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IAOS

International Association for Obsidian Studies

Bulletin

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NEWS AND INFORMATION

NEWS AND NOTES

Have news or announcements to share? Send them to IAOS.Editor@gmail.com for the next issue of the *IAOS Bulletin.*

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: IAOS SECRETARY/TREASURER

We wish to thank Matt Boulanger for his many years of service to the IAOS as Secretary/Treasurer, but we are now overdue for an election for that office. That means that it's time for nominations for our next IAOS Secretary/Treasurer. Elections will be held this winter and the winner announced at the 2020 IAOS meeting at the SAAs in Austin, TX. The winner will begin serving immediately after the 2020 IAOS meeting and will coordinate with Matt Boulanger for the handoff of accounts and records. The Secretary/Treasurer's duties are outlined on page two of this issue of the *Bulletin*. If you, or someone you know, would be interested in serving as IAOS Secretary/Treasurer, please send a nomination and candidate statement to Kyle Freund at kylepfreund@gmail.com. Candidate statements will be published in the winter issue of the *Bulletin.*

Responsibilities of the IAOS Secretary/Treasurer

We are now seeking nominations and candidate statements for the position of IAOS Secretary/Treasurer. Please email these to President, Kyle Freund at kylepfreund@gmail.com. Candidate statements will be published in the winter issue of the IAOS Bulletin.

The Secretary-Treasurer, subject to the directives of the President in consultation with the Vice President, shall be responsible for maintaining contact with the President and Vice President, have charge of administrative matters under the direction of the President, be responsible for the administration of the finances of the IAOS subject to provisions in these By-laws.

Duties of the Secretary-Treasurer are to:

1. Announce all meetings to the membership of the IAOS, either by mail, email, or through the IAOS Newsletter.

2. Maintain and distribute minutes of all meetings to the Executive Board.

3. Keep and update membership rolls of the IAOS on both electronic and written media, maintaining a minimum of two backup copies of electronic membership, By-laws, Working Policies, and other documents authorized or adopted by the IAOS

4. Maintain records of all financial transactions in accordance with standard bookkeeping practices.

5. Have custody of all money and securities for the IAOS.

6. Assemble and mail or email articles, and announcements to the membership.

7. Mail/email and receive applications for membership.

8. Conduct elections as described in Article 9.

The Secretary-Treasurer is directed to correspond with every IAOS member each year, encouraging them to renew their membership, informing them of any changes in annual dues, IAOS activities, and officers. This correspondence may be included in a bulletin or newsletter that discusses other IAOS matters.

As soon as possible following the Annual Meeting, the Secretary-Treasurer will mail or email to all members of the Executive Board a copy of the current By-laws, a copy of the minutes of the Executive Board and Annual Meeting, and a copy of membership materials and IAOS stationary.

NOTES FROM THE PRESIDENT

Summer is finally here, and like many of you I am gearing up for this year's field season. The summer will bring me to eastern Europe, Italy, and then back to Florida. As always seems to be the case, the length of my stay in each region will depend on the decisions of funding agencies.

The 2nd International Obsidian Conference (IOC) is taking place in Sárospatak, Hungary this May, and I anticipate catching up with many of you there. The session abstracts span a wide range of topics, from geology, provenance, and use-wear, to an exploration of the "allure of obsidian." The conference builds on the successful IOC in Lipari in 2016 and will no doubt facilitate lots of interesting discussion. Based on the photos on the website, it should be a picturesque and inviting venue. An excursion to visit the Carpathian obsidian outcrops will be a highlight of the trip.

It's been a busy year for IAOS, and we have been involved in a number of endeavors. We held our election for IAOS President and received interest from three highly-qualified candidates. Sean Dolan won the election and will take over at next year's SAA Annual Meeting. I hope that Lucas Martindale Johnson and Dora Moutsiou will continue to remain active in the organization in the future.

The SAAs were in Albuquerque this year, and it was colder and windier than I expected. The city was beautiful, and I enjoyed sampling some of the great food and local beers. I snuck away for a day to visit Chaco Canyon and was not disappointed (picture below). The canyon features multiple great houses, lots of hiking, and a variety of petroglyphs waiting to be discovered by a careful eye. Former IAOS President Ana Steffen and Nick Jarman also organized a joint IAOS/PQEMIG field trip to the Jemez Mountains obsidian source. Due to flight delays I was unable to attend, but was told that it was a great experience - despite the snow.

Congratulations go out to former IAOS President Steve Shackley for winning the SAA Fryxell Award for Interdisciplinary Research. Steve's 30 plus year career has spanned the fields of anthropology, archaeology, geology, and museum studies, and many IAOS members were part of his honorary session. Dinner and margaritas were an appropriate way to cap off the symposium. Also of note was the IAOS-sponsored session on "Advances in Obsidian Studies of the Old and New Worlds" organized by Yuichi Nakazawa and Phyllis Johnson.

More pictures of IAOS events at the SAA meetings in Albuquerque are on the next page.

Have a great summer!

Kyle Freund, IAOS President
Department of Anthropology
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Left: Steve Shackley presenting during the Fryxell Award session at the 2019 SAA meetings in Albuquerque. Photo credit: Sean Dolan.
Right: Three academic generations: Geoff Clark (Steve Shackley's Ph.D. Adviser), Steve Shackley, and Carolyn Dillian (Steve Shackley's Ph.D. Advisee). Photo credit: Kathy Butler.

Participants in the 2019 Fryxell Award session honoring Steve Shackley. (left to right) Kyle Fruend, Mark McCoy, Jennifer Kahn, Jeffery Clark, Bonnie Clark, Rosemary Joyce, Carolyn Dillian, Nicholas Tripcevich, Steve Shackley, Robin Torrence, Ellery Frahm, Sean Dolan, Mike Glascock, Jeff Speakman, Robert Tykot, Christopher Stevenson.

CONGRATULATIONS TO M. STEVEN SHACKLEY

Contributed by Christopher Stevenson

Professor M. Steven Shackley has been awarded the 2019 Fryxell Award for Interdisciplinary Research in Archaeology. Over a long and productive career of thirty years Professor Shackley is best known for his work on obsidian characterization in the American Southwest where he has been on the forefront of elemental analysis using X-ray fluorescence (XRF) spectrometry as a basis for understanding regional interaction in prehistory. In this capacity, he has been a steady voice arguing for the importance of high-quality scientific research in archaeology and geological sciences. Complementing this regional focus, are his contributions to the international field of obsidian studies.

In order to recognize these outstanding career accomplishments, a half-day session on obsidian sourcing studies was organized at the 2019 Annual Meeting of the Society for American Archaeology in Albuquerque, New Mexico. Fifteen papers were presented on XRF analysis in regions across the globe, ranging from New Mexico to Near Oceania. Professor Shackley served as the session discussant and gave the audience many personal details about the history of his academic career. A post-session dinner was held afterward at a fine Mexican restaurant to continue the celebration that recognizes how much Steve has contributed to our field of research.

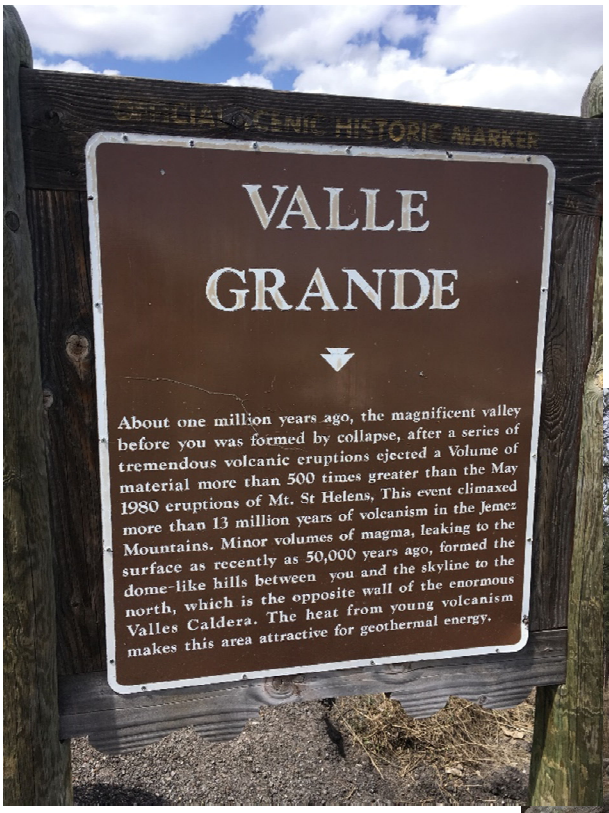
Steve Shackley has provided an EDXRF analysis of the Fryxell Medallion. He noted: "I would classify it somewhere between a Cu brass (Zn) and bronze (Sn). There is some Pb as well. The Zn will keep the Cu from patinating too much I assume."

The instrumental method is at: http://swxrflab.net/anlysis.htm. The 32X LB 17 standard is a leaded bronze from MBH Analytical Ltd. in England. The recommended values are included.

