas La Blanca: Cruceros Phase	CHA	1.380952	1.380952	0.171429	0.114286	145	145	18	105	12
cruceros_31b	Salinas La Blanca: Cruceros Phase	CHA	1.386792	1.377358	0.179245	0.132075	147	146	19	106	14
cruceros_32a	Salinas La Blanca: Cruceros Phase	CHA	1.371429	1.390476	0.171429	0.12381	144	146	18	105	13
cruceros_32b	Salinas La Blanca: Cruceros Phase	CHA	1.375	1.384615	0.173077	0.125	143	144	18	104	13

Sample ID	Context	Source	Rb/Zr	Sr/Zr	Y/Zr	Nb/Zr	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)
cruceros_33a	Salinas La Blanca: Cruceros Phase	CHA	1.361905	1.371429	0.171429	0.114286	143	144	18	105	12
cruceros_33b	Salinas La Blanca: Cruceros Phase	CHA	1.390476	1.371429	0.180952	0.12381	146	144	19	105	13
cruceros_34a	Salinas La Blanca: Cruceros Phase	CHA	1.378378	1.387387	0.171171	0.126126	153	154	19	111	14
cruceros_34b	Salinas La Blanca: Cruceros Phase	CHA	1.384615	1.394231	0.153846	0.125	144	145	16	104	13
cruceros_35a	Salinas La Blanca: Cruceros Phase	CHA	1.371429	1.390476	0.180952	0.152381	144	146	19	105	16
cruceros_35b	Salinas La Blanca: Cruceros Phase	CHA	1.349057	1.367925	0.169811	0.150943	143	145	18	106	16
cruceros_36a	Salinas La Blanca: Cruceros Phase	CHA	1.361905	1.361905	0.171429	0.142857	143	143	18	105	15
cruceros_36b	Salinas La Blanca: Cruceros Phase	CHA	1.361905	1.371429	0.161905	0.12381	143	144	17	105	13
cruceros_37a	Salinas La Blanca: Cruceros Phase	CHA	1.380952	1.390476	0.171429	0.133333	145	146	18	105	14
cruceros_37b	Salinas La Blanca: Cruceros Phase	CHA	1.35514	1.364486	0.158879	0.121495	145	146	17	107	13
cruceros_38a	Salinas La Blanca: Cruceros Phase	CHA	1.346535	1.366337	0.168317	0.09901	136	138	17	101	10
cruceros_38b	Salinas La Blanca: Cruceros Phase	CHA	1.366337	1.366337	0.168317	0.108911	138	138	17	101	11
cruceros_39a	Salinas La Blanca: Cruceros Phase	CHA	1.407767	1.417476	0.145631	0.097087	145	146	15	103	10
cruceros_39b	Salinas La Blanca: Cruceros Phase	CHA	1.38835	1.407767	0.165049	0.097087	143	145	17	103	10
cuadros_01a	Salinas La Blanca: Cuadros Phase	TAJ	0.470588	0.813725	0.063725	0.044118	96	166	13	204	9
cuadros_01b	Salinas La Blanca: Cuadros Phase	TAJ	0.520408	0.903061	0.071429	0.045918	102	177	14	196	9
cuadros_02a	Salinas La Blanca: Cuadros Phase	CHA	1.382353	1.392157	0.156863	0.088235	141	142	16	102	9
cuadros_02b	Salinas La Blanca: Cuadros Phase	CHA	1.368932	1.398058	0.15534	0.097087	141	144	16	103	10
cuadros_03a	Salinas La Blanca: Cuadros Phase	CHA	1.447368	1.421053	0.157895	0.122807	165	162	18	114	14
cuadros_03b	Salinas La Blanca: Cuadros Phase	CHA	1.481818	1.5	0.181818	0.109091	163	165	20	110	12
jocotal_01a	Salinas La Blanca: Jocotal Phase	CHA	1.396226	1.415094	0.160377	0.113208	148	150	17	106	12
jocotal_01b	Salinas La Blanca: Jocotal Phase	CHA	1.403846	1.442308	0.163462	0.105769	146	150	17	104	11
jocotal_02a	Salinas La Blanca: Jocotal Phase	CHA	1.413462	1.480769	0.173077	0.105769	147	154	18	104	11
jocotal_02b	Salinas La Blanca: Jocotal Phase	CHA	1.373832	1.439252	0.158879	0.121495	147	154	17	107	13
jocotal_03a	Salinas La Blanca: Jocotal Phase	CHA	1.440367	1.431193	0.174312	0.100917	157	156	19	109	11
jocotal_03b	Salinas La Blanca: Jocotal Phase	CHA	1.427273	1.409091	0.163636	0.1	157	155	18	110	11
jocotal_04a	Salinas La Blanca: Jocotal Phase	SMJ	1.098039	1.696078	0.127451	0.088235	112	173	13	102	9
jocotal_04b	Salinas La Blanca: Jocotal Phase	SMJ	1.141414	1.767677	0.131313	0.10101	113	175	13	99	10
sm-42a	Salinas La Blanca: Surface Collectio	SMJ	1.087379	1.737864	0.145631	0.126214	112	179	15	103	13
sm-42b	Salinas La Blanca: Surface Collectio	SMJ	1.07767	1.728155	0.126214	0.126214	111	178	13	103	13