Sample	Mn %	Fe %	Co %	Ni %	Cu %	Zn %	As %	Mo %	Ag %	Sn %	Sb %	Au %	Pb %	Bi %
FRYXELL MEDALLION	0.00	0.11	BDL	0.31	90.06	5.02	0.00	BDL	0.03	2.82	0.02	BDL	1.55	0.03
32XLB17	0.19	0.49	0.11	0.45	75.32	0.64	1.36	BDL	0.94	5.83	3.69	0.01	10.75	0.23
32XLB17 recommended	0.20	0.53	0.01	0.44	74.83	0.63	1.51	nr	0.91	5.97	4.10	nr	9.83	0.22

BDL=below detection limits
nr= not reported

Photos from the IAOS/Prehistoric Quarries and Mines Interest Group field trip to Valles Caldera, led by Ana Steffen and Nick Jarman. It was cold and snowy, but we had a wonderful time! Thank you, Ana and Nick! Photos by Carolyn Dillian:



IAOS Sponsored SAA Session: Advances in Obsidian Studies in the Old and New Worlds

Contributed by Phyllis Johnson

The 2019 IAOS-sponsored Society for American Archaeology (SAA) session entitled "Advances in Obsidian Studies in the Old and New Worlds" was organized by Yuichi Nakazawa and Phyllis Johnson in an effort to explore novel methods and advances in traditional methods for the study of obsidian that were applicable worldwide. The session included seven excellent papers covering a broad range of methodological approaches (including obsidian hydration dating (OHD), x-ray fluorescence (XRF) analyses, agent-based modeling (ABM), obsidian procurement strategies, and the uses of pitchstone) and geographical regions (California, Guatemala, Japan, and Scotland). Robert Tykot kindly served as the discussant for the session. Here, I briefly describe the contributions of each paper.

The session began with two papers on obsidian hydration dating. In *Paleo-temperature Adjustment for Obsidian Hydration Dating*, Alexander Rogers and Christopher Stevenson discussed their newly developed method for extending the range of validity of obsidian dates further into the Paleolithic period than previously thought possible. This method corrects for the instability of temperatures over the past hundred thousand years and extends possible dates back to 200,000 years. The authors concluded that a paleotemperature correction is necessary for artifacts with ages greater than about 13,000 years. This method has been documented in *IAOS Bulletin* 59 (Rogers 2018).

In *An Assessment of the Intrinsic Water Content toward Understanding Obsidian Hydration: A Case Study of Paleolithic Obsidian from the Shirataki in Hokkaido, Japan*, Yuichi Nakazawa and Kyohei Sano followed Rogers and Stevenson with their case study that applied OHD to an the Kyu-Shirataki 3 site in Hokkaido, Japan, where as many as 147,000 obsidian artifacts have been collected, in order to provide empirical data connecting hydration measurements to archaeological questions. The main problem identified by the authors for using OHD to date obsidian from this site is that obsidian nodules derived from the same source buried under same ambient temperature may have had different hydration rates. The authors identified three potential causes for these differences: sample size, human behavior, and intrinsic water content, though these have not yet been tested. Future research will include measuring the water content for each specimen in order to determine if water content causes these differences.

The following three papers applied chemical sourcing strategies to the analysis of obsidian artifacts. In *Variation in Obsidian Source Consumption within the Kingdom of Piedras Negras*, Max Seidita, Alejandra Roche Recinos, Whittaker Schroder, Charles Golden, and Andrew Scherer presented the results of portable XRF (pXRF) of approximately 2,100 obsidian artifacts derived from nine sites within the Piedras Negras kingdom in order to examine the structure and nature of obsidian procurement in the Piedras Negras kingdom. The authors found that while the majority of the analyzed artifacts were sourced from the El Chayal source in southern Guatemala, the marketplace contained a wider variety of obsidian sources than any of the other sampled contexts, including an obsidian workshop at the site of Budsilha. The authors suggested that future work should include analysis of production techniques in conjunction with sourcing data to provide a better understanding of the structure of obsidian provisioning systems.

In *Assessing the Potential for ED-XRF in Archaeometric Studies: A Focus on Data Sharing and Bulk Chemical Analysis*, Jeffrey Ferguson stressed that, although XRF can provide valuable information for archaeological research, this does not mean it is always the most appropriate method. XRF is increasingly becoming popular for analyzing obsidian due to its speed and low cost. Though obsidian is one of the most ideal archaeological materials for XRF analysis, Ferguson noted that it is important to understand the limits of the region you study, as many have compositionally-similar sources, resulting in overlapping or inaccurate results. Furthermore, best practices include using a single, properly calibrated instrument, and materials that are chemically complex, such as ceramics should not be analyzed using pXRF.

In *Temporal Changes in Obsidian Procurement Strategy during the Upper Paleolithic on Hokkaido: Pre-LGM and LGM assemblages in the Tokachi plain and Ishikari Lowland*, Masami Izuho and Jeffrey Ferguson paired XRF with neutron activation analysis (NAA) of obsidian artifacts to assess how social organization and mobility patterns changed in the south of Paleo-Sakhalin-Hokkaido- Kurile Peninsula (s-PSHK) between 34,000-23,000 years BP. The authors found that during this time, the sources closest to the site (0-30km) dominated the assemblage, but between 27,000-23,000 years BP, foragers obtained 10-20% of obsidian from distant sources (greater than 30km). Future research will focus on assessing 1) how the mobility pattern changed; and 2) how land-use patterns changed.

In *Potential Applications for Agent-Based Modeling in Obsidian Studies,* Phyllis Johnson discussed her preliminary work developing an ABM to examine the post-depositional movement of lithic artifacts. More specifically, Johnson seeks to understand how microdebitage (measuring < 4mm) moves after archaeological sites are abandoned. Johnson has collected 480 soil samples from the Late Classic Maya capital of Guatemala for the purpose of collecting microdebitage in order to identify areas where primary obsidian reduction took place. This work is particularly timely because many Maya sites in Mesoamerica are being heavily threatened by rapid deforestation and looting. A decade ago, the majority of Tamarindito was still covered in rainforest. Today, however, only the two main plazas have forest cover. As such, Johnson hopes to use these data to test the accuracy of the model, which will then be used to target those areas of Tamarindito that are most vulnerable to erosion and the loss of data for further research.

To end our session, Clive Bonsall and Maria Gurova presented *Pitchstone in Prehistory: New Insights into the Mesolithic and Neolithic Use of Pitchstone in Scotland*. Like obsidian, pitchstone is a volcanic glass, but it differs from obsidian in several ways, including having a higher water content, a duller luster, and often a "hackly" fracture. The only known European sources of pitchstone are in Arran and Eigg of the British Tertiary Volcanic Province. During the Mesolithic, pitchstone appears to only have been used in Arran, but its use spread throughout northern England and Ireland during the Neolithic period. In the present study, Bonsall and Gurova used pXRF to reanalyze 28 artifacts from 22 sites originally analyzed by Williams-Thorpe and Thorpe (1984) using XRF and NAA. Though the original study determined that these artifacts were all sourced from Arran, the present reanalysis determined that none of the artifacts were from known Arran sources, but not all sources have been analysed. Furthermore, usewear analyses proved very difficult in distinguishing usewear from taphonomic damage. Though this study remains preliminary, the authors demonstrate that there is much work to be done to understand archaeological uses of pitchstone.

OBSIDIAN ARTIFACTS FROM LA VENTA AND SOURCES IN MESOAMERICA

Michael D. Glascock[1], Kylie Gannan[1], and Thomas R. Hester[2]

[1]University of Missouri, Columbia; [2]University of Texas, Austin

Presented at SAA 2019 Fryxell Symposium in honor of M. Steven Shackley

Introduction

Obsidian was one of the most extensively used lithic materials in prehistoric Mesoamerican society, and it maintained this role from the Formative period until the early years of the Spanish Colonial era. From 1968 through 1972, Robert Heizer and colleagues at U.C. Berkeley used X-ray fluorescence (XRF) to analyze obsidian artifacts from several well-known archaeological sites in Mesoamerica. The sites include La Venta, Cempoala, Cholula, El Tajin, and Quiahuitzlan, all located in Mexico. The results of their investigations were reported in a series of articles in *Contributions of the University of California-Archaeological Research Facility* (Hester et al. 1972; Jack et al. 1968, 1972).

The artifacts from the U.C. Berkeley studies were in the possession of Thomas Hester until the summer of 2018, when he transferred them to MURR. We thought it might be interesting to re-analyze the artifacts using modern methods and to assign the artifacts to sources based on comparisons to the more comprehensive database for obsidian sources in Mesoamerica accumulated at MURR over the past ~40 years.

Historical Background

The archaeological site of La Venta is located in the southern state of Tabasco and is well known to Mesoamerican archaeologists as a Formative Period site of the Olmec civilization. Following the decline of the original Olmec capital at San Lorenzo around 900 BCE, La Venta became the leading Olmec site. For about 500 years, La Venta was the most significant cultural, economic, and population center for the Olmecs. Obsidian was used abundantly at La Venta. Due to the distance from La Venta to the nearest sources, the raw material must have been acquired through a mechanism involving long distance trade or exchange.

The studies of Heizer and colleagues at La Venta and other sites were the very first attempt by archaeologists to use chemical composition to identify the source(s) of obsidian artifacts in Mesoamerica. The vast majority of the artifacts studied were in the form of prismatic blades of various sizes, shapes, and thicknesses.

Heizer's group analyzed the obsidian artifacts using a rapid-scan XRF procedure by which they measured five mid-Z elements: Rb, Sr, Y, Zr, and Nb. The elements were selected because they have excellent properties for measurement by XRF. First, they are sensitive to XRF at concentrations down to few parts per million. Second, due to their size and/or charge, these elements are incompatible with crystallization and they tend to remain in the melt phase of the magma during the rapid cooling process that produces obsidian. These properties make them sensitive indicators of the differences between individual obsidian sources.

Because appropriate standard reference materials (SRMs) were unavailable to calibrate their XRF instrument for obsidian measurements, Heizer's group resorted to using peak areas as their method for discriminating between different obsidian sources. An obvious limitation with the reporting of peak areas is that the data are instrument-specific. Therefore, it is not possible to compare their measurements with

measurements made on a different XRF spectrometer or measurements by other analytical methods such as neutron activation analysis (NAA) or inductively coupled plasma (ICP).

A second more important limitation to the work by Heizer and colleagues is that at the beginning of their investigations, knowledge regarding the locations of obsidian sources in Mesoamerica was very limited. As a result, they assigned labels such as Type A, B, C, D, and E to identify the major groups explaining more than 95% of the artifacts. Types F, G, etc. were used to identify the remaining groups. The results were presented in a series of ternary diagrams such as the one shown in Figure 1 for obsidian artifacts at the site of La Venta.

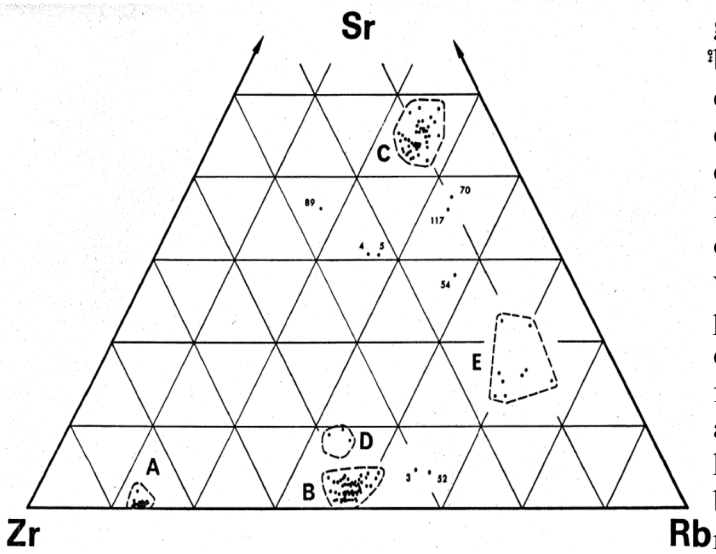


Figure 1. Ternary plot showing artifacts from La Venta reported by Jack and Heizer (1968) based on peak areas for Rb, Sr, and Zr. Five major types were identified by Types A, B, C, D, and E.

In 1968, the only known obsidian source in Mexico was one located near Pachuca, Hidalgo from which the distinctive greenish obsidian was obtained. The Pachuca source was identified as Type A. In the Guatemalan highlands, two sources were known at Ixtepeque and El Chayal. However, the latter were not a match for one of the major groups, and due to the limited information on the Ixtepeque or El Chayal sources, they did not feel confident in assigning either Guatemalan source to one of the minor groups.

By 1972, a few more sources were discovered and linked to the various types. Type D was identified with the Zaragoza obsidian source, Type E was assigned to the obsidian from Orizaba, and the minor source Type G was assigned to Guadalupe Victoria. Eventually, the sources corresponding to Types B and C were realized as Paredon and San Martin Jilotepeque, respectively. However, they did not explicitly identify the locations of sources for the remaining minor types.

A third limitation to the work by Heizer's group was that the known obsidian sources had been sampled only casually. That is, typically a couple of source samples were collected. No efforts were made to assemble systematic collections from primary outcrops or secondary locations such as quebradas and rivers. Not only was there no information on the possible variation within individual sources, the possibility that sources with significant chemical variation might overlap with a source from a different location was unknown. In addition, the possibility that a source might have multiple chemical fingerprints could not be tested. Although the Berkeley group recognized that more extensive trace analyses should be conducted to more precisely define the chemical limits of each obsidian type, they did not accomplish this work.

In 1980, however, Robert Cobean initiated a collaboration with the University of Missouri Research Reactor (MURR) to systematically collect and analyze the obsidian sources in east central Mexico and Guatemala (Cobean 1991; Glascock et al. 1998). Cobean collected more than 900 source samples, weighing nearly 1000 kilograms, and sent them to MURR for analysis by NAA. NAA provided the advantage of high-precision and accuracy, many more elements,

Standard	Mn (ppm)	Fe (%)	Zn (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)	Th (ppm)
SRM-278	342	1.35	37	131	60	37	287	18	15
JR-1	768	0.602	23	251	28	43	93	14	26

Table 1. Quality control results from analysis of SRM-278 obsidian rock and JR-1 rhyolite.

and access to a suite of well-known standard reference materials (SRMs) certified by the National Institute of Standards and Technology (NIST), US Geological Survey (USGS), Geological Survey of Japan (GSJ), etc. After a couple of years, several hundred source samples were analyzed allowing MURR to create a database for the obsidian sources in Mesoamerica. The database facilitates the ability to inspect internal variation within obsidian sources and the identification of localized subsources within sources. More than 25 different sources were characterized and several of these were discovered to have multiple subsources that could be traced to locations within the primary source area. Sources in Mesoamerica found to have multiple subsources include: Pachuca with three, Ucareo with three, Zaragoza with two, and San Martin Jilotepeque with six.

Figure 2 shows the five above-mentioned archaeological sites and the most important obsidian sources known after Cobean (1991). All of Cobean's samples were later re-analyzed by XRF, so that the reported data might be useful to colleagues who only have XRF (Glascock 2011).

Analytical Procedures

The artifacts from La Venta (290) and the four other sites (191) were analyzed by XRF in the Archaeometry Lab at MURR using a

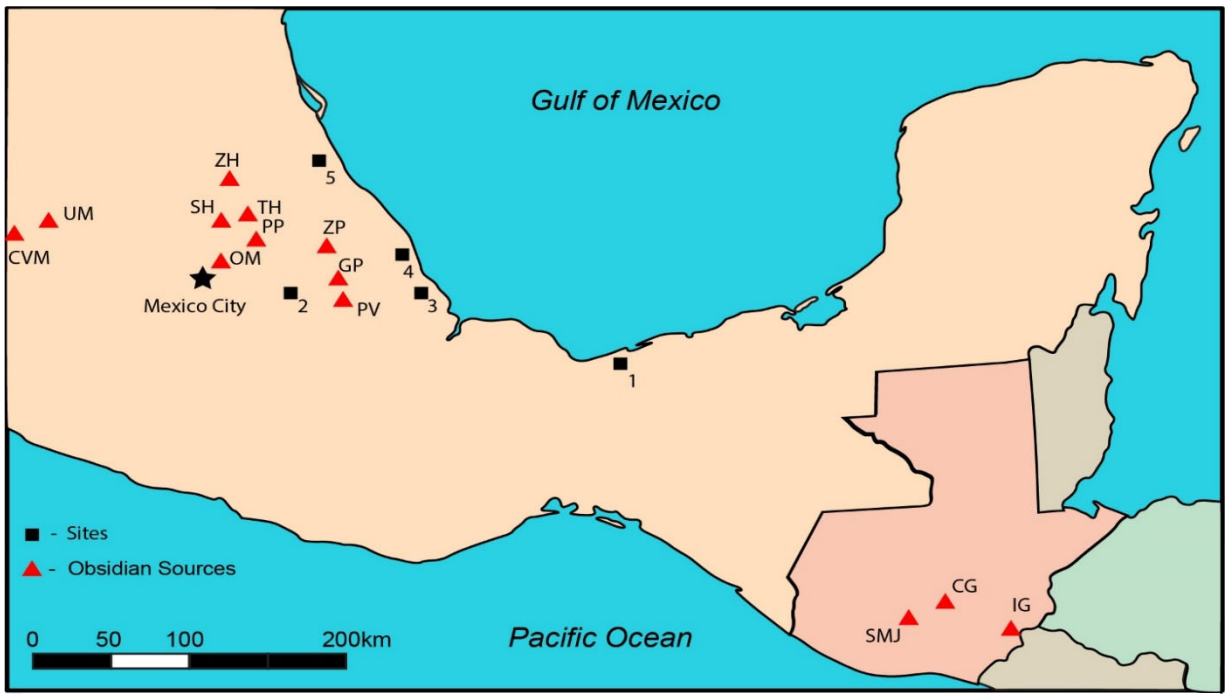


Figure 2. Archaeological sites in this study and the obsidian sources linked to the sites. Sites are: 1=La Venta, 2=Cholula, 3=Cempoala, 4=Quizhuitzlan, and 5=El Tajin. Sources are: CG=El Chayal, IG=Ixtepeque, SMJ=San Martin Jilotepeque, PV=Orizaba, GP=Guadalupe Victoria, ZP=Zaragoza, PP=Paredon, OM=Otumba, SH=Pachuca, TH=Tulancingo, ZH=Zacualtipan, UM=Ucareo, and CVM=Cerro Varal.

ThermoFisher ARL Quantx EDXRF spectrometer with a rhodium x-ray target and 3.0 mm diameter collimator for the x-ray beam. The spectrometer was operated at 35 kV with a 0.05 mm-thick palladium primary beam filter to measure the K-alpha lines for the elements Mn, Fe, Zn, Rb, Sr, Y, Zr, Nb, and Th. Counting times of 120 seconds were used on each sample. Trace element intensities were converted to concentrations using least-squares calibration normalized to the rhodium Compton-scatter peak on the basis of 40 obsidian source samples of "infinite thickness" from sources previously analyzed by NAA and ICP-MS (Glascock and Ferguson 2012). The calibration was checked periodically by analyzing pressed powdered samples of certified rock standards from the National Institute of Standards and Technology (NIST), the U.S. Geological Survey (USGS), or the Geological Survey of Japan (GSJ). Overall precision for the obsidian data was determined to be on the order of 2% and the accuracy is within 5% based on the international standards SRM-278 from NIST and JR-1 from the GSJ we used as our quality controls. Results for the latter standards are listed in Table 1.