Obsidian

A BRIEF NOTE ON HYDRATION RATES FOR THE BODIE HILLS OBSIDIAN REGIONAL SOURCE, EASTERN CALIFORNIA, BASED ON INFRARED SPECTROSCOPY AND OPTICAL MEASUREMENT

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Introduction

Here we present a short pre-look at the results of a regional study on the Bodie Hills obsidian source, Mono County, eastern California, USA. This paper is designed to provide useful data to the working archaeologist; the full analysis, with complete data, will be published in a forthcoming book (Stevenson et al. n.d.).

Geologic Context

The Bodie Hills source, in Mono County, eastern California, (Figure 1) is especially significant archaeologically, since raw material from that source was exploited prehistorically over many millennia and widely traded to the west, across the Sierra Nevada, and into the Central Valley of California. There, it has been identified by XRF at numerous archaeological sites (King et al. 2011). The high frequency of occurrence makes it potentially very useful for chronology building in a region where local obsidian deposits are not present, but previous attempts to compute a hydration rate based on archaeological data have not been successful.

The Bodie Hills obsidian surface deposits occur in two forms, discrete terrace outcrops of cobble, and as alluvially deposited lag flows. The surface extant of the Bodie Hills Obsidian Quarry (CA-MNO-4527) has been studied extensively in the last two decades with nearly 1618 hectares of deposit being delineated (Halford 2008). These extensive

obsidian deposits served for millennia as an important indigenous quarry location. Bodie Hills obsidian (BHO) occurs in great quantities, often dominating other types of flaked lithic materials within archaeological deposits throughout north-central California (Hull and Mundy 1985; Jackson and Ericson 1994; King et al. 2011). BHO is also common in archaeological assemblages in western Nevada (Carey 2016; Hutchins and Simmons 2000). Recently, BHO was identified in archaeological assemblages on Santa Catalina Island nearly 570 kilometers (340 miles) and a boat ride removed from its origin (Gill 2019).

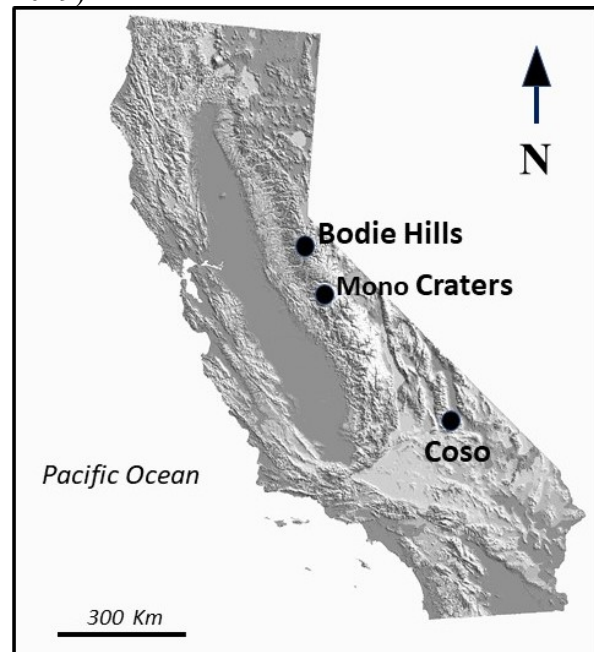


Figure 1. The location of obsidian geological sources in California mentioned in the text.

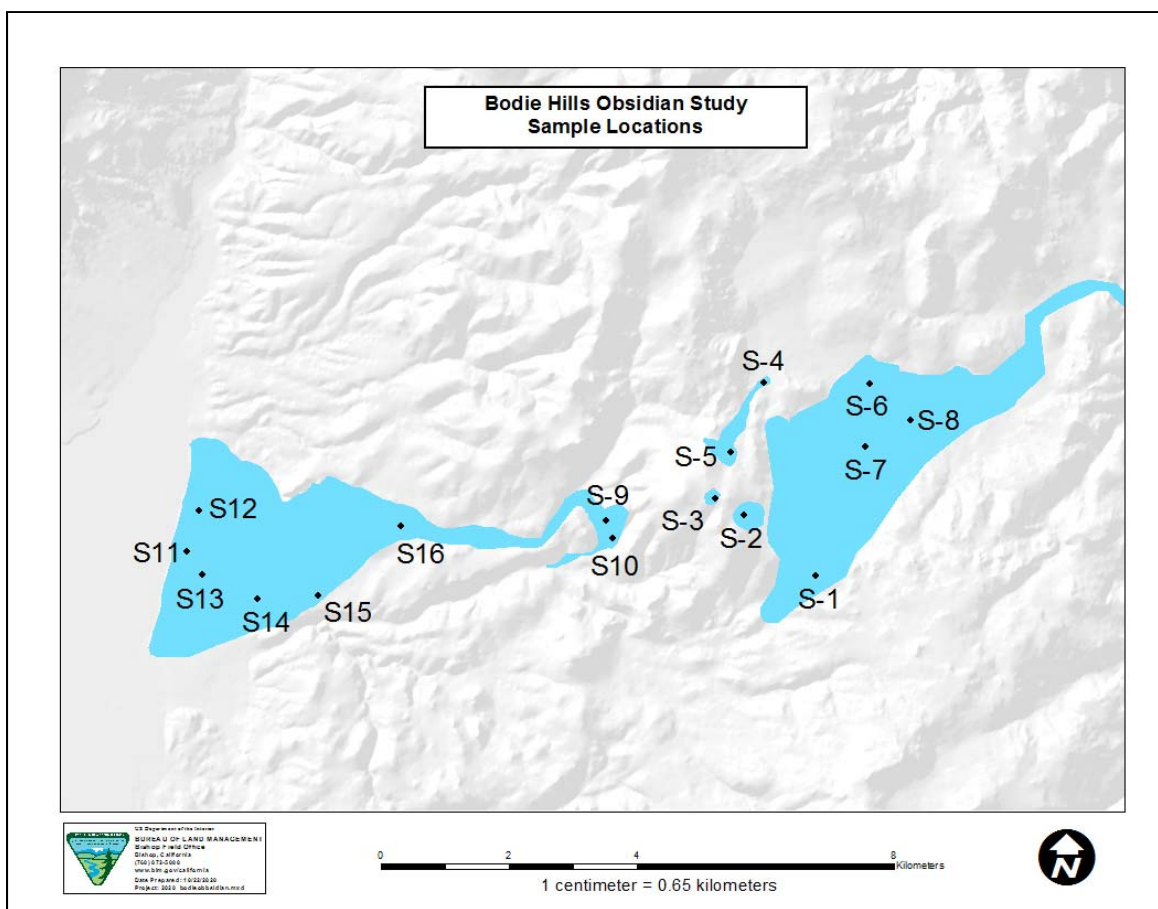


Figure 2. The Bodie Hills volcanic field (shaded) with sampling locations visited in this study.

Obsidian Mineralogy

Obsidian is an aluminosilicate glass formed by cooling of rhyolitic magma. Obsidians, like all glasses, contain small amounts of water which is "frozen in" during the cooling process. The water content is determined almost entirely by the cooling history of the magmatic melt (Shelby 2005). The water occurs in two species, molecular water (H_2O_m) and hydroxyl (OH), the latter which is formed by a chemical reaction between molecular water and the glass matrix during the molten phase (Doremus 1994, 2000, 2002; Ihinger et al. 1999; Zhang 2008; Zhang et al. 1991; Zhang and Behrens 2000). The sum of these two water species is referred to as H_2O_t . Lava flows that cool slowly tend to be water rich (0.4-2.6% H_2O_t) while faster cooling flows lead to dry obsidians (0.1-

0.3% H_2O_t) since there is little time for the dissolved OH to reconvert to H_2O as temperature decreases. The water content is known to be the primary compositional determinant of hydration rate (Kuroda et al. 2018, 2019; Rogers 2015; Stevenson et al. 2000, 2019, 2021). Thus, this study focuses on characterizing the intrinsic water content of the BHO field as well as determining hydration rate.

Hydration Rates

Because of its archaeological significance, considerable effort has been directed at calculating a usable rate of hydration for this source. The effort began shortly after the initial fieldwork was completed (Ericson 1977, 1981) and has continued using both derived and empirical approaches (Hull 2011;