Results

Out of 481 artifacts analyzed from the five archaeological sites, four were immediately recognized as samples of chert due to their extremely low values for all trace element values. The remaining 477 artifacts were compared to data for all known sources in Mexico and Guatemala for individual provenance determination. Instead of using ternary plots to present and interpret our data, we examined a series of two-dimensional scatterplots combined with 90% confidence ellipses to surround the source data.

As mentioned earlier, the fact that most of the artifacts are not infinitely thick poses a problem when using scatterplots of elements (Hughes 2010). The artifact distributions are seriously skewed or elongated along the correlation lines between elements. To compensate for this problem with tiny or thin artifacts, we examined multiple combinations of element ratios on both axes which greatly improved our ability to identify the correct sources. For this work we were most satisfied with Figure 3 which shows a scatterplot of element-to-geometric mean (GM) ratios on both axes.

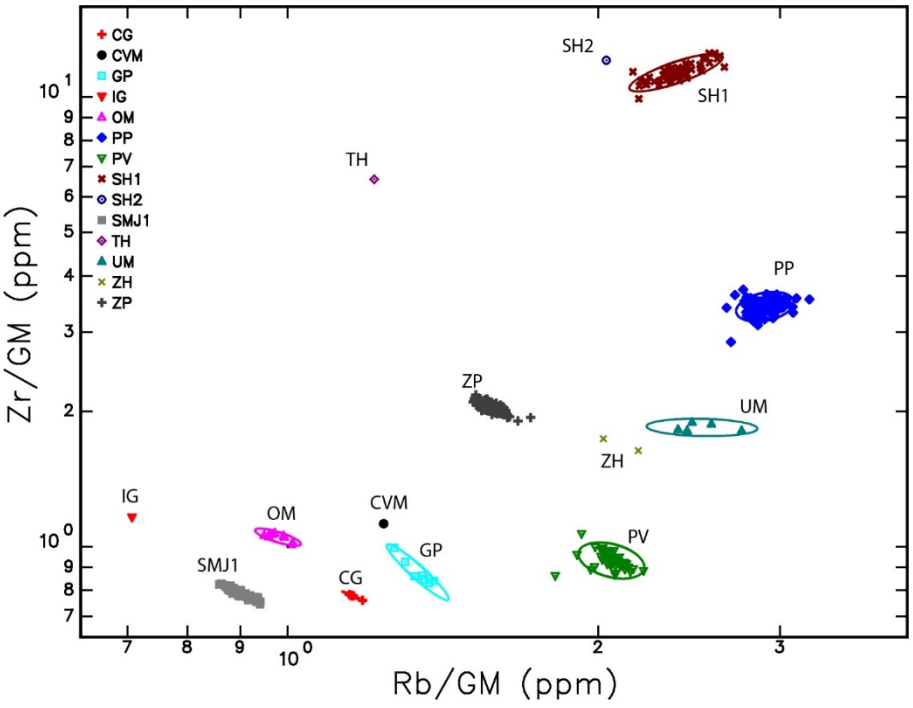


Figure 3. Scatterplot of Rb/GM versus Zr/GM for artifacts from La Venta and four other sites. GM is the geometric mean. The source abbreviations are the same as those in Figure 2.

The GM is defined by

$$GM = \sqrt[3]{(Rb+1)(Sr+1)(Zr+1)}$$

where *Rb*, *Sr*, and *Zr* are the element concentrations in parts per million. The value (1) was added to each concentration to account for possible non-detects.

Our final results are summarized in Table 2, which compares the source assignments made by Heizer's team with those made at MURR. With a few minor exceptions there were no great surprises for the major Types A thru E. Two artifacts originally assigned to the Pachuca source were found to be from the source at Tulancingo and a subsource of Pachuca. Two artifacts originally assigned to Paredon and Zaragoza were incorrectly assigned.

On the other hand, the most interesting results were discovered for the artifacts categorized as minor types or unassigned. Three of the Guadalupe Victoria artifacts have been reassigned to different sources. Three previously unassigned artifacts have now been assigned to the San Martin Jilotepeque source. A few of the unassigned artifacts have been assigned to the El Chayal and Ixtepeque sources. Finally, the sources at Otumba, Ucareo, and Cerro Varal previously unknown to the U.C. Berkeley group were found to have artifacts at the site of La Venta.

Summary

The work presented here shows that revisiting an old project by using modern technology and procedures can be rewarding. Information not available to the original investigators has revealed evidence that was not apparent when the original study was conducted. The more comprehensive database at MURR for obsidian sources in Mesoamerica, based on systematic collections of multiple samples from each source, helped us to be more successful at realizing differences between sources and the variations within individual sources. This knowledge greatly reduced the number of artifacts that could not be assigned to a specific source. Whereas, the U.C. Berkeley group was unable to assign 4% of the original artifacts, we were successful in assigning every one.

Berkeley Type ID	Berkeley assignments	MURR assignments	Source Names
chert	4	4	chert
A	62	60	Pachuca-1
B	140	139	Paredon
C	81	85	San Martin Jilotepeque
D	113	112	Zaragoza
E	49	49	Orizaba
F	2	2	Zacualtipan
G	10	7	Guadalupe Victoria
minor types	20	5	El Chayal
		1	Ixtepeque
		9	Otumba
		5	Ucareo
		1	Cerro Varal
		1	Tulancingo
		1	Pachuca-2
Total	481	481	

Table 2. Comparison between results from U.C. Berkeley and MURR.

The importance of using analytical tools with a calibration that can be linked to certified SRMs is also recognized. Unlike data from the original study, the data discussed here can be compared to data from other XRF instruments or other laboratories without the requirement of repeating measurements on every sample.

Due to the presence of many tiny and thin artifacts, we also demonstrate that the problem of identifying sources when using elemental plots that have skewed or elongated distributions relative to source samples can be reduced by using plots of element ratios. In addition, we want to emphasize that examining a single plot is often not sufficient. One should examine every possible combination to reduce the potential for an error.

Finally, with sources used coming from as far away as Ixtepeque (500 km) and Cerro Varal (1000 km), we have confirmed that the Olmec traveled widely or were in contact with distant groups involved in long distance exchange. This shows that the distances from sources to sites were much greater than Heizer and colleagues realized.

Acknowledgements

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A NEWLY DISCOVERED SOURCE OF ARCHAEOLOGICAL OBSIDIAN NEAR DUNCAN, ARIZONA AND ITS COMPOSITIONAL RELATIONSHIP TO THE COW CANYON SOURCE, EASTERN ARIZONA: THE VALUE OF MINOR SOURCES

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In 2016, John Roney, while directing an archaeological survey for the University of Texas, San Antonio's field school north of Duncan, Arizona above the Gila River, discovered a potential primary source of obsidian (Figures 1 and 2). The initial XRF analysis indicated an elemental composition similar to the Cow Canyon obsidian source located in the Blue Range to the north of the San Francisco and Gila Rivers in northern Greenlee County, Arizona, approximately 80 linear km north of Duncan. On 31 May 2018 a geoarchaeological examination and collection at what is now called the Duncan obsidian source indicated that the source is likely a Tertiary (Neogene) period, coalesced rhyolite dome complex with scattered small marekanites at light density, most smaller than 30 mm in diameter, and not yet discovered in regional archaeological contexts. The similar

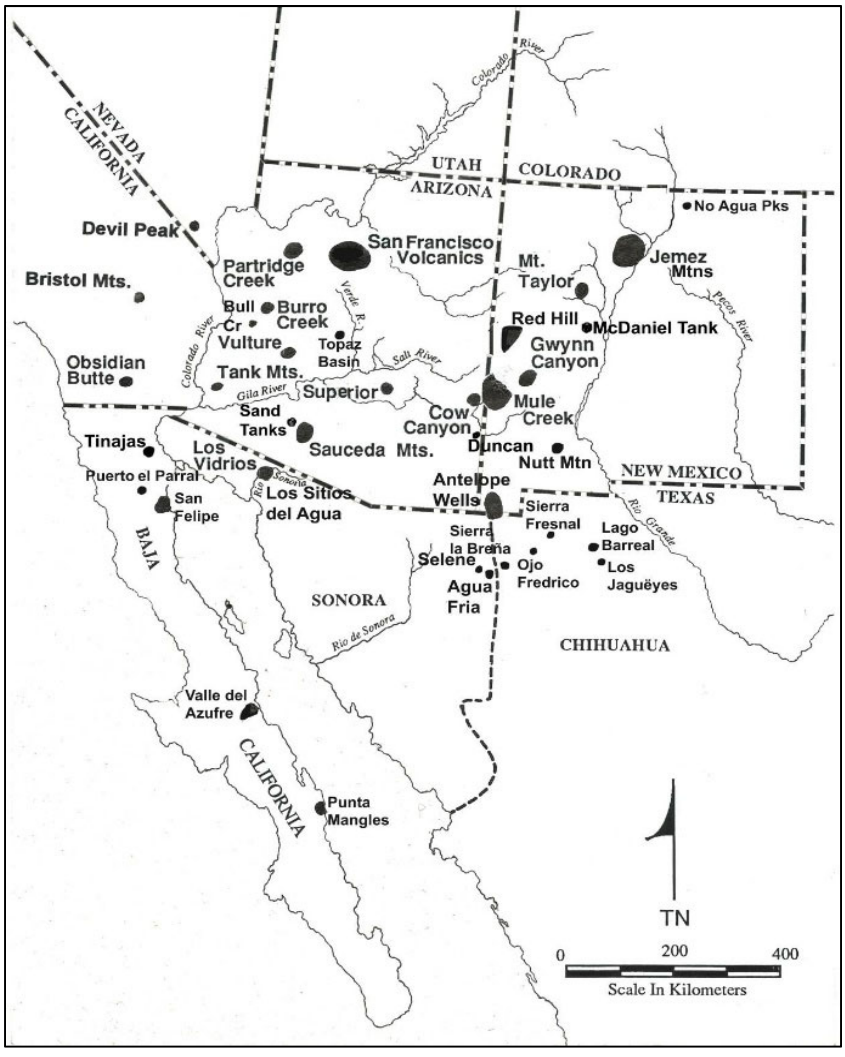

Figure 1. Approximate location of currently known and characterized sources of archaeological obsidian in the greater North American Southwest, including the Duncan source.

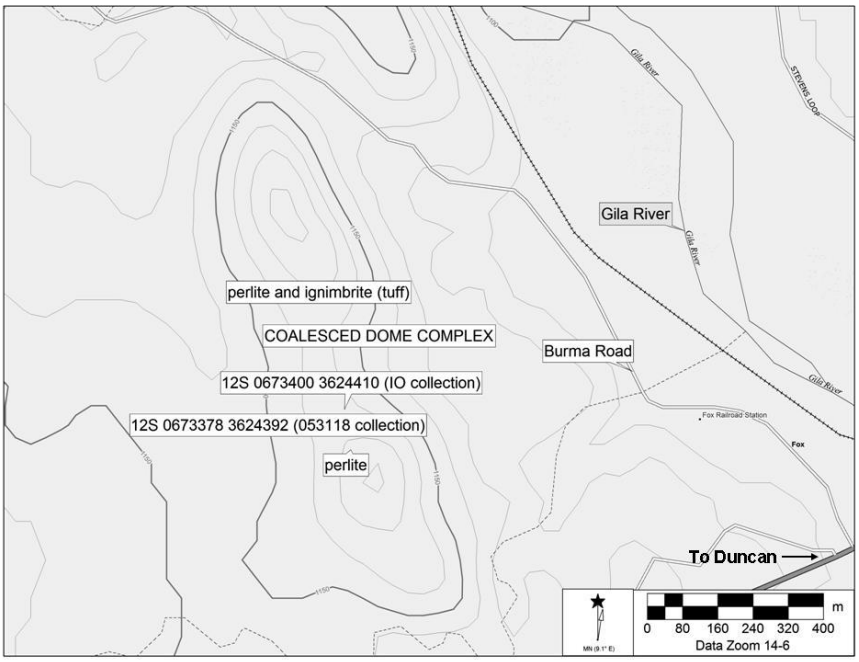

Figure 2. Duncan obsidian source locality and geological features

elemental composition between Cow Canyon, a major Mogollon-Datil Volcanic Province source of archaeological obsidian in the Southwest, and the Duncan source requires careful analysis when using x-ray fluorescence spectrometry (XRF) in order to discriminate these two sources (Mills et al. 2013; Shackley 2005; Shackley et al. 2018). While the Duncan obsidian source has not yet appeared in regional archaeological contexts, this "minor" source of archaeological obsidian can yield useful information about prehistoric regional territories, social networks, and procurement strategies.

Geoarchaeological Source Description

The Duncan obsidian source is located in Greenlee County, Arizona at an elevation of 1150 m AMSL approximately 5 km northwest of Duncan, Arizona, above Plio-Pleistocene alluvial terraces on the west side of the Gila River and directly above Burma Road (Figures 1 and 2). The source is defined by two coalesced rhyolite domes that exhibit remnant obsidian marekanites (nodules) in highly eroded aphyric perlitic tuff and perlite, in a structure that is about 1500 m long oriented northwest/southeast (see Figure 2). Typical of Neogene rhyolite dome structures in the North American West, the overlying obsidian zone and perlite have generally eroded off the domes, in this case into the saddle between the two domes, on the slopes of the domes, and likely eroding into the Gila River system (Fink and Manley 1987; Hughes and Smith 1993; Shackley 2005; see Figure 2). No marekanites were discovered in the existing wash below and east of the domes.

There have been no specific geological studies of this structure. The original geological mapping of Greenlee County, Arizona, by Wilson and Moore (1958) shows the area here as "Tr - rhyolite, includes tuff and agglomerate", but nothing specific at that scale. More recently Richter et al.'s (1983) geologic map of the Guthrie 1º quadrangle including Graham and Greenlee Counties provides no specific data either. Walker's 1990 Ph.D. dissertation is the best discussion of the Ash Peak area rhyolites, but again his study area was just north of the Duncan domes. We can say that given the above discussion in the geological literature, and the eroded structure of the domes, that the source is likely Neogene in origin, typical of rhyolite extrusions in the

region (Shackley 2005; Shackley et al. 2018), but no specific chronology is available.

Ash Peak and Mogollon-Datil Area Geology

Walker's Ph.D. dissertation study examined the Ash Peak volcanics, including what he petrochemically defined as biotite rhyolites, crystal-rich rhyolites, and crystal poor rhyolites, the latter best describes the rhyolite (obsidian) at the Duncan domes, however the composition of the biotite rhyolite with higher Sr and Ba is more similar to the Duncan obsidian composition (Walker 1990:178; Table 1). No mention of obsidian was made specifically by Walker. These rhyolites are dated to ~20 Ma typical of Neogene silicic events in this part of western North America including the adjacent Mogollon-Datil Volcanic Province (Richter et al. 1983; Shackley et al. 2018). As in the Mogollon-Datil these rhyolites were likely produced by re-melting a granite basement (see Elston 2008; Shackley et al. 2018; Walker 1990). This re-melting of a large plutonic rock body is likely responsible for the similar composition seen in both the Duncan and Cow Canyon obsidian as well as the similarities observed in Mogollon-Datil rhyolites (Shackley et al. 2018; see discussion below).

The marekanite density as seen in May 2018 was rather low, and probably no more than about five per 25 m^2. The largest marekanite recovered in 2016 and 2018 was 44.9 mm in largest dimension, but most are nearly half that size or smaller. At least two bipolar flakes were present, so it had been discovered prehistorically.

Thin flakes appear smoky gray and translucent, and seem to be a good media for tool production based on bipolar reduction for XRF analysis (c.f. Shackley 1990, 2005). The megascopic character is different from the Cow Canyon marekanites that are uniformly nearly transparent in flake dimensions (Shackley 1995, 2005). While it is likely that the Duncan marekanites have been eroding into the Gila River system since the Neogene, it does not appear in the archaeological record even in sites in the immediate area (Shackley 2016, 2017, 2018). Archaeological sites in the region exhibit a small proportion of Cow Canyon, but the majority are from one of the three major source localities of the Mule Creek Obsidian Complex (Shackley 2005; Shackley et al.

	N	Minimum	Maximum	Mean	Std. Deviation
Ti	55	1008	1810	1299.8	191.8
Mn	55	283	427	337.0	29.3
Fe	55	9305	13864	11278.2	1027.9
Zn	55	42	152	69.1	24.7
Rb	55	125	175	154.6	9.4
Sr	55	60	81	71.1	4.2
Y	55	24	36	29.6	2.5
Zr	55	110	140	128.8	6.2
Nb	55	12	30	21.2	3.4
Ba	55	390	693	585.4	44.2
Pb	55	17	30	22.9	2.9
Th	55	8	30	19.8	5.6

Table 1. Mean and central tendency for Duncan obsidian trace elements (ppm). Only obsidian included in this data table (see http://swxrflab.net/Duncan.htm for elemental data including tuff and perlite samples).

2018). Both Cow Canyon and the Mule Creek Complex source groups erode into the San Francisco and Gila River systems (Houser et al. 1985; Shackley 1992, 2005, 2016, 2017; Shackley et al. 2018; Figure 1). While it could certainly just be sampling error (none yet recovered), the Duncan obsidian source is likely such a numerically small source, it probably was not encountered often in prehistory, although there are large Late Archaic (Early Agricultural) through Late Classic sites in the area. In Gila River Quaternary alluvium, secondarily deposited Cow Canyon and Mule Creek complex sources are often found in higher densities and larger nodule sizes than at the primary Duncan source. This could also be a factor explaining why Duncan obsidian is not recovered in regional archaeological contexts. Finally, without acquiring Ba when analyzing archaeological obsidian with XRF, it is certainly possible that any Duncan obsidian recovered archaeologically might be mistaken for Cow Canyon, as discussed below. This means that assemblages analyzed by XRF instruments that cannot acquire the higher Z elements could mistakenly assign Duncan obsidian to Cow Canyon. Indeed, all of the analyses completed by this laboratory with the benchtop Quant'X XRF that did not acquire Ba could be in that category, although the low density and small nodule sizes at Duncan and the results in local archaeological contexts suggest that Cow Canyon would dominate in any regional archaeological assemblage. Additionally, as mentioned above, Cow Canyon obsidian is uniformly nearly transparent in flakes and small bifaces and the Duncan marekanites are smoky brown and translucent. While always hazardous, the megascopic character could be used as a first approximation when assigning to source and selecting the non-transparent artifacts for further analysis (see Shackley 2011).

The Mogollon-Datil Volcanic Complex and Cow Canyon versus Duncan Sources

Both Cow Canyon and the Duncan sources are on the western margin of the Mogollon-Datil Volcanic Complex, a large volcanic field that includes some of the most frequently used obsidian sources in the North American Southwest (Elston 2008; Mills et al. 2013; Shackley 2005; Shackley et al. 2018). The Antelope Creek locality at Mule Creek and Cow Canyon are Neogene Period signature sources that were used from Paleoindian through historic periods (i.e., Diné) for tool production, and have been integral in understanding exchange, territory, migration and social networks during the Late Classic of the Southwest (Hamilton et al. 2013; Mills et al. 2013; Shackley 2005, 2007; Shackley et al. 2018).