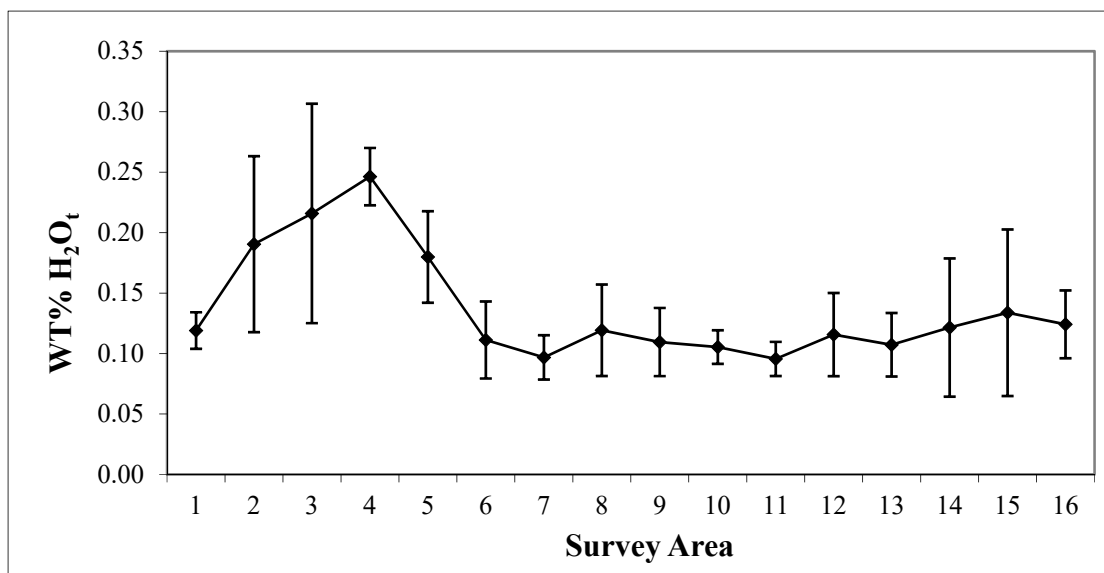


Figure 3. Total water content (H₂O_t) averages and standard deviations by survey area.

Halford 2008; Jackson and Ballard 1999; Michels 1982; Rogers 2010; Whitaker and Rosenthal 2010). While some of the formulated rates have reportedly found success within limited elevational or geographic regions, the results of this multi-decade long attempt are summarized by Hull (2012: 6) who states: "... despite some very sophisticated and concerted efforts in recent years, archaeologists have been unable to develop a rate formula for Bodie Hills obsidian that can both be applied to the central Sierra Nevada, as a whole, and produce sufficiently accurate results." Hull (2012) did acknowledge that the approach of Rogers and Yohe (2013) had produced the best result, to date.

Present Study

Obsidian specimens (N = 114) were collected from sixteen surveyed areas (SA-1 through SA-16) within the Bodie Hills region (Figure 2). We determined structural water content by Fourier Transform Infrared (FTIR) spectroscopy. Specimens were cut and polished to optical transparency, and density and thickness were measured. Infrared absorbance was measured at the 3570cm⁻¹,

4500cm⁻¹, and 5200cm⁻¹ bands to determine weight percent total water (H₂O_t), hydroxyl (OH), and molecular water (H₂O_m). Concentrations of water species were then calculated using the Beer-Lambert law (Levine 2002), using the molar absorption coefficients of Newman et al. (1986).

We found that the water content data fell into two groups (Figure 3). Group 1 includes Survey Areas 2, 3, 4, and 5, and has a mean water content of 0.2078 ± 0.0616 wt% H₂O_t. Group 2 exhibits an average water content of 0.1125±0.0354 wt% H₂O_t. The difference between the two groups is statistically significant at the 95% confidence level. However, no geochemical difference in anhydrous composition has been reported to date. The mean water content for the two groups combined is 0.1227 ± 0.0537 wt% H₂O_t. This contrasts with the water content for the Coso volcanic field, which lies in the range of 0.6 – 1.0 wt% (Rogers 2008; Stevenson et al. 1993). Further, for Coso a geochemical signature distinguishing the source flows has been reported (Hughes 1988), but not for Bodie Hills.

The hydration rate was then computed from the wt% H₂O_t by the calibration equation

of Rogers (2015) and Rogers and Stevenson (2017). The hydration rate at 20°C for Group 1 was found to be $11.25 \pm 0.83 \mu^2/1000$ years and for Group 2 it is $10.0 \pm 0.43 \mu^2/1000$ years; a composite rate for all samples is $10.36 \pm 0.72 \mu^2/1000$ years. Accelerated hydration on a sample from each group confirmed the hydration rate determinations from structural water content values.

Conclusion

We conclude that the Bodie Hills obsidian is quite dry, and thus we would expect it to be slow-hydrating, as in fact it is. However, the water content clearly falls into two groups, the difference between which is statistically significant. Since there is currently no geochemical signature distinguishing the two groups, the preferred value of hydration for archaeological analysis is the composite rate of $10.36 \pm 0.72 \mu^2/1000$ years at 20°C. The fact that laboratory hydration confirms the rate gives added confidence.

Complete data and description of the methods employed will be found in Stevenson et al. (n.d.).

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1. Develop standards for analytic procedures and ensure inter-laboratory comparability.
2. Develop standards for recording and reporting obsidian hydration and characterization results
3. Provide technical support in the form of training and workshops for those wanting to develop their expertise in the field.
4. Provide a central source of information regarding the advances in obsidian studies and the analytic capabilities of various laboratories and institutions