After the original analysis of the Duncan obsidian samples, it became immediately apparent that the Duncan source was compositionally similar to the Cow Canyon source north of Duncan. The Duncan source is upstream from Cow Canyon and the secondary deposition of Cow Canyon, so it is impossible for the Duncan source to be secondary deposits of Cow Canyon, and the structure of the domes are certainly a primary source of the Duncan obsidian (see Figure 1).

Compositional Analysis of Duncan and Cow Canyon Obsidian[1]

Fifty-eight obsidian, perlite, and tuff samples were analyzed for trace elements and oxides from the Duncan coalesced domes (Table 1, Figures 3 and 4; raw elemental data online at: http://swxrflab.net/Duncan.htm). In order to confirm that the obsidian marekanites were derived from those dome structures, samples of perlite and silicic tuff were analyzed as well, and the composition is the same for the rock samples and obsidian indicating that the obsidian is derived from these domes and the marekanites are the remnants of the eroded

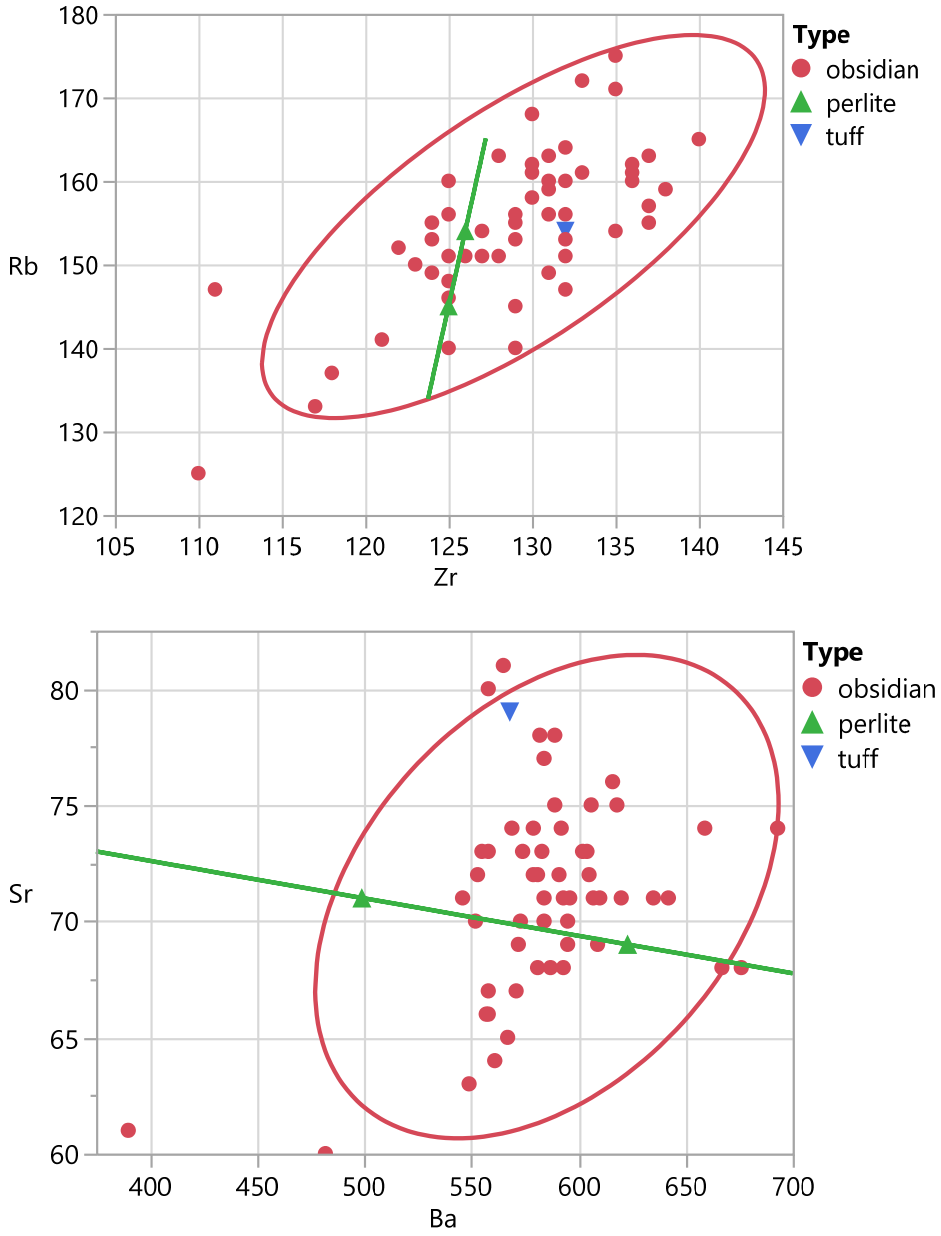

Figure 3. Zr versus Rb (top) and Ba versus Sr (bottom) bivariate plots of the Duncan obsidian source standards, perlite, and tuff samples from the Duncan obsidian dome complex. Confidence ellipses at 95%.

obsidian zone above the crystalline rhyolite (Hughes and Smith 1993; Mahood and Stimac 1990; Fink and Manley 1987; Shackley 2005; Zielinski et al. 1977; Figure 3; see online raw data: http://swxrflab.net/Duncan.htm). Additionally, the major and minor oxide analyses of a sample of the obsidian indicates a high silica peraluminous rhyolite similar to Cow Canyon (Table 2 and Figure 4). The composition of the Duncan obsidian is quite similar for all samples analyzed in most elements, particularly in the mid-Z incompatible elements (see Shackley 2005, 2011; Table 1, and Figures 3 and 4; see raw elemental data online at http://swxrflab.net/Duncan.htm).

Sample	Na_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	MnO	Fe_2O_3	Σ
	%	%	%	%	%	%	%	%	%	
053118-1-2	2.989	0	12.931	73.049	6.671	1.261	0.311	0.079	2.386	99.677
RGM1-S4	4.045	0	12.918	73.857	4.933	1.433	0.292	0.05	2.228	99.756
USGS RGM-1 recommended	4.07	0.28	13.7	73.4	4.30	1.15	0.27	0.036	1.86	99.076

Table 2. Major and minor oxides for a single Duncan obsidian sample, the USGS RGM-1 source standard, and USGS recommended values. All measurements in weight percent (%).

Cow Canyon versus Duncan Obsidian Composition

As mentioned above, originally it appeared that the Duncan source and the Cow Canyon obsidian source exhibited the same elemental composition (Figure 5). This would obviously complicate source assignment of archaeological artifacts in this region. It is not unusual for Mogollon-Datil Volcanic Province obsidian sources to exhibit very similar elemental composition, although the eruptive chronology and isotopic signatures are quite dissimilar (Shackley et al. 2018). This is due to remelting of the underlying Precambrian granite basement in the region during the Neogene that produced the rhyolite (obsidian) thus creating rhyolite and obsidian with similar composition in this large region (see Elston 2008; Shackley et al. 2018). This appears to have been the case with Cow Canyon and Duncan, and as with the Mule Mountain and Nutt Mountain case, strontium (Sr) and barium (Ba) appear to separate the two sources, particularly the latter element (Shackley et al. 2018; see Figure 5). As noted above, however, barium is not routinely analyzed for most archaeological obsidian projects, but from now on when using XRF either benchtop or portable units, barium should be acquired if possible when a Cow Canyon/Duncan composition is evident.

The Duncan obsidian source as a minor source of archaeological obsidian has not been recovered in archaeological contexts thus far. It is quite possible that re-analyzing some archaeological assemblages that contain Cow Canyon obsidian using XRF, particularly in local sites, could detect Duncan obsidian, although this is unlikely given the small size of the source and the small quantity and nodule

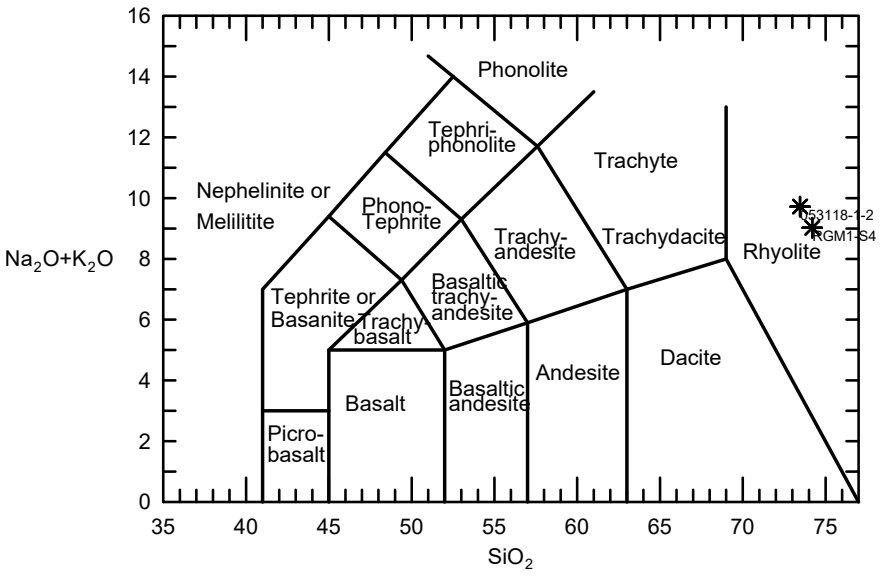

Figure 4. TAS plot of Duncan obsidian sample 053118-1-2 and USGS RGM-1 rhyolite standard (Le Maitre et al. 1989).

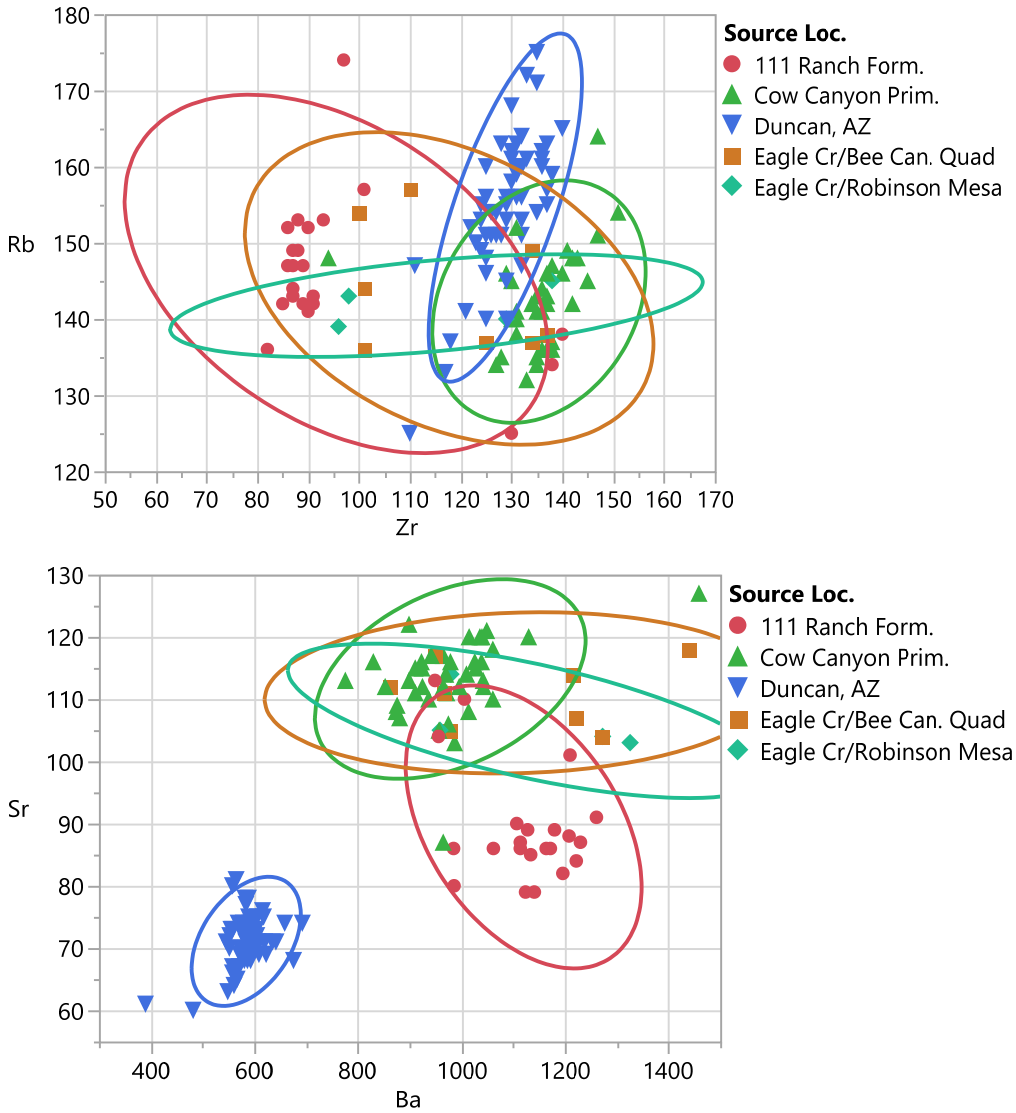

Figure 5. Zr versus Rb (top) and Ba versus Sr (bottom) bivariate plot of Cow Canyon source locality and Duncan source standards. Confidence ellipses at 95%. Note that Rb and Zr do not discriminate the two sources. Ba and to a certain extent Sr are required to do so. However, the 111 Ranch Formation secondary deposit obsidian of Cow Canyon and Duncan obsidian can be discriminated using Rb and Sr. Parenthetically, note that the Cow Canyon source localities (111 Ranch Formation, Cow Canyon primary, and the Eagle Creek localities) exhibit some variability on these four elements, but overlap significantly within 95% confidence ellipses. Whether this is due to geological processes (i.e. fractionation) or chronological differences in eruptive events is not yet known.

sizes of obsidian available at the source. Additionally, in the analysis of over 250 samples from ten local sites, including Early Agricultural through ceramic period sites excavated by the UTSA field school, no Duncan obsidian was recovered. There may be some archaeological situations where discrimination of these two sources could be important, such as the need to understand territorial boundaries, or at nearby sites in the southeastern Arizona/southwestern New Mexico region.

In this region when a Cow Canyon composition is inferred it would be prudent to acquire barium (Ba) in addition to the mid-Z elements typically acquired by XRF (see

Figure 5). Given the small size of the Duncan source proper, and small nodule size, it is unlikely that the Duncan source would be a major component of any assemblage, however. Still, as evident with other "minor" sources of archaeological obsidian, understanding these artifact quality sources that do not seem to be of interest in prehistory allows for clarity in understanding procurement, exchange, territoriality, and social networking in the region (Shackley 2001; Mills et al. 2013; Shackley and Tucker 2001).

Acknowledgements

Special thanks to John Roney for alerting me to the Duncan source, and taking me up to the domes, and to Bob Hard (UTSA) for letting me run with this data. The fieldwork and laboratory analysis of the Duncan source was undertaken as part of the UTSA project and U.S. Bureau of Land Management permitting.

Note

[1] The instrumental methodology is published and available online at http://swxrflab.net/anlysis.htm. See also (Shackley et al. 2016).

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A HYDRATION RATE FOR QUEEN OBSIDIAN, WESTERN NEVADA, BASED ON DENSITY AND WATER CONTENT

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Abstract

The Queen obsidian source has provided significant amounts of obsidian to the archaeological record in western Nevada and eastern California. This paper describes a computation of hydration rate for the source, employing two methods: a laboratory-based rate determined from intrinsic water content, and a previously-published archaeological rate based on temporally-sensitive artifacts. Computation of the archaeological rate required reconstruction of the effective hydration temperature (EHT).The resulting rates agree surprisingly well: 10.49 ± 0.22 μ^2/1000 years for the laboratory method (N = 5), and 10.34 ± 0.52 μ^2/1000 years from archaeological data (N = 1), both at an EHT of 20°C. The two are not statistically distinguishable, so the recommended rate for age computations is the average of the two, 10.41 μ^2/1000 years at 20°C, with a CV of 0.15.

Introduction

The Queen obsidian source is located in western Nevada. It has provided significant amounts of obsidian to the archaeological record in western Nevada and eastern California. Queen obsidian is frequently found in archaeological sites in the northern Owens Valley area of eastern California and across the western slope of the Sierra Nevada, with decreasing amounts in more southerly sites. As a result of its regional ubiquity, it is frequently used as a resource in obsidian hydration dating. This paper describes a computation of hydration rate for the Queen source, employing two methods: a laboratory-based rate estimated from intrinsic water content, and an archaeological rate based on time sensitive artifacts.

Obsidian hydration is a process in which molecular water diffuses into the glass matrix. Diffusion is a process of mass transport driven by a concentration gradient; in this case the gradient is supplied by the adsorbed water layer on the surface of the obsidian. The glass matrix is formed of tetrahedrons of silica (SiO_2) and alumina (Al_2O_3), bonded at the corners by a shared oxygen atom (Shelby 2005: 81ff.). During the molten phase of obsidian molecular water within the melt reacts with the silicon atoms to form SiOH (silanol) (Doremus 2002), which breaks one of the Si – O – Si bonds, creating a non-bridging oxygen (NBO) that becomes linked to a hydroxyl (OH). Once the melt has cooled, a greater number of NBO sites increases the openness of the glass matrix, and the bonding of OH creates pathways that facilitate the diffusion of molecular water as it progressively moves into the free volume of the glass matrix (Kuroda et al. 2018, 2019). The diffusion rate of molecular water in glass is thus strongly influenced by the fraction of NBO in the glass, and in particular by the fraction of SiOH bonds (Stevenson et al. 2019).

The intrinsic, or structural, water exists as two species in the glass, molecular water (H_2O_m) and hydroxyl (OH), known together as total water (H_2O_t). The OH is chemically bound and immobile, while the H_2O_m not removed by degassing or interconversion to OH is in the interstices of the matrix. Although OH is the determining factor for hydration rate, it is proportional to total water, so H_2O_t can be used as a proxy in computations of hydration rate.

The total water may be estimated from the glass properties. Both the density and the water content are controlled by the rate at which the

melt cools (Shelby 2005: 147ff.) and are thus correlated. This forms the physical basis for the determination of water content from density (Stevenson et al. 2019).

Finally, the classic method for estimating a hydration rate archaeologically is by correlation of hydration rim readings with radiocarbon-based ages or ages of associated artifacts. Computing a valid rate requires adjusting the hydration rim readings for the effective hydration temperature (EHT) of the site, which in this case is in the Bishop Tablelands in eastern California. Here we use this method as a cross-check on the rate based on water content as estimated from density.

Intrinsic Water Content Method

Hydration rate of obsidian is determined primarily by the intrinsic (or structural) water content of the material (Stevenson et al. 2019 and references therein). The structural water content is strongly correlated with the density of the obsidian (Ambrose and Stevenson 2004; Stevenson et al. 2019), so that by measuring the density of a specimen, its water content can be determined by equation (1):

$$w=0.013 + (1.561 - 0.013)/\{1 + \exp[236.63*(d - 2.3236)]\}+1.7896*\exp(-1.2486*d) \quad (1)$$

where w is $wt\%H_2O_t$ and d is density in gm/cm^3 (Stevenson et al. 2019: 235).

The density of an obsidian specimen can be determined gravimetrically. A specimen is weighed in the air and in a heavy liquid of known density, and specimen density computed by Archimedes' principle. The method is described in detail in Stevenson et al. (2019), including the accuracies required and the necessary temperature calibrations.

Zhang et al. (1991) and Zhang and Behrens (2002) developed equations relating hydration rate of rhyolitic melts to temperature, pressure, and water content for studies of magma dynamics. However, their equations are for high temperatures and pressures, and do not yield valid rates at archaeological temperatures. For archaeological analyses, an equation of the same form but with different numerical parameters has been developed to compute hydration rate at archaeological temperatures:

$$k=\exp(37.76 - 2.289*w - 10433/T + 1023*w/T \quad (2)$$

where w is $wt\%H_2O_t$ and T is EHT in °K (Rogers 2015; Rogers and Stevenson 2017).

For this investigation, densities were measured for five specimens of Queen obsidian by the gravimetric method. Structural water content was computed by equation (1), and the hydration rate at 20°C was computed equation (2). Density, water content, and hydration rates are in Table 1.

Spec. No.	Density, gm/cm^3	$wt\%H_2O_t$	Hydration rate
BARD10D	2.3402	0.1367	10.33
BAR010E	2.3426	0.1246	10.18
BARC06B	2.3376	0.1589	10.61
BARC06C	2.3378	0.1570	10.58
BARC06D	2.3368	0.1698	10.75

Table 1. Queen densities and water content. Rate in μ^2/1000 yrs @ 20°C

The mean of these rates is 10.49 ± 0.22 μ^2/1000 years at an EHT of 20°C.

Finally, the activation energy of the obsidian specimens can be computed by

$$E = 10433 - 1023*w \quad (3)$$

with w defined as above (Rogers 2015; Rogers and Stevenson 2017). The result is 10280°K, which is used in the archaeological rate estimate below.

Archaeological Method

Data Set and Analysis

Basgall and Giambastiani (1995:44) analyzed Queen obsidian artifacts from the Bishop Tablelands area of eastern California, and computed a best fit equation of

$$t = 82.74*r^{2.06} \quad (4)$$

where t is age in radiocarbon years before the present (rycbp, with "the present" understood

as 1950) and r is hydration rim in microns. This equation was apparently the result of a linear best fit to hydration rims on temporally-sensitive projectile points, in which the fit was between ln(t) and ln(r). However, the fit does not recognize the physics of the process, and the original data were not published. Hydration is a diffusion process, and hence, by definition, the exponent in the right side of the equation must be equal to 2, so that

$$t = r^2/k \quad (4)$$

where k is the hydration rate. The analysis methodology was not published, so it was not possible to re-analyze it. Instead, the analysis was based on equation (4) itself.

The analytical procedure was to select a set of hydration rim readings and compute the corresponding age by equation (4). The ages were then converted to calibrated years before 1950 (cyb1950) using Calib 6.0, and 50 years was added to adjust to the year 2000 (cyb2k). Finally, a linear least-squares best fit was made between r^2 (independent variable) and t in cyb2k (dependent variable). Table 2 presents the data used.

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rim, μ	t, rcybp	t, cyb1950	rim ^{2}, μ^2	t, cyb2k
2	345	398	4	448
4	1439	1353	16	1403
6	3317	3558	36	3608
8	5999	6850	64	6900
10	9500	10824	100	10874
12	13830	16927	144	16977
14	18999	22621	196	22671

Table 2. Queen obsidian data, Bishop Tablelands.

The linear best fit constrained to pass through the origin yields a slope of 114.57 yrs/μ^2, with an R^2 = 0.9977. The rate is the reciprocal of the slope, or 8.73 μ^2/1000 years at the EHT for the Bishop Tablelands. The high value of R^2 is deceptive and is occurring because the equation is a fit to a fit, not a fit to raw data.

Effective Hydration Temperature Adjustment

Computation of EHT requires three climatic parameters: average annual temperature (T_a); annual seasonal variation, or hot-month mean minus cold-month mean (V_a); and mean diurnal variation (V_d) (Rogers 2007). The temperature parameters are then used to construct a numerical model of the temperature history to which the obsidian was exposed. The model consists of a constant term equal to T_a, a cosine term with a period of twelve months and an amplitude of $V_a/2$, and a cosine term with a period of 24 hours and an amplitude of $V_d/2$. The effective hydration temperature iss computed by numerical integration of the hydration rate over the modeled temperature history (details in Rogers 2007).

Most archaeological sites are not collocated with meteorological stations, but temperature parameters for them can be estimated by regional temperature scaling (Rogers 2008a). 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. Such data can be down-loaded from the web site of the Western Regional Climate Center.

The temperature model here is based on thirteen sites in the upper Mojave Desert and desert mountains of eastern California, ranging from Baker, California, at 940 ft above mean sea level (amsl) to Mt Barcroft at 11,800 ft amsl. Details of the method are in Rogers 2008a.

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

$$T_a = 22.25 - 0.0018*h, \quad 940 < h < 11{,}800, \quad (5)$$

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

The annual temperature variation can be predicted by

$$V_a = 23.14 - 0.0005*h, \quad 940 < h < 11{,}800, \qquad (6)$$

with h 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

$$V_d = 15.8ºC \qquad (7)$$

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

The site at the Bishop Tablelands for which equation (4) was derived is at an altitude of 4500 ft, which allows computation of the temperature parameters and resulting EHT (Table 3)

Parameter	Value, °C
Annual average temperature, T_a	14.15
Annual (seasonal) variation of the mean, V_a	20.89
Mean diurnal variation, V_d	15.80
Effective hydration temperature, EHT	18.59

Table 3. Temperature parameters for the Bishop Tablelands.

For comparison purposes hydration rates are typically quoted at a reference temperature of 20°C, which is higher than the EHT at the site; the rate adjustment for EHT is

$$k_{20} = k_s * \exp(-E/293.15 + E/EHT_s) \qquad (8)$$

where k_{20} is the hydration rate at 20°C, k_s is the rate at the EHT for the site, E is the activation energy of the diffusion-reaction process in the obsidian in °K, and EHT_s is the EHT for the site in °K. For this case, E = 10280°K and EHTs = 291.74°K (= 273.15 + 18.59), Making this correction then yields an archaeological rate of 10.34 μ^2/1000 years at 20°C.

Discussion

This analysis shows that the hydration rate computed from water content derived from density measurements agrees closely with the hydration rate derived from archaeological data.

The density data for the Queen specimens (Table 1) are fairly tightly grouped, with a mean of 2.3390 ± 0.0024 gm/cm^3. Previous studies have shown that the gravimetric method yields accuracies of the order of 0.002 gm/cm^3, so the standard deviation observed may be due to experimental error rather than actual variations in water content. However, the density data and resulting rate, 10.49 ± 0.22 μ^2/1000 years at 20°C, are based on a small sample (N = 5), so the very small standard deviation may not be characteristic of the Queen source as a whole.

The archaeological rate derived here, 10.34 μ^2/1000 years at 20°C, is not computed from primary data but from a best fit thereto, and accuracy is unknown; however, previous studies have indicated a typical uncertainty of 5% for rates based on obsidian-radiocarbon association, which gives a standard deviation in this case of 0.52 $\mu^{2/}$1000 yrs. Table 4 summarizes the rate data for comparison.

Method	Mean, μ^2/1000 yrs	Std. dev., μ^2/1000 yrs	N
Laboratory	10.49	0.22	5
Archaeological	10.34	0.52	1

Table 4. Comparison of Queen hydration rates @ 20°C

Performing a t-test on these two rates yields a t = 0.28, so the difference is not statistically distinguishable at the 95% confidence level. Thus, for the purpose of age computations, we recommend using the mean of the two, or 10.41 μ^2/1000 years at 20°C.

The CV = 5% cited above for archaeological rates is based on the best fit to a data set used to compute rate; it does not account for possible

variations between data sets. Stevenson et al. (1993) have shown that significant variations in water content can occur from specimen to specimen within a geochemical source, thus causing variations in hydration rate (see also Rogers 2008b); such variations add to the 5% cited above. Due to the uncertainties surrounding the Queen archaeological data and the small sample size for the laboratory data set, we recommend using a CV of 15% (0.15) for age calculations until a larger sample of Queen obsidian can be measured.

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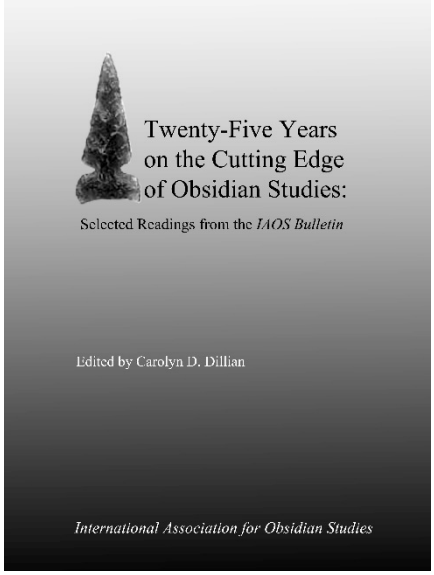

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1. Develop standards for analytic procedures and ensure inter-laboratory comparability.
2. Develop standards for recording and reporting obsidian hydration and characterization results
